Parhelion
Underwriting Ltd

Forest Resilience Finance
Opportunities & Challenges

Helping Forests Adapt to Climate Change

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Executive Summary

This paper is intended to support the climate finance community, consisting of policy makers; multilateral agencies; development finance institution and private sector insurance and capital markets, in understanding the value that forests create; what risks forests face; how climate change will impact these risks and lastly, the role of traditional and innovative climate finance solutions to address the values at risk.

Forest landscapes generate significant value globally. This value may be captured in established and developed markets through activities such as commercial timber production or through smaller more fragmented markets for non-timber forest products. Equally, forests also provide high value ecosystem services, the value of which is often not directly captured by any one entity and remains outside of any commercial value chain and, thus, is perceived as a 'free common good'.

These values are at increasing risk from climate change and if lost will incur potentially huge costs to be replaced or re-created in other ways (and some of the values are irreplaceable and are at risk of being lost forever). These risks therefore need to be managed, financed or transferred. However, the impacts of climate change will manifest in several ways. Firstly, by changing the probability and or severity of a risk means areas that are currently insurable may eventually become uninsurable for the private sector. There also become a point where the risk is too great even for public schemes. Secondly, the slow onset nature of shifts in climatic zones are difficult to predict accurately and thus manage. Nonetheless, slow onset events are likely to have the greatest macro-economic impacts.

Traditional mechanisms such as insurance, debt and equity finance already play an important role in forest finance. However, penetration by commercial insurance underwriters in to forestry is very low. What insurance that is bought is only for commercial plantations. Non-commercial or public forests are not insured. Coverage is limited to fire and windstorm risk. Coverage for 'pest' is not traditionally bought.

The sustainable development sector is however recognising that new and innovative financing mechanisms can be deployed to attract additional capital; transfer risk and finance adaptation measures. These instruments range from parametric insurance instruments through to impact bonds.

Investment flows into adaptation and resilience to climate change are dramatically lower than in climate mitigation. The latest figures from the Climate Policy Initiative (CPI) indicate that less than seven percent of public climate finance can be identified with climate adaptation[1]. Even more importantly, the small amount of public sector adaptation investment has seen only limited private sector involvement (less than ten percent in some cases) and little to no leverage of private sector finance.

With over 100 trillion USD of investment assets under management by pension funds, sovereign wealth funds, and insurance companies, the 'private sector' is often invoked as the necessary bridge financier for forest conservation. However, attracting capital for deployment in the real

[1] Buchner et al. (2015) The Global Landscape of Climate Finance, Climate Policy Initiative

emerging market economy is not that easy and information on private finance flows for forest conservation and sustainable management is limited.

This paper looks at the sources of value that forests generate. We then consider the role of both traditional insurance and innovative finance and how this may be applied to forests. We draw on emerging innovative finance case studies to inspire the conversation of financial innovation to finance forest climate resilience.

As demonstrated herein there are good opportunities to develop and implement innovative financing structures to support close-to nature forest management measures that increase the climate resilience of forest landscapes.

However, clearly identifying and aggregating sources of revenue and profit (and their risk exposure in light of increasing global temperatures) that need protection and or could support an instrument can represent significant transaction costs, particularly in markets that are fragmented. Therefore, it is appropriate for public entities (e.g. governments, municipalities, trade associations) and development financial institutions to seed such transactions. This may include developing actional information on values; undertaking pilot transactions that can be replicated and de-risking first transaction to prove the efficacy of such instruments.

Capital market instruments for forest resilience only work if there is a willingness to compensate or pay for the multiple forest services that are being consumed, and if there is some form of monetization and value exchange between those that use, and those that secure continued production. There are various ways how these values can be monetized, with varying degrees of visibility to the end consumer. In electricity markets, for example, consumers have very little transparency about the true price they pay for fossil fuel generated electricity as the combined amount of fossil fuel subsidies does not show in their monthly power bill. Yet, in many countries with renewable energy support schemes, the costs of these schemes are made visible on the power bill, making people perceive renewable energy as a more expensive luxury good.

It is a common perception that forest products and ecosystem services are being taken for granted ('a gift from nature') or used without acknowledging that someone is working hard to assure continued service delivery. Governments need to play a key role in educating and informing people that forests globally are at risk and that (no matter where) they need continued protection and maintenance in order to play the multiple vital roles that we need them to play to manage a warming world.

Thus, financial innovation to attract international capital markets relies on smart communication and innovative pricing at local or national level. e.g. smart water tariffs or road taxes that show a forest resilience charge.

The International climate finance community will need to continue and increase collaboration to facilitate, design and implement financing solutions for forest adaptation. Nonetheless, important steps have been taken and lay a crucial foundation for future progress.

1. Introduction

This paper is intended to support the climate finance community, consisting of policy makers; multilateral agencies; development finance institution and the private sector insurance and capital markets, in understanding the value that forests create; what risks forests face; how climate change will impact these risks and lastly, the role of traditional and innovative climate finance solutions to address the values at risk.

1.1 Climate Change Impacts on Forests

The IPCC Special Report on 1.5 C degrees (released in October 2018), as well as the IPCC's 5th Assessment Report from 2014 confirm that climate change is happening at a pace that is too fast for multi-functional forests to adapt to changing local climatic conditions through natural regeneration and selection. Tree species that are suited to certain sites today are likely to reach their ecological limit within the next decades due to increased local temperatures and extreme weather events, putting at risk the multiple functions and ecosystem services of natural forests globally on the medium to long-term. A synthesis of the IPCC findings on forests is included in the Annex.

Tree mortality and associated forest dieback will become apparent in many regions sooner than previously anticipated and is already influencing species composition, structure and age demographics, as well as successional trajectories in affected forests, and in some cases led to decreased plant species diversity and increased risk of invasion. A global analysis of tree hydraulic safety margins found that 70% of surveyed tree species operate close to their limits of water stress tolerance, indicating that vulnerability to drought and temperature stress will not be limited to arid and semiarid forests.

The world's temperate forests act as an important carbon sink, absorbing 34% of global carbon accumulation in intact forests and 65% of the global net forest carbon sink (total sink minus total emissions from land use)[2]. Recent indications are that temperate forests and trees are beginning to show signs of climate stress, including a reversal of tree growth enhancement in some regions; increasing tree mortality; and changes in fire regimes, insect outbreaks, and pathogen attacks.

To counteract these trends and to help forest ecosystems to adapt to the changing climate, it is key that sustainable management and protection of forests today includes 'near to nature forest management measures' that strengthen the adaptive capacity of the forest, for example:

- Species diversification,
- Diversification of age structure (near to nature),
- increase genetic diversity within tree species,
- increase resilience within tree species,
- reduce time to harvest (lower diameters)

[2] Earlier projections of increased tree growth and enhanced forest carbon sequestration due to increased growing season duration, rising CO2 concentration, and atmospheric nitrogen deposition must be balanced by observations and projections of increasing tree mortality and forest loss due to fires and pest attacks.

The composition and resilience of forest biomes affects their ability to deliver ecosystem-services, non-timber forest products as well as protective functions to settlements and other infrastructure relevant to local and national economies and livelihoods.

Research carried out for central Europe shows that drinking water quality is found to be better and quantity of production is reported higher for deciduous forests compared to coniferous stands. This is due to the deeper humus layer and rooting depth in deciduous stands that increases filtration and adsorption and hence, result in lower nitrate concentration. Reduced interception (transpiration) of broadleaf species also results in comparatively higher water production and, hence, dilution of nitrate in the aquifer.[3]

> *Recent findings suggest that the role of forests in meeting the EU's climate target of -80% by 2050 (compared to 1990) has thus far been underestimated.*
> *Implementing Climate Smart Forestry (CSF) could unlock a combined mitigation impact of **441 Mt CO2/year by 2050**. This is more than double compared to previous estimates without CSF (90–180 Mt CO2/year by 2040).*

Besides stand composition, forest management techniques also impact drinking water quality and quantity: nitrate, sulphate, chloride, magnesia and calcium concentration in the aquifers is found to be higher under clear cuts compared to natural regeneration. Further factors reducing wash out- are small management plots and ground cover vegetation. Storm and pest damage that result in 25-30% of tree death is reported to lead to increased nitrate concentration in surface aquifers as well as spring water.[4]

Identifying and developing long-term climate-sensitive forest building (and management) strategies building on the principles of 'Climate Smart Forestry[5]' is still at a research state in most countries. For many forest administrations, recent focus has been on REDD+ readiness activities such as developing forest inventories, carbon stratification maps, deforestation & degradation driver analysis etc. It is likely that climate change impacts on forest biomes are not entirely known and, hence, not included in carbon stock/ removal projections developed today and protection and management strategies are not tailored to maximize the mitigation potential long term[6].

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[3] With some exemptions such as Alder and leguminous trees.
[4] http://test.waldwissen.net/wald/boden/bfw_wald_wasser/index_DE
[5] CSF includes (1) reducing and/or removing greenhouse gas emissions; (2) adapting and building forest resilience; and (3) sustainably increasing forest productivity and incomes. This balanced approach helps to create greater synergies and reduces the trade-offs between climate policy, income maximisation from forestry and other societal, forest-related goals.
[6] Nabuus et al. (2017): By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry, Forests 2017, 8, 484; doi:10.3390/f8120484

1.2 The Financing Gap

Increasing the adaptive capacity of existing forest ecosystems against climate change is undoubtedly more cost effective than losing the forest ecosystems, their biodiversity and other services first and recovering the damage later[7,8]. However, in most countries, forestry administrations are lacking the funds to protect and support forests effectively to adapt to the changing climate.

Current public-sector pledges in the Paris Agreement of 100 billion USD per year by 2020 will not cover the estimated 93 trillion USD needed by 2030 to stay on a <2C pathway[9]. This funding gap applies to all sectors, but particularly to the forest and land use sector that only sees about 3.5-5% of current public climate finance[10].

Investment flows into adaptation and resilience to climate change are dramatically lower than in climate mitigation. The latest figures from the Climate Policy Initiative (CPI) indicate that less than seven percent of public climate finance can be identified with climate adaptation[11]. Even more importantly, the small amount of public sector adaptation investment has seen only limited private sector involvement (less than ten percent in some cases) and little to no leverage of private sector finance.

With over 100 trillion USD of investment assets under management by pension funds, sovereign wealth funds, and insurance companies, the 'private sector' is often invoked as the necessary bridge financier for forest conservation. However, attracting capital for deployment in the real emerging market economy is not that easy and information on private finance flows for forest conservation and sustainable management is limited.

While institutional investors such as pension funds and endowments show a growing interest in timber land investments with £80 billion in assets under management globally, only a fraction of that money is invested in developing countries.

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[7] Once a natural forest has been destroyed, it is close to impossible to restore its full value as some of the damage is irreversible (loss of soil and biodiversity). While comprehensive studies that take into account the full swede of sources of values of natural forests are lacking, examples exist in-situ, such as the Mata Atlântica, Brazil's Atlantic Rainforest that has been lost in the last century and left behind millions of hectares of degraded land that has now little economic value and causes an alarming level of water stress to the cities of Sao Paolo and Rio de Janeiro. The Brazilian Government has pledged the restoration of 1 million ha of the Mata Atlântica to the Boon Challenge Initiative, however, did not disclose the estimated amount of financing needed.

[8] The Bonn Challenge was launched in 2011 by the Government of Germany and IUCN, and later endorsed and extended by the New York Declaration on Forests at the 2014 UN Climate Summit. It aims at restoring 150 million ha of land once under forest. While it does not speak of the costs to restore the 150 million ha, the number of initiatives needed and the comparatively slow effort to date show that transaction costs alone are enormous http://www.bonnchallenge.org/

[9] Delgado C. et al (2015): Restoring and protecting agriculture and forest landscapes and increasing agricultural productivity, New Climate Economy, Working Paper

[10] Falconer et al. 2015, EU REDD Facility: Three tools to unlock finance for land use mitigation and adaptation

[11] Buchner et al. (2015) The Global Landscape of Climate Finance, Climate Policy Initiative

Information on private finance for Sustainable Forest Management (SFM) is starting to emerge particularly for downstream wood processing investments, however, there is no systematic effort to collect and synthesize the data. Funding needs for SFM is estimated at $70-160 billion per year globally (SFM including management of natural forests, commercial plantations as well as wood processing), whereas Official Development Assistance (ODA) and other public-sector funding makes up for not more than 3% of that required amount.[12]

Commercial forest plantations in developing countries cover an estimated 66 million ha, of which about one third is in private ownership. Total private investments in commercial plantations in developing countries is estimated at $ 1.8 billion for the year 2011, of which Brazil takes over about 80% of the total market share.[13]

Locally controlled forests are estimated to involve one billion people and a quarter of the world's forests, providing US$ 75–100 billion each year in goods and services and a broad range of other economic, environmental, social, cultural and spiritual benefits. However, these activities often don't receive any finance or grant support in emerging markets.

Albeit growing, private investments into conservation are still comparatively low and accounted for $ 1.9 ban between 2009 – 2013, which was beefed up substantially by public investments from Development Finance Institutions with a contribution of $ 21.5 billion in the same period. Of that DFI funding the largest share went into water quantity and quality conservation ($15.4 billion)[14].

2 Value at Risk

This chapter provides an overview of the value at risk by considering the sources of value that forests produce. These include timber, non-timber forest products as well as other eco-system services and functions for traditional and cultural purposes.

Forests provide four key functions to people:

1. Direct subsistence (food, feed, medicinal products)
2. Income generation (local, regional or international trade)
3. Cultural (tradition, rituals, recreation)
4. Protection from natural extreme events and hazards (e.g. avalanches, floods)

Income generation from timber products is a well-established, if sometimes poorly regulated sector. Non-Timber-Forest-Products (NTFP) are less well-established, but no less important. The Food and Agriculture Organization (FAO) classifies NFTP as shown in Table 2 below.

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[12] Castrén et al. (2014), Private Financing for Sustainable Forest Management and Forest Products in Developing Countries: Trends and drivers. Washington, DC: Program on Forests (PROFOR)

[13] Castrén et al. (2014), Private Financing for Sustainable Forest Management and Forest Products in Developing Countries: Trends and drivers. Washington, DC: Program on Forests (PROFOR)

[14] NatureVest and Eko Asset Mgmt 2014: Investing in Conservation, A landscape assessment of an emerging market

Table 2: Classification of NTFP (FAO 1995)

Category	Product types
Food products	Fruits, seeds, nuts, edible fungi, species, vegetables, starches, oils, sap and resin
Medicinal plants	Leaves, roots, etc
Ornamental purposes	Flowers, foliage, ferns, Christmas trees etc
Fibre	Bamboos, grasses
Oils extract and colorant	From leaves, roots, bark
Safe spaces in times of civil war or other calamities	

Data availability on NTFP and eco-system services provided by forest biomes continues to be scarce and scattered at EU as well as at global level[15]. However, understanding is growing that Non-Timber-Forest-Products play a vital role in sustaining local livelihoods and reducing poverty and hence play a key role in achieving the 2030 Sustainable Development Goals. Approximately 300 million people globally live in forests but a much larger number depends on forests for daily survival and subsistence: 20% of the global population or 1.6 billion people. NTFP play a major part in providing nutrition and tradable commodities to local communities and as such are main lever to prevent further impoverishment of marginalised communities.[16]

In Switzerland the NTFP sector is characterised by a largely informal institutional set-up, with people mainly hunting and foraging for pleasure, recreation and traditional reasons. Game and honey are the two products sold via formal channels so data on quantities collected are comparatively good. Regional groups exist that collectively work on the maintenance of chestnuts as traditional landscape features which includes the collection and sale of edible chestnuts.[17]

In Chile, NTFPs are an important income source for marginalised communities, particularly in the southern regions of the country, home to the Mapuche communities, one of the 8 recognised ethnic groups in the country, and that represents 87% of the indigenous people. Many Mapuche communities are impoverished and have limited opportunities to participate in economic activities, yet they possess a large amount of knowledge of the native flora and how to use it for human purposes. Thus, collecting and selling NTFPs is a key income source for many of the communities.[18]

2.1 Switzerland

While global average surface temperature increase is reported at 0.8 °C since industrialisation, this value is found to be significantly higher in Switzerland, about 1.7 °C in the same period (mainly due its landlocked geographical location where oceans do not act as temperature buffer). The global 2 °C target, hence, is expected to lead to an increase of at least 4 °C in Switzerland by the end of the century compared to pre-industrial times. This temperature increase and related

[15] State of Europe's Forest/SoEF 2011, Global Forest Resources Assessment/GFRA 2010

[16] Limacher S., Walker, D. (2012): Nicht-Holz-Waldprodukte in der Schweiz

[17] Limacher S., Walker, D. (2012): Nicht-Holz-Waldprodukte in der Schweiz

[18] https://pqdtopen.proquest.com/doc/304829719.html?FMT=AI

pressures from longer drought periods and pests pose an imminent threat to the resilience of forest biomes in the country that are already felt today.

32% of the surface area is covered by forest, totalling in 1.31 million ha, 71% of which is community owned with the remaining 29% under private ownership. Of the total forest area, 585k ha (or 49%) is protection forest, in some regions the share is as high as 90%. About 26k species directly rely on the forest (35% of all species in the country) and forests are home to about 50% of all species of national priority.

Three key climate mitigation functions of forests are recognised

1. Forests are carbon sinks due to sequestration of CO2 in forest vegetation and soils
2. Long-term carbon sequestration in wood products (such as timber houses)
3. Substitution of fossil energy through the use of wood for replacing energy intensive materials (e.g. concrete) or energy production

Climate change will have a profound impact on these forests, resulting notably in the shifting of vegetation zones some 500-700 metres (1,640-2,297 feet) higher in altitude, as well as more frequent periods of drought, forest fires and pest infestations, researchers have found.

Trees that germinate and begin growing in Switzerland today will already be experiencing a marked change in climate during their lifetime, researchers have said. They emphasised that adapting forest management practices will be essential to helping Swiss forests survive climate change, and continue to provide the key services humans rely on, such as wood production and shelter from natural hazards.

Timber stock stands at 422 million m3 (351 m3/ha), of which 33% is deciduous wood and 67% coniferous wood. Timber growth is reported at 10 million m3/year, and economically usable volume is 8.2 m3/year. Harvested timber stood at 4.46 Mio. m3/year in 2016, and consumption (including the re-use of recycled wood) totals about 10.5 million m3/year. 6,223 people are directly employed in forest enterprises (equivalent to 5,223 full-time positions), and about 82 k people are employed in the timber, pulp and paper industry.

Of the harvested timber, demand of coniferous wood is going up mainly due to a surge in demand for firewood which represents about 40% of wood consumed in the country. 50% gets sold as logs to sawmills and about 10% as pulp to papermills and industrial wood uses. The region (Kanton) of Bern showed highest yields with 918k m3 in 2017, followed by the region of Zürich (422k m3), Waadt (398k m3), Graubünden (374k m3) und Aargau (372k). About two thirds of the wood stems from forests under public community ownership such as municipalities and co-operatives, whereas one third comes from private forests.[19]

Scientists sounded the alarm after the bark beetle damaged 320,000 cubic metres of spruce in 2017 – 3-4 times more than in the entire period 2008-2012. They are warning of a worsening situation this year. The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) said the rise in damage caused in 2017 was “worrying”. Storm, snow and the hot summer weather

19 https://www.bafu.admin.ch/bafu/de/home/themen/wald/fachinformationen/waldbewirtschaftung/holzernte.html

have stressed the spruce further, leaving them more susceptible to attack by the pest species, which prefers weak or not-long-dead trees for breeding, the WSL said.

Mountains, seas and deserts used to provide considerable barriers to the movement of plants or animals, but Switzerland has seen a rise in the number of insects coming from the other side of the globe, in particular from Asia. "There have been a few non-native insects in Switzerland for several years, but we're now seeing a worrying spike in numbers," says Stève Breitenmoser, an entomologist at the Changins-Wädenswil Agroscope research station. "The main reason for the proliferation of all these insects is the rise in trade and transcontinental shipping, but some species manage to establish themselves on a long-term basis because of rising temperatures."

Creatures such as the oriental chestnut gall wasp are establishing themselves in Switzerland, an insect that, at only three millimetres long, is practically invisible to the naked eye. The tiny wasp first appeared in canton Ticino, where it caused major problems in 2011, before it soon made its way around the Alps. It has now also been spotted in cantons Graubunden and Valais.

Certain species have been completely wiped out in Switzerland in the past. Elm trees, widely present in the country's forests in the early 1900s, have all but disappeared after falling prey to Dutch elm disease, a fungus spread by the Elm bark beetle. And the common box tree, often used in garden hedges, is under widespread attack in Switzerland from the boxwood moth, a green and black caterpillar.

When a non-native organism invades a new environment, it often does not have any direct predators or parasites, meaning it's in a good position to quickly adapt to its new surroundings. Invasive insects don't just damage cultivated or wild plants. They also take the place of other species.

Swiss environmental group Pro Natura says the problem presents a serious threat to the protection of native plants and animals. "Invasive species are the second-biggest cause of biodiversity loss, after habitat destruction," says spokesman Nicolas Wüthrich.

Recently the Zurich canton mounted a massive operation to try to rid the city of Winterthur of Switzerland's worst ever invasion by the Asian longhorn beetle. In all, 64 infested trees were cut down, their roots completely pulled up and the material taken in closed containers for incineration.

The spring of 2017 was too hot and the soil too dry for the flat roots of the spruces in the forests around Zurich. However, the dry and hot weather was certainly a boon for the spruce bark beetle, who likes to make a home underneath the tree's surface. Normally the spruce evicts the beetle by drowning it in resin, but this year there was not enough liquid to do so. Hence, there has been more beetle-infested wood noted in Zurich forests, and in order to prevent further infestation, foresters usually cut down the afflicted trees. Table 3 below considers in more detail the sources of value that Switzerland derives from forests.

Table 3 Sources of Value: Switzerland

Sources of value	Who captures the value	Captured values (CHF)	Potential for capturing values	Note
Timber, industrial & energy wood	Large, medium and small private businesses	202 million CHF/ year[20]	value of standing timber that could be economically harvested 8.8. billion CHF in 2014[21]	Case Study of Mitelland Forest: lost income due to climate change estimated at av. 13 CHF/ ha and year (11 - 21 CHF/ha depending on forest management strategy)[22]
Honey **Game** **Mushrooms** **Christmas trees** **Chestnuts**	Small private business and families	52 million 19.5 million CHF 11.4 million CHF 3.6 million CHF/ year 0.5 million CHF[23]		data availability is limited, annual data gets reported in 8-year intervals
Water quantity **Water quality**	Water utilities Adjacent communities	no information available	Costs of groundwater protection on forest land by category[24]: Scenario 2-35 CHF / year*ha Scenario 3 - 166 CHF / year*ha max. 514 CHF/ year*ha	Biggest impact has higher share of broadleaf species in high protection zones[25]
Air quality		no information available		
Carbon sequestration (in forests and wood products)	Forest owners (Government)	total amount sold unclear	1.5 million t CO_2/year[26]	potential under optimised forest management

20 https://www.bafu.admin.ch/bafu/de/home/themen/wald/fachinformationen/waldbewirtschaftung/holzernte.html

21 BFS (2016) Ökonomische Bewertung des stehenden Holzvorrates der Schweiz

22 Pauli et al. (2014): Ökonomische Konsequenzen zeitlich und räumlich differenzierter Adaptationsstrategien

23 All data for 2010 except annual data for Christmas trees, Limacher S., Walker, D. (2012): Nicht-Holz-Waldprodukte in der Schweiz

24 Blattert (2012): Trinkwasserschutz-Tool - Berechnung von Mehraufwand und Minderertrag infolge des Trinkwassershutzes im Wald. Schlussbericht

25 http://test.waldwissen.net/wald/boden/bfw_wald_wasser/index_DE

26 No mitigation without adaptation, Switzerland's approach to secure the multiple benefits of forests in a changing climate

Sources of value	Who captures the value	Captured values (CHF)	Potential for capturing values	Note
Avalanche protection	Adjacent communities	no information available	value of intact protection forest 184 k CHF/ year * ha (Andermatt, 2009)[27]	Dense, diverse, younger stands have highest protective function. Case studies for Andermatt show annual collective risk is impacted by protective function of forests and ranges from 72k CHF (baseline scenario of managed forests) to 3million CHF (scenario no/ reduced avalanche protection from forest).
Reduced erosion (sedimentation)	Utilities (energy & water)	no information available	3.9 - 4.9 billion CHF (1997)[28]	
Flood control	Local communities Municipalities/ cities Business in the area	no information available		
Biodiversity/ Genetic resources	Citizens and tourists (potentially also pharmaceutical and agro-industry)	no information available	2.8 billion CHF (1997)[29]	willingness to pay for the promotion of biodiversity 40 to 80 CHF/ ha and year; 140-270 million CHF per year[30]
Recreation	Local communities domestic tourists international tourists organisations & clubs (e.g. horse-riding clubs)	no information available	10.5 billion CHF/ year[31]	Estimate of willingness to pay based on travel cost calculation. Today only source is public support for forest roads & trails, fees only for exclusive use (mountain bike parks etc.), sponsoring by private companies[32]
Noise filter		no information		

[27] Teich, M., Bebi, P. (2009): Evaluating the benefit of avalanche protection forest with GIS-based risk analyses—A case study in Switzerland, Forest Ecology and Management 257, 1910–1919
[28] Kissling-Naef (1999): Großer Wert und wenig Geld? Über die Honorierung von Waldleistungen, Schweizerische Zeitschrift für Forstwesen, 150 (1999) 2:41-48, Zürich
[29] Kissling-Naef (1999): Großer Wert und wenig Geld? Über die Honorierung von Waldleistungen, Schweizerische Zeitschrift für Forstwesen, 150 (1999) 2:41-48, Zürich
[30] Bade et al. (2011): Willingness to pay for forest management activities fostering biodiversity, Schweizerische Zeitung für Forstwesen 162 (211) 111: 382-388
[31] BAFU 2007: Wald in Wert Setzung für Freizeit und Erholung, Situationsanalyse, Bern
[32] BUWAL (2005) Der monetäre Erholungswert des Waldes, Umweltmaterialien N1. 193, Bern

2.2 Chile

Chile encompasses an extraordinary diversity of landscapes, from deserts in the north, to temperate rainforests in the south, from the heights of the Andean Mountain Range, to the fertile valleys in between the Cordillera de los Andes and the coastal mountain range.

In 2017, the total forest area covered about 18 million ha of which 14.6 million ha is native forest (or 19% of the national territory), 3.1 million ha plantations (eucalyptus and pine), and 179t ha of mixed forest. The Chilean forest definition for natural forest differentiates between so-called adult forest, secondary forest, adult-secondary forest and shrub forest (INFOR 2018).

The Forest sector provided 114,000 full-time employment opportunities in 2017, of which almost 50% are in forest management and logging, and the remainder in almost equal shares in the primary and secondary forest industry.

In the same year, the value of exported wood products from plantations stood at 5.27 billion USD, representing 7.8% of the total export value. Almost 50% of plantation wood exports is in form of chemical pulp (2.4 billion USD), followed by sawn wood (548 million USD), panels and veneers (543 million USD) and other products (1.4 billion USD). The value of exported wood products from native forests totalled 4.2 million USD in 2017, contributing 0.08% of total forest sector exports.

Administratively, the country is divided into 16 regions. Forestry activity takes place from central Chile (Valparaiso) to the south with the Concepción area as its centre where a large share of the plantations and secondary industries (pulp and paper, sawmills, production of wood panels) settled. Most native forest is found from the VIIIth to the XIth region, together with sawmills processing industries (veneers and plywood) specialised in native species.

The native forest cover has been reduced by almost 50% over the past century mainly due to agricultural expansion (crops and cattle), as well as the need for fuel wood, charcoal and construction timber. Today, deforestation is limited but degradation continues to weaken natural forest biomes.

Research suggests that over the past 80 years, average temperature increased by 0.25 C each decade in high mountain regions (over 2000 meter above sea level), leading to reduced snow production, longer and more severe droughts and higher frequency of forest fires. In January 2017, Chile experienced the worst fires in rural areas that affected plantations as well as natural forest in more than a century[33]. For the region of Biobio, the water from snow and glaciers feeding surface aquifers reduced by 60% over the past decades. In this regard, natural forests play a key role in securing fresh water supply for the population into the future.

Table 4 below considers in more detail the sources of value derived from forests in Chile.

[33] Infor (2018): Anuario Forestal 2018, Boletín Estadístico No. 163, Ministerio de Agricultura

Table 4: Sources of Value: Chile

Sources of value	Who captures the value	Captured values	Potential for capturing value	Note
Plantation Timber, industrial & energy wood **Chemical pulp** **Sawn wood** **Panels and veneers** **Chips** **Other products**	3 large enterprises 11 medium sized companies 714 medium sized forest owners 22,747 small forest owners	Exports only[34]: **5.27 billion USD (2017)** 2.4 billion USD (2017) 0.548 billion USD (2017) 0.543 billion USD (2017) 0.349 billion USD (2017) 1.28 billion USD (2017)		SFM[35]: 187k USD/ ha * year (secondary forest) 226k USD/ha*year (old-growth forest) unsustainable management: 135k USD/ha * year (secondary forest) 224k USD/ha*year (old-growth)
Natural forest wood products[36]	15 companies, of which the largest owns 67% of the market share, 18% the 2nd largest followed by the rest	0.42 billion USD (2017) Firewood: 10 million m3 from natural forests per year in centre-south regions		Standing timber 3.34 billion m3 swb 248 m3 swb/ha
NTFP **Honey, Chilean hazel, Boldo leaves, Ornamental flowers & fruit branches, Maqui leaves & fruits, mushrooms, Chilean guava, Chilean Acorn, Soap bark tree (*Quillaja Saponaria*)**	Many small producers often from marginalised communities, only few larger intermediaries	41 million USD (2017)[37]		
Water quantity **Water quality**		no information available	145k USD/ ha * year	Case study of the Llancahue watershed supplying the city of Valdivia estimating water production costs[38]
Air quality		no information available		

[34] INFOR 2018: Anuario Florestal, Ministerio de Agricultura

[35] Nahuelhual, L. et al (2006): Valores económicos del bosque nativo chileno: un conocimiento clave para orientar la toma de decisiones, Revista Ambiente y Desarrollo 22(1): 35-40, Santiago Chile, 2006

[36] INFOR (2018): Bosque Nativo, Boletín No. 15

[37] INFOR 2018: Productos Forestales No Madereros, Boletín No. 32, http://www.gestionforestal.cl/pfnm/estadisticas/estadisticas.htm

[38] Nahuelhual, L. et al (2006): Valores económicos del bosque nativo chileno: un conocimiento clave para orientar la toma de decisiones, Revista Ambiente y Desarrollo 22(1): 35-40, Santiago Chile, 2006

Sources of value	Who captures the value	Captured values	Potential for capturing value	Note
Carbon sequestration (in forests)		unclear how much of that is sold on the voluntary market today	10 million t CO2e per year[39]	only carbon sequestration in forests staying forests, conversion of other land uses to forests, conversion of plantations to natural forests
Avalanche protection		no information available		IUCN Research project is on the way[40]
Avoided erosion & sedimentation		no information available	14,722 ha/year (2006)[41]	Case study for temperate native forest in the Region of Valdivia, cost of recovering soil fertility after clear cuts.
Biodiversity/ Genetic resources		no information available		
Recreation		no information available	3,527 USD/ha (2006) 896 USD/ha (2006)[42]	Case study for two national parks (Puyehue & Vicente Perez Rosales), calculating travel costs of domestic visitors as a proxy to assess the 'willingness to pay' for recreational use. The Ecoregion is home to 56 protected areas.
Noise filter		not captured		

[39] ENCCRF (2016) NREF/NRF Nivel de Referencia de Emisiones Florestales/ Nivel de Referncia Forestal Subnacional de Chile

[40] IUCN (2015): ECOSISTEMAS PARA LA PROTECCIÓN DE INFRAESTRUCTURA Y COMUNIDADES: El rol de los bosques de alta montaña en la Región del Biobío, Chile, Hoja Informativa

[41] Nahuelhual, L. et al (2006): Valores económicos del bosque nativo chileno: un conocimiento clave para orientar la toma de decisiones, Revista Ambiente y Desarrollo 22(1): 35-40, Santiago Chile, 2006

[42] Nahuelhual, L. et al (2006): Valores económicos del bosque nativo chileno: un conocimiento clave para orientar la toma de decisiones, Revista Ambiente y Desarrollo 22(1): 35-40, Santiago Chile, 2006

3 Forestry Risk Finance

3.1 Forest Insurance

Commercial forestry companies use diversification as a key risk management tool. This includes ensure diversity in terms of ages of plantations; species; geography. Similarly, physical risk management tools are also used e.g. fire breaks and graduated tree sizes to reduce 'hard edges'.

'A largely untapped potential'

is the title of a study by Swiss Reinsurance (2015) into forestry insurance. The 'potential' is enormous as the total global forest area was estimated to be 3999 million hectares in 2015, representing 30.6% of the global land area (FAO-Global forest resources assessment 2015). It is 'largely untapped' as 93% is natural forest which is difficult to value, as it typically comprises many different species of varying ages and different growth rates.

Table 5: Insurance Penetration in Different Countries (Welten, 2010)

Country	Insurance Penetration (% of forest area)	Comment
Austria	0%	Catastrophic fund is in place, no forestry insurance is active.
France	7%	
Germany	2%	
Sweden	70%	
Switzerland	0%	Catastrophic fund is in place, no forestry insurance is active.
The Netherlands	12%	The main insurance company OBV (Onderlinge Bossen Verzekering) covering about 55,000hs.

Table 5 above shows that Sweden stands out as a significant buyer of forestry insurance. According to the Swedish Forestry Agency there are 300,000 private forestry owners in the country who own 50% of the forests. As the average of these holdings is only around 50 acres it is probable that these assets are insured in the same way that an individual would protect other assets such as homes and cars.

Protecting an asset is fundamentally the role of insurance, by risk transference to the insurer of the perils identified by the insured as having the potential to cause harm to the asset. To be affordable 'the premiums of the many pay for the losses of the few'. Insurers seek to form diversified portfolios of risk so no one loss they suffer has a disproportionate effect on their profitability. Thus they might insure homes, businesses, cars and forests in geographically diverse regions, and may then seek to lay off, or reinsure, either a portion of individual risks they have assumed or specific perils in their portfolio can also be laid off. This provides further distribution of risk which makes the unexpected less likely to have a large adverse impact on profitability as the loss is spread thinly. For the insured the benefits of being able to replace a damaged asset when it is damaged are many. A householder suffering a fire can have their home rebuilt, and business owners can protect their livelihoods, for instance.

Forests become valuable assets as they grow into mature timber and the hazards that potentially affect them also change. For instance, a sapling won't be very susceptible to wind damage. However, a mature tree can be blown over with ease. The sapling will have cost money to plant and maintain however so replacement of damaged trees of any age has financial consequences which become more severe as the tree matures. Thus, Insurance companies have long recognised the need to provide insurance products to forestry owners and 'named peril' insurance is available in the market. Insurers have recognised those perils which are most likely to affect a forest and in a typical list the foremost would be fire, lightning and wind. Others often named include flood, hail, earthquake, ice and snow. Explosion and aircraft impact are added to fire and lightning policies. Coverage for losses caused by pests isn't routinely offered. An insured therefore has a choice of perils to be insured and the Insurer will charge a premium for each peril insured.

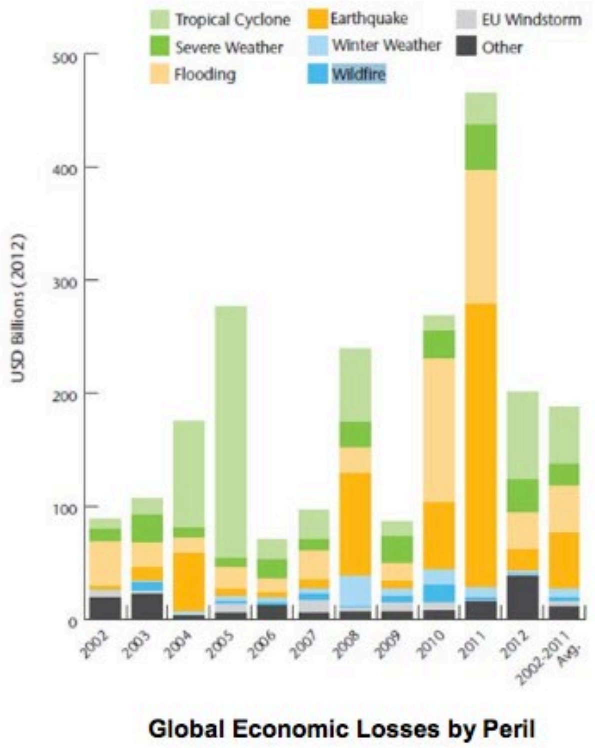
Reasons for low uptake of forestry insurance

Swiss Re states that the 'available forestry insurance solutions' in Chile includes the aforementioned perils and also sub-limited firefighting expenses. They also assert that only 1.2% of Chilean forests are insured. The Lloyd's of London based MGA Pardus, where a lot of forestry knowledge resides, also generally insures named perils.

Given the uniquely long crop rotations in forests which range from 10 to 200 years explains to an extent why insurance is not bought in most cases, as it causes an unattractive drain on cashflow as the crop is harvested so rarely. For larger commercial forest operators this is less of an issue as rotation cycles are shorter.

In a United Nations Environment Program survey of large reinsurers and insurers around the globe, less than half wrote forestry insurance, many citing the lack of reliable risk assessment capabilities (UNEP 2008). Many private forest owners decline insurance, even when available, because they do not rely on their forests as a main source of income, and because public assistance after a storm—to compensate for incurred losses or to assist with cleanup and replanting—is often available. For example, in Switzerland and Austria where government catastrophe funds are in place, forestry insurance is virtually non-existent.

Germany's showing is a bit better, with 2% of forestland insured. Penetration in the United Kingdom is around 10% (EFI 2010) and in France around 7%. It is worth noting that these numbers may grow; after severe losses to France's maritime forests during winter storm Klaus in 2009, for example, the government passed a law in 2010 that limits state support for post-storm clean-up and reforestation to insured forestland, which goes into effect partially starting in 2011 and fully in 2017 (Government of France, 2010). Looking at the different left-hand scales in the chart below shows the huge gap between economic loss and insured loss for 'wildfire' in common with other perils.



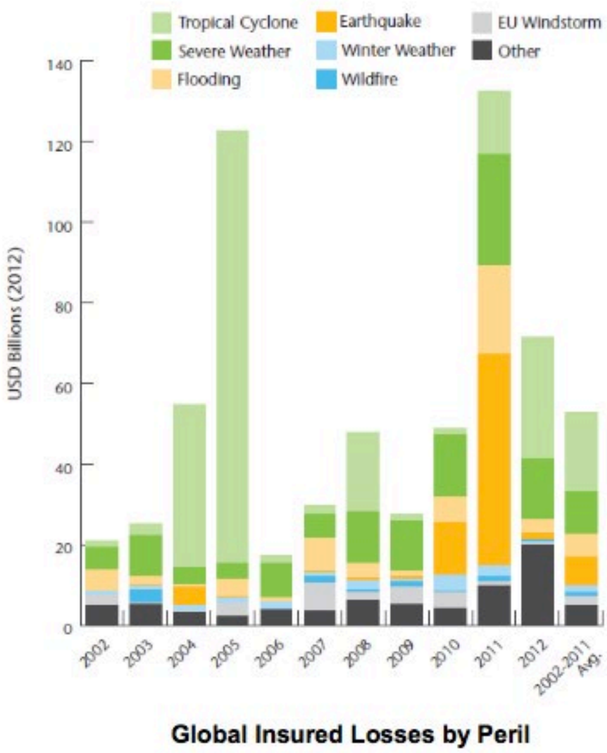


Figure 1: Global economic and insured losses from major catastrophic events over the period 2002- 2012 (Aon Benfield, 2012)

In instances where insurance is purchased there are different bases of **indemnity available**. For young newly established forests it is appropriate to cover the costs of replanting in the event of loss. For more mature forests where the timber has an economic value other settlement options are more suitable. Realisation value is based on the sale value of the timber at the time of loss whereas the NPV (net present value) basis relies on projected future incomes. It is also possible to pre-agree sum insured per area.

Salvage is an important factor in loss settlement. For example, after storm Erwin/Gudrun in Sweden in 2005, a vast number of logs were wet-stored for several years to avoid the significant timber price drop caused by the resulting oversupply. This meant that it took several years for the final loss amount to be calculated.

The **demand for forestry insurance** tends to come from areas where the risks are perceived to be high, so there is an element of anti-selection in the market. Sweden, South Africa, Australia and New Zealand are examples of these. Indeed, the largest amount of recorded forestry damage in the Nordic region was in January 2005, when winter storm Erwin (named Gudrun by the Norwegian Meteorological Institute) damaged an astounding 250 million trees, or 160,000 hectares, in two days. The roughly 75 million cubic meters of damaged timber is nearly equal to the entire annual harvest of Sweden, and economic losses from forest damage were estimated at 1.9 billion Euros in 2005 currency (EFI 2010). Most of the affected area consisted of Norway Spruce (80%), followed by Scots Pine (18%), with deciduous trees such as Birch making up the remaining 2%. The storm resulted in an estimated 50,000 forestry insurance claims (Olson 2008), totaling approximately 275 million Euros in insured losses (out of about half a billion Euros of total insured losses in Sweden).

Firms who model catastrophe losses for a range of perils affecting different asset classes have built models for forestry. These are not sophisticated as they don't take as a starting point the damage that a particular peril will do to a given forest. Partly this is due to the lack of available data and partly because there are relatively few buyers of forestry insurance so the means don't justify the end. The models available are based on an analysis of past losses which are then simulated and a loss probability curve is then fitted and tested against past events to ensure a degree of accuracy and reality.

Under one scenario, the global average area burned reportedly decreased slightly by about 7% during the first half of the 20th century[43]. The authors of this study attributed this to human factors, such as increased fire prevention, detection and firefighting efficiency, abandonment of slash-and-burn cultivation in some areas, and permanent agricultural practice in others. During the second half of the 20th century, this trend reportedly reversed with a 10% increase in global area burned under that scenario. However, this trend is not reflected everywhere and there are regional variations and substantial uncertainties[44]. Overall this increase in the latter half of the last century has been attributed to land management changes, including increases in deforestation fires in the tropics[45], but it may also reflect a 'return' to a more 'natural' fire regime in areas where fire had been suppressed.

Given that it is difficult to assess the extent to which the perils that could affect forests have changed at all makes the pricing of insurance difficult. The perils are dynamic, and the forest asset is dynamic also as it grows in value over time. New technology has made it possible to value the asset more accurately. Satellites, drones and LIDAR, which gives a 3D laser scan, are the enabling technologies.

Willis Towers Watson (WTW) have used these technologies in a groundbreaking way in developing a new insurance product which they have recently sold to a forestry owner in Chile. Using satellites and LIDAR they mapped the insured's plantations to a granular level. Each pixel was analyzed to determine the tree mixture in it and its age, so a value could be ascribed to each pixel/block. The forestry owner was prepared to tolerate a level of losses in a year above which he wished to transfer the risk to insurers.

Insurers then set a parametric trigger above which they would start to pay. This trigger equated to the level of loss that the insured was willing to bear. A burn index kept track of losses that were accumulating over time and even after the trigger had been reached. The higher the burn index during the year the greater the proportion of the insurance limit bought was paid out to the insured, up to the point when it was exhausted.

LIDAR technology is particularly useful in forest fire situations as it sees through smoke whereas satellites are best deployed to photograph in high resolution the area of forest to be insured. Combined together these new techniques opens up a number of potential insurance applications in addition to the Chilean case study already described.

The ability to describe accurately the forest to be insured in terms of tree mix by species and age and the topography of the trees' surroundings is the frontier of forestry data capture. There are however approaches which have been developed recently which bypass the need for accurate data on the crop to be insured. These rely on a predetermined point being exceeded which triggers

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[43] Mouillot F. and Field C.B. (2005) "Fire history and the global carbon budget: a 1◦× 1◦ fire history reconstruction for the 20th century" Global Change Biology 11:398–420

[44] Flannigan M.D., Krawchuk M.A., de Groot W.J., Wotton B.M. and Gowman L.M. (2009) "Implications of changing climate for global wildland fire" International Journal of Wildland Fire 18:483-507

[45] Mouillot F. and Field C.B. (2005)

the policy to respond.

Weather triggers, so called parametric triggers, were one answer to the problem, the rationale being that likely damage could be calibrated to a specific weather condition. For example, a trigger might be set using hurricane speed winds (74mph) with speeds greater than this assumed to cause damage to a forest. Thus the policy pays once the single trigger threshold has been met. There is significant basis risk in this approach in that damage may occur at lower wind speeds than the trigger speed with an uninsured loss resulting. Such policies are easy to administer as the single determination to be made is whether the trigger has been met. They are also limited to a single peril.

Munich Re amongst others sells a policy designed to be more fully encompassing than single peril parametric policies. They designed a policy which responds to 'all risks' of damage which might affect a crop by using a 'yield index'. Yield is the output of a crop, by which time the crop will have had to endure any perils that nature has thrown at it. The basis risk is much reduced and the payout does not rely on any model and its parameters. As forestry only occasionally has a yield the definition would need to be adapted to work in a forestry environment.

The responsibility of governments to protect forests for the national interest requires them to set aside budgets to manage the forests. In Alberta, Canada, the provincial government budgeted to spend a certain amount on firefighting wildfires in the province. This was backstopped with an insurance policy that paid in the event the province ran over budget by a margin. This kind of approach is effective in that it delivers resources(money) when it is most needed and could be of interest to commercial forestry owners who also spend considerable sums on fire suppression, in addition to fire prevention measures.

An overrun in fire prevention spend would occur for instance in a particularly dry spell when the need to clear brush and drought affected trees becomes more acute. A parametric trigger based on rainfall could be a useful proxy in this instance. If the rainfall failed to reach a specific depth then the policy could pay, which money would be used to provide more fire prevention measures at a time when they are most needed.

There are some innovative ways to insure forestry risks as has been shown. The WTW product is a good blend of the old and the new. It makes use of technology (new) to determine the sums to be insured(old) at a granular level (new). It is a policy of indemnity(old) in that the insured is placed back in the same position as was the case before the loss. The burn index(new) ties the level of loss into the insured's budgeting process as it puts a cap on the amount that is borne by the insured. Forestry Insurance however remains 'a largely untapped potential'

3.2 Adaptation and Resilience in the Green Bonds Market

According to Climate Bond's (CBI) analysis, only 3-5% of green bonds proceeds can be traced to Adaptation and Resilience (A&R) related efforts (~USD 12 billion) to date. Leading issuers are development banks (25%) and government-backed entities (22%), followed by financial corporates (20%, primarily commercial banks in China), and sovereign and local governments (14% and 13%). Non-financial corporates are underrepresented in allocating proceeds to A&R—accounting for 19% of overall green bond issuance but only 5% of A&R proceeds.

A&R-linked issuance spans 23 countries, led by China, France, Netherlands, and the US. Beyond what is described here, there may be additional bond financing going towards A&R that is not captured in the Climate Bonds Initiative's database because the bond is not labelled green, A&R features are integrated into the projects' design phase, or A&R strategies are not adopted with explicit reference to climate change impacts.

The water sector accounts for the highest share of proceeds allocated to A&R in the green bond market. Examples of issuers include South Africa's Cape Town, New York State Environmental Facilities Corporation, and utilities such as DC Water in the US and K-Water in Korea, with proceeds allocated to securing drinking water supply, installing water meters, reducing combined sewage water overflow, and storm water management. In the Netherlands, NWB Bank has issued green bonds to provide loans to local water authorities to fund projects related to flood protection, water management and water quality.

Forestry and the land-use sectors also have a relatively high share of proceeds going towards A&R measures. A leading issuer in this sector is the State of California, with proceeds going towards coastal protection and restoration of rivers and watersheds. Another example is China's Chouzhou Commercial Bank, with over 50% of proceeds financing ecological protection and adaptation, including land rehabilitation.

In the energy, building and transport sectors, allocation of proceeds to A&R is less explicit. One example of an issuer in the energy sector is Latvian power utility Latvenergo, which had flood protection measures explicitly included in their green bond framework issued for renewable energy and grid efficiency. In the buildings space, most proceeds remain focused on energy efficiency. Sweden's Östersund municipality provides an example of how adaptation for buildings may be explicitly prioritized alongside emissions reductions requirements. In the transport sector, Hong Kong MTR includes adaptation in its green bond framework, but it is unclear whether the adaptation is specific to transport infrastructure.

As noted above, a main difficulty of tracking A&R proceeds is that bond frameworks do not provide sufficiently detailed breakdown on the use of proceeds. Furthermore, the Climate Bonds database excludes bonds with significant allocation to non-capital-intensive measures such as R&D and training. This precludes the tracking of bonds that may have proceeds going towards "soft" A&R measures. For example, Starbucks' USD500m sustainability bond in 2016 was excluded from the database because a large portion of bonds went towards the purchase of coffee beans from farmers following Coffee and Farmer Equity Practices, training and providing loan financing programs for farmers. **Bonds are rarely issued for financing such "soft" measures, however, because such measures are not explicitly tied to a revenue stream. Corporate bond issuers such as Starbucks are able to attract investors nevertheless because of the investors' trust in the size of the underlying balance sheet.**

Another challenge is that A&R considerations may already be incorporated to a certain extent into asset features through increasingly stringent building codes and engineering standards, particularly in developed countries. Meanwhile, increasing awareness of climate risks is translating to improved transparency and disclosure mechanisms to track A&R related efforts. For instance, the investor-led organization Global Real Estate Sustainability Benchmark (GRESB) recently developed a Resilience Module to assess how companies plan to address potentially disruptive events and changing conditions due to climate change. Improvement of such mechanisms will make it easier to track, prioritize, and increase funding for A&R over time.

Challenges investing in Adaptation & Resilience

Uncertainties around how to evaluate or measure existing and potential physical climate risks, difficulties in quantifying A&R benefits, mismatch in time-horizons and language barriers make investing in A&R challenging. The list below summarizes some of the major barriers to investing in A&R:

Lack of knowledge on adaptation needs and options

UNEP identifies three key knowledge gaps in adaptation as: 1) gaps in knowledge production, 2) inadequate integration of knowledge, and 3) limited transfer and uptake. In particular, developing countries lack the capacity to systematically identify, assess, and prioritize adaptation needs. There is also uncertainty about the rate, scale, and cumulative impact of climate risks, and few studies to date have attempted to systematically analyse the financial impact of physical climate risks. Because losses due to climate change do not appear on balance sheets, businesses are not incentivized to actively reduce those losses.

Lack of investible opportunities

The limited number of investible opportunities is a major barrier. The difficulty of measuring resilience benefits and the lack of clarity on financial returns of A&R investments create unattractive risk-return profiles for investors. Private sector efforts to address adaptation are not yet mainstream. Unless A&R projects can meet commercial standards of risk and return, it will be difficult to get institutional investors on-board. Moreover, the context-specific and often small-scale nature of adaptation projects make them difficult to identify and aggregate.

Mismatch in time-horizons

Risks that are material for a physical asset or a company are not necessarily material for their investors, nor priced in by financial analysts. The financial impact of chronic climate risks may accumulate incrementally over the long-term in the form of increasing operating or capital expenditures, while acute disaster-related disruptions may be dealt with under a force majeure clause, removing liability from responsible parties. Moreover, insurance products are often based on historical data and catastrophe modelling results that project only a year in advance, failing to take account longer-term patterns of climate change.

Language Barrier

Language differences between public and private sector prevents the communication of adaptation as a common priority. For the public sector, A&R is a matter of ensuring the safety of populations and guaranteeing the reliable functioning of infrastructure in the face of climate risks. On the other hand, the Global Adaptation & Resilience Investment (GARI) Working Group's report found that private investors were less aware of "adaptation" as an investment priority, but more in terms of reliability, disaster recovery, business continuity, and maintenance or supply chain issues.

Opportunities for investing in Adaptation & Resilience

Climate risks and the need to build climate resilience present new opportunities, in both developed and developing countries. There is a need for A&R innovation across a range of sectors. Such innovations include water-efficient technology, drip irrigation, wind-, flood-, and heat-resilient building materials, new financial and insurance products, early warning systems, drought-resistant seeds, and new health products, among many others. The private sector can also gain multiple non-financial benefits by investing in A&R, in the form of enhanced liability management, increased reputation among local communities, and employee protection.

Innovative green bond financing mechanisms can help enhance the risk-return profiles of A&R projects for investors. For instance, aggregation mechanisms identify and combine small-scale projects into a larger investment vehicle, reducing private investors' time spent on performing due diligence. The Paris Climate Bond concept pioneered by Climate Mundial uses this approach to aggregate projects aligned with the UNFCC's Clean Development Mechanism. This is focused on mitigation, however, and such an aggregation mechanism does not yet exist for adaptation.

Another example of innovative green bond financing is a "pay-for-success" mechanism that allows investors to share the performance risk of A&R projects. For example, DC Water's Environmental Impact Bond raised funds to build green infrastructure that could help reduce storm water runoff. Based on pre-determined performance tiers, if the project successfully reduces runoff (>41%), investors receive an additional payment of USD3.3m. If the project is not successful (<18%), the utility receives a risk share payment of USD3.3m from the investors. The downside of such mechanisms is that they generally require long project preparation times.

Finally, blended finance can help reduce the perceived risk-reward profile of A&R green bond projects by on-boarding MDBs and public-sector entities as guarantors, providing technical assistance during the project design phase, and offering co-financing options with donor.

3.3 Forests Risk Finance Innovation

As noted above financing of forest adaptation risk face a number of challenges, be they the slow onset nature of changes to climatic zone or the low penetration of traditional insurance instruments. However, innovative capital market and risk finance instruments have the potential to attract new sources and approaches to risk finance to increase the climate resilience of specific ecosystems. It is therefore timely to take a broader look at these instruments and their potential to raise funding for long-term forest climate resilience measures also with a view to stabilize and maximize the mitigation potential of natural forests globally.

Recent innovations such as catastrophe and resilience bonds offer potential approaches to combining recovery and risk reduction, while green bonds may provide pre-disaster financing under appropriate conditions. In the insurance industry we are seeing innovation on parametric insurance products, that release money triggered by events that meet pre-defined indicators (e.g. winds that surpass a pre-defined speed in a pre-agreed area).

Innovative finance is able to both unlock additional funding as well as better align interest, timing, duration and risk to different counter parties. There is growing interesting in the international sustainable development community to adapt and exploit these innovations to improve climate finance flows and increase climate finance stock.

Innovative finance seeks to develop and/or apply non-traditional mechanisms to meet humanitarian or development financing needs – often this means the adaptation of capital market instruments to new contexts, creating access to greater levels of funding from a more diverse range of sources (including the private sector), enabling better risk management, providing greater reliability to funding in terms of delivery, timing, and duration, and better incentivising results.

While innovative finance approaches for forest adaptation are still somewhat limited, many lessons can be drawn from innovations in other sectors, including public health and natural disaster spaces. Parametric insurance mechanism such as the Pandemic Emergency Finance Facility (PEFF); Africa Risk Capacity (ARC); Caribbean Catastrophe Risk Facility (CRIFF) and Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) are examples of such innovation. These parametric insurance instruments make direct links to a pre-determined parametric or index trigger. Since they are not linked to any indemnity, there is no need for loss adjustment, enabling rapid pay out.

In order to structure these instruments, it is important to identify a robust and independent trigger that cannot be manipulated, thus avoiding moral hazard. Similarly, the potential for basis risk i.e. the pay-out is significantly different from what is intended or required, need to be considered carefully.

Forecast Based Financing for disaster relief is another example of innovative finance being applied for public good. The International Federation of Red Cross and Red Crescent Societies (IFRC) Disaster Relief Emergency Fund established a mechanism that automatically releases funds before a disaster strikes, based on forecast information. This enables the rapid implementation of pre-planned activities. Again, forecast-based financing requires sufficient data to be able to accurately forecast events and trigger the release of funds.

A further example of innovative finance are social and development impact bonds. These instruments attract upfront capital from investors, for the delivery of a programme by an implementing organisation. The programme results are assessed against specific, pre-determined measures of success. If the required results have been achieved, the investors are repaid capital plus interest by the Government (in the case of Social Impact Bonds), or an impact investor (in the case of Development Impact Bonds). If the programme has failed to achieve the required results, the investor receives no interest and loses part of the capital investment. These 'performance based' instruments enable risk management as well as incentivisation of desired outcomes. However, the ability to accurately measure programme impact is essential to Social and Development Impact Bonds, and so is only applicable to specific types of interventions.

Table 6 below considers the different sources of value for forest products that have been identified and quantified in Section 3. It looks at the potential to apply innovative financing mechanisms to support adaptation financing for these sources of value.

Table 6: Opportunities for Forest Finance Innovation

Sources of value	Suitability	Comments and suggestions
Timber, industrial & energy wood	High	Existing financing market for commercial forestry already in place with a good understanding of the asset class. There has been increased interest in recent years from institutional investors with long term liabilities (e.g. pension funds and life assurance companies) who see the long-term investment in forests a good match for their long-term liabilities. A large market allows scale and diversification. National schemes (such as the disaster fund in Switzerland) however may be crowding-out private insurance capital from providing solutions.
Honey **Game** **Mushrooms** **Christmas trees** **Chestnuts**	Medium	These markets are often informal and fragmented in nature. However, there is potential for securitisation via an asset backed security (ABS). These instruments take small loans or assets (e.g. credit cards, car loans etc.), pool them together and then apportion risk via tranches. This enables multiple small assets to be aggregated in to large, investable vehicles with risk tailored to match investor appetite. Facilitating would need to be done by sector trade representatives e.g. Honey producer organisations, which could engage their members to add a 'resilience

Sources of value	Suitability	Comments and suggestions
		price premium'. Investment proceeds could then be used, for example, to finance bee friendly stand diversification.
Water quantity Water quality	High	This sector has high suitability to attract innovative finance due to high level of institutional organisation, clear value extraction and ability to pass costs to end consumers. Similarly, the cost of replacing this eco-system service would be high if lost. Climate Change is already affecting water quantity. Greater understanding of specific risk exposures and values generated would better enable potential for Impact Bond. Success stories: Water Funds that establish multi-stakeholder processes and bring in private capital in emerging markets[46].
Air quality	Medium	Loss of forests would require air filtration to be replaced by increased mitigation measure, leading to higher prices in Swiss emissions trading scheme. A levy on this scheme could be used to fund an Impact Bond to support Swiss Forests.
Carbon sequestration (in forests and wood products)	Low	Similar to air quality services provided by forests, if lost the carbon sequestration from forests would need to be replaced by increased mitigation or other sequestrating activities. However, sequestration by forests represent relatively low-cost sequestration option.
Avalanche protection		Medium – research is on the way to explore values at risk and opportunities for insurance policies. High value ski resorts already have high spending commitments on avalanche management. They may therefore have an interest in using forestry strategies for avalanche protection. However, there is strong correlation between warming climate and reducing avalanches as snow cover retreats.
Reduced erosion	Low	Currently not captured values. Research on the way for insurance policies in flood prone areas but not linked to forest management.
Flood control	High	Similar to water quality and quantity, this service would be expensive to replace if natural eco-system services were lost. There is potential for an Impact Bond funded by water companies, municipalities and cities that would have to invest in flood control in the event of forests not naturally providing this service.
Biodiversity	Medium	Potential for Impact Bond facilitated by Ministries.
Recreation	Low	Low - trail centres that offer exclusive use could add a 'resilience charge', low acceptance among population to charge for recreational use of forests
Noise filter	Low	No values captured

[46] https://waterfundstoolbox.org/

4 Inspirational Case Studies

4.1 Water Funds

Water Funds are emerging globally bringing together public and private stakeholders working together on a conservation goal to create funds that act like endowments: the largest water users in an area – including major brewers, municipal water authorities, a sugar cane growers association and others – make voluntary investments into a central fund. When the fund is fully capitalized, earnings are directed toward conservation activities upstream, such as reforestation, and to enabling rural people who live near key waterways to start small businesses and organic gardens that avoid damaging forests and grasslands.[47]

Examples in South America include:

1. The Lima Water Fund (Aquafondo) – which provides water to the world's second largest desert city - has been an influential actor in the establishment of Peruvian water tariffs that require service providers to earmark 1% of revenue to invest in natural infrastructure and, in the case of Lima, 3.5% for disaster mitigation and climate change adaptation.
2. The Monterrey Water Fund in Mexico has united over 60 members from private, government, non-profit, and academic sectors to protect drinking water sources for the over 4 million inhabitants of the city's metropolitan area.

The Water Producer concept in Brazil (which turned a PES scheme into law) has achieved considerable success. It is built on the principle that landowners should be compensated for the opportunity costs they incur for generating hydrologic services downstream users need. In Brazil, this has resulted in three general approaches: (1) watershed committees that gather and redirect investments from companies, water-dependent industries and government agencies to landowners in source watersheds, (2) the establishment of PES schemes in state and municipal laws, and (3) utility-driven projects similar to those elsewhere in Latin America.

4.2 Coastal zone management trust & hurricane insurance – Mexico

At the beginning of 2018, the State of Quintana Roo in Mexico, in cooperation with the Puerto Morelos Reef National Park authority (CONANP), and the Hotel Owners Association, supported by an international environmental conservation group, has announced the creation of a "Coastal Zone Management Trust"[48]. As of today, the trust fund has not yet been established, but its structure and purpose bring a swede of innovations to conservation finance that could be relevant to other ecosystems and regions globally. Most importantly, it introduces a multi-stakeholder model that brings together Governments, tourism industry and conservation bodies, and it introduces an insurance cover that will be triggered by extreme events and can release money quickly in order to react immediately after a disaster event.

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[47] https://waterfundstoolbox.org/regions

[48] http://www.swissre.com/global_partnerships/Designing_a_new_type_of_insurance_to_protect_the_coral_reefs_economies_and_the_planet.html

The trust fund is overseen by a board which holds seats for the State Government, as well as representatives from the scientific community and the environmental organisation that made a grant donation to the fund[49]. The fund has three main objectives:

1. maintain and conserve the beaches against weather risk, pollution and damage caused by increasing tourist numbers
2. secure against frequent but less severe weather events
3. insurance coverage for hurricanes

The fund is proposed to bed filled through the collection of a portion of the federal tourism tax that is collected by municipalities (and payed by the hotels to use the beaches and federal land). The board will decide how to use the funds, which will include payment for restoration and maintenance activities that ensure the health of the reef and the beach, as well as purchasing an insurance policy in the case of extreme weather events, such as hurricanes.

SwissRe proposed a parametric insurance policy on a designated stretch of reef and beach with the following draft terms:

Cover	Parametric Wind Insurance Policy
Term	1-3 years is feasible
Limit	USD 20,000,000 for Reef Polygon and USD 30,000,000 for Cancun Beaches Polygon. Maximum combined limit USD 50,000,000 with no reinstatement
Location	State of Quintana Roo, Mexico
Triggering Event	A tropical cyclone passing through the Polygons. The pay-out is based on the maximum intensity of the tropical cyclone within the polygons and respective percentage agreed in the insurance contract. The intensity is defined in miles per hour (mph) of one-minute sustained wind speed at 10 meters above ground according to Saffir–Simpson hurricane wind scale.

As of now the procurement process to select a local insurer that will issue the parametric policy has not been implemented, hence, the structure is not yet operational.

4.3 Forest Resilience Bond (FRB) – US

The US Forest Service has identified 58 million acres in need of restoration nationwide but lacks the resources to implement treatment. Unhealthy and overgrown forests across the western U.S. expose communities to heightened wildfire risk and severity, causing substantial damage to built infrastructure and natural ecosystems and diminished and degraded water supplies to alarming

[49] https://www.nature.org/content/dam/tnc/nature/en/documents/TNC-CoastalManagementTrust_Infographic_04.pdf

levels.[50] Forest restoration in this context means the strategic removal of excess vegetation to return forests to a healthier state. The diverse benefits include:

- Reduced risk of high-severity wildfire,
- improved water quantity,
- protected water quality,
- avoided carbon emissions,
- protected habitat and species,
- and community resilience.

The Forest Resilience Bond (FRB) deploys private capital to pay for forest restoration costs upfront, thus reducing the costs for beneficiaries over the project lifetime. Beneficiaries include private landowners, public agencies and utilities. They repay investors (foundations and state pension funds) over time when the project delivers benefits to them, such as decreased fire severity, protected water quality, and increased water yield. For each beneficiary project success will be defined and monetized through a pay-for-success model designed to share cost savings among beneficiaries (e.g. for the US Forest Service the success may be a completed restoration in a certain area, for a water utility success may be defined as a certain amount of water generated as a consequence of the restoration activity).

By bringing together multiple payers to share the cost of restoration and tying payments to realized economic benefits, the FRB creates a sufficiently compelling business case for landowners as well as investors.[51]

4.4 Corporate Sustainability Bonds

In 2016, two large retailers issued their first sustainability bonds: Apple ($1.5 billion issued in February, followed by a second issuance worth $1 billion) and Starbucks ($500 million in its first issuance, followed by second issuance of $770 million). For Apple, proceeds will be used to execute energy efficiency and renewable energy projects at its facilities, improve supply chain management, procure safer and recycled materials for its products and reduce the need to mine rare earth materials.

By issuing its first sustainability bond, Starbucks will finance projects in the coffee growing regions that aim to promote socio-economic advancement and environmental sustainability. Proceeds of the sustainability bond may be allocated to

- coffee purchases and related transportation and storage expenditures, from suppliers that are third-party verified as complying with the Coffee and Farmer Equity Practices (C.A.F.E)
- capital investments and labour expenses to run current farmer support centres and to set up new farmer support centres planned in the near-term. The aim of the farmer support centres is to help suppliers and farmers implement C.A.F.E. practices.
- new and refinanced loans to coffee farmers directly and through lending organizations that provide funding for trade finance as well as investments in restoration and infrastructure improvements.

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[50] Blue Forest Conservation & Encourage Capital (2017): Forest Resilience Bond, Fighting Fire with Finance – A Roadmap for collective action

[51] http://www.wri.org/blog/2016/11/forest-resilience-bond-leveraging-innovative-finance-science-and-partnerships-fight

Customer demand for transparency is one force driving brands such as Starbucks to innovate along with market shifts towards ethically sourced commodities. For many forest products, the supply chain is less visible, hence, the need for sustainability improvements are harder to communicate to consumers.

5 Conclusion

As can be seen in Table 6: Opportunities for Forest Finance Innovation (Sec. 4.3) there are good opportunities to develop and implement innovative financing structures to implement close-to nature forest management measures that increase the climate resilience of forest landscapes. However, clearly identifying and aggregating sources of revenue and profit that need protection and or could support an instrument can represent significant transaction costs, particularly in markets that are fragmented.

Therefore, it is appropriate for public entities (e.g. governments, municipalities, trade associations) and development financial institutions to seed such transactions. This may include developing actional information on values; undertaking pilot transactions that can be replicated and de-risking first transaction to prove the efficacy of such instruments.

Capital market instruments for forest resilience only work if there is a willingness to compensate or pay for the multiple forest services that are being consumed, and if there is some form of monetization and value exchange between the ones that use and those that secure continued production. There are various ways how these values can be monetized, with varying degrees of visibility to the end consumer. In electricity markets, for example, consumers have very little transparency about the true price they pay for fossil fuel generated electricity as the combined amount of fossil fuel subsidies does not show in their monthly power bill. Yet, in many countries with renewable energy support schemes, the costs of these schemes are made visible on the power bill, making people perceive renewable energy as a more expensive luxury good.

It is a common perception that forest products and ecosystem services are being taken for granted ('a gift from nature') or used without acknowledging that someone is working hard to assure continued service delivery. Governments need to play a key role in educating and informing people that forests globally are at risk and that (no matter where) they need continued protection and maintenance in order to play the multiple vital roles that we need them to play to manage a warming world.

Thus, financial innovation to attract international capital markets relies on smart communication and innovative pricing at local or national level. e.g. smart water tariffs or road taxes that show a forest resilience charge).

The funding strategy to be used for any specific forest landscape will depend primarily on the geographic, economic, and institutional circumstances in each location. But it is possible to create a general framework to catalogue the different approaches to financing, from which locally-determined funding strategies can be formed.

The following key questions help to get started on the assessment of the choice and suitability of a funding instrument:

What are the sources of value to be protected/ enhanced?	Water quality & quantity, NTFP, Wood and timber products, bioenergy, flood or avalanche protection, erosion prevention, carbon sequestration, biodiversity, noise reduction, air filtration etc. Governments can help to increase the knowledge and understanding of forest products and services and support data collection and aggregation.
Which of these products/ services have a market today?	Buyers and sellers have an interest in protecting their market segment and supply chain. These are obvious stakeholders to include in the discussion of financial innovation to support continuous forest management measures (e.g. water utilities).
Who else is using these products and services without paying for them?	This can be anyone, e.g. international corporates, large or small businesses, municipalities or individual people. Mapping stakeholders and understanding their interests is key to manage a successful multi-stakeholder process.
What can be sources of local or national income to pay for forest adaptation?	Thinking creatively of pricing and taxation innovation. This will be the revenue stream that will attract capital market instruments.

The International climate finance community, consisting of policy makers; multilateral agencies; development finance institution and the private sector insurance and capital markets, will need to continue and increase collaboration to facilitate, design and implement financing solutions for forest adaptation. Nonetheless, important steps have been taken and lay a crucial foundation for future progress.

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Annex - Vulnerability of Forests to Climate Change

The Inter-governmental Panel on Climate Change (IPCC) is the international body for assessing science related to climate change. They provide policy makers with regular assessments of scientific basis of climate change, its impacts and future risks, as well as options for adaptation and mitigation. They have reviewed and published extensively on forests and climate change. Below we are pleased to provide a synthesis of the IPCC work on this topic.

The IPCC publications are shared among three Working Groups, a Task Force and a Task Group. Key publications are the Assessment Reports, the most recent of which, the fifth cycle, was published in 2014. Of particular relevance to this research are the contributions of the IPCC Working Group II (WGII) to the IPCC Fifth Assessment Report (2014) and the Special Report on Global Warming of 1.5% (October 2018); the relevant detail from the latter is incorporated into this text. The Sixth Assessment Report is currently a work in progress and is due to be finalised in 2022.

WGII assesses the vulnerability of socio-economic and natural systems to climate change, negative and positive consequences of climate change, and options for adapting to it. WGII also takes into consideration the inter-relationship between vulnerability, adaptation and sustainable development. The assessed information is considered by sectors (water resources; ecosystems; food & forests; coastal systems; industry; human health) and regions (Africa; Asia; Australia & New Zealand; Europe; Latin America; North America; Polar Regions; Small Islands).

Within this century, magnitudes and rates of climate change associated with medium- to high-emission scenarios pose a high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of terrestrial and freshwater ecosystems (medium confidence). Whilst the future of the interaction between climate and forests is unclear, it is accepted with a high level of confidence that carbon stored in the terrestrial biosphere (e.g., in peatlands, permafrost, and forests) is susceptible to loss to the atmosphere as a result of climate change, deforestation, and ecosystem degradation (high confidence). Increased tree mortality and associated forest dieback is projected to occur in many regions over the 21st century, due to increased temperatures and drought (medium confidence). Forest dieback poses major environmental risks for carbon storage, biodiversity, wood production, water quality, amenity, and economic activity.

Many species will be unable to move fast enough to track suitable climates under mid and high rates of climate change. Species in flat landscapes will be particularly vulnerable as they will have to move further to remain within favourable climates, with plants and trees especially vulnerable due to their low dispersal capacity.

The direct effects of climate change on stored terrestrial carbon (86% of which is stored in forests) include high temperatures, drought and windstorms; indirect effects include increased risk of fires and pest and disease outbreaks. Increases in the frequency or intensity of ecosystem disturbances such as droughts, wind storms, fires, and pest outbreaks have been detected in many parts of the world and in some cases are attributed to climate change (medium confidence).

Forests, Woodlands and Climate Change

Climate change and forests interact strongly; air temperature, solar radiation, rainfall, and atmospheric CO2 concentrations are major drivers of forest productivity and forest dynamics, and forests help control climate through the large amounts of carbon they can remove from the atmosphere or release, through absorption or reflection of solar radiation, cooling through evapotranspiration, and the production of cloud-forming aerosols.

Fires play a dominant role in driving forest dynamics in many parts of the world; forest susceptibility to fire is projected to change little for the lowest emissions scenario, but substantially for the high emissions scenario examined in the report. There is low agreement on whether climate change will cause fires to become more or less frequent in individual locations, although climate change mediated disease and insect outbreaks could exacerbate climate-driven increases in fire susceptibility.

The greatest risks for large positive feedbacks from forests to climate through changes in disturbance regimes arise from widespread tree mortality and fire in tropical forests and low-latitude areas of boreal forests, as well as northward expansion of boreal forests into Arctic tundra. Recent evidence suggests (low confidence) that the stimulatory effects of global warming and rising CO2 concentrations on tree growth may have already peaked in many regions and that warming and changes in precipitation are increasing tree mortality in a wide range of forest systems, acting via heat stress, drought stress, pest outbreaks, and a wide range of other indirect impact mechanisms. Detection of a coherent global signal is hindered by the lack of long-term observations in many regions and attribution to climate change is difficult because of the multiplicity of mechanisms mediating mortality.

Forest Mortality and Climate Change

Increased tree death has been observed in many places worldwide. It is sufficiently intense and widespread in some areas as to result in forest dieback and has in some regions been attributed to climate change. In detailed regional studies in western and boreal North America, the tree mortality observed over the past few decades has been attributed to the effects of high temperatures and drought, or to changes in the distribution and abundance of insect pests and pathogens related, in part, to warming (high confidence). Increased levels of tree mortality following drought episodes have also been detected in multiple tropical forests and Europe.

Tree mortality and associated forest dieback will become apparent in many regions sooner than previously anticipated (medium confidence). Earlier projections of increased tree growth and enhanced forest carbon sequestration due to increased growing season duration, rising CO2 concentration, and atmospheric nitrogen deposition must be balanced by observations and projections of increasing tree mortality and forest loss due to fires and pest attacks.

Forest dieback has influenced the species composition, structure and age demographics, and successional trajectories in affected forests, and in some cases led to decreased plant species diversity and increased risk of invasion.

Climate change alone is not projected to lead to abrupt widespread loss of forest cover in the Amazon during this century (medium confidence), but a projected increase in severe drought episodes, together with land use change and forest fire, would cause much of the Amazon forest to transform to less dense, drought- and fire-adapted ecosystems, and in doing so put a large stock of biodiversity at elevated risk, while decreasing net carbon uptake from the atmosphere (low confidence). Large reductions in deforestation, as well as wider application of effective wildfire management, lower the risk of abrupt change in the Amazon, as well as the impacts of that change (medium confidence).

A global analysis of tree hydraulic safety margins found that 70% of surveyed tree species operate close to their limits of water stress tolerance, indicating that vulnerability to drought and temperature stress will not be limited to arid and semiarid forests. Strategies to reduce forest mortality include preference of species better adapted to relatively warm environmental conditions.

Negative Impact of Climate Change Mitigation Measures on Forests

Widespread transformation of terrestrial ecosystems in order to mitigate climate change, such as carbon sequestration through planting fast-growing tree species into ecosystems where they did not previously occur, or the conversion of previously uncultivated or non-degraded land to bioenergy plantations, will lead to negative impacts on ecosystems and biodiversity (high confidence). For example, some the land use scenarios accompanying possible mitigation scenarios feature a large expansion of biofuel production, displacing natural forest cover.

Climate change and invasive alien plant species generally increase the risk and intensity of fire, and the interaction is being reported more frequently as some invasive plants and insects have already been shown to benefit from climate change. They will establish and spread into new regions where they are introduced; an “alien invasion” which will be exacerbated by increasing movement of people and goods in the modern world, combined with land use changes worldwide. The selection of tolerant or resistant families and clones may reduce the risk of damage by pests and diseases in pure stands.

Boreal Forests

The Special Report on Global Warming to 1.5% (2018) states that boreal forests are particularly at risk of climate change-induced degradation and loss. Most projections referenced in the Fifth Assessment Report suggest a poleward expansion of boreal forests into tundra regions, accompanied by a general shift in composition towards more temperate plant functional types. Projections of climate-driven changes in boreal forests over the next few centuries remain uncertain on some issues, partly as a result of different processes of change being considered in different models. In particular, the inclusion or exclusion of fire and insects makes a big difference, possibly making the boreal forest more susceptible to a rapid, nonlinear or abrupt decline in some regions.

Recent observed change and dynamic vegetation modelling suggest that regions of the boreal forest could experience widespread forest dieback. If such shifts were to occur, they would put the boreal carbon sink at risk. Recent and longer-term assessments indicate with high confidence that many areas of boreal forest have experienced productivity declines, with the best evidence to date indicating that these “browning trends” are due to warming-induced drought, Conversely, productivity has increased at the boreal-tundra ecotone, where more moist conditions may be generating the expected warming-induced positive growth response.

Where they occur, warming and drying, coupled with productivity declines, insect disturbance, and associated tree mortality, also favour greater fire disturbance (high confidence). The boreal biome fire regime has intensified regionally in recent decades, exemplified by increases in the extent of area burned but also a longer fire season and more episodic fires that burn with greater energy output or intensity. The latter is particularly important because more severe burning consumes soil organic matter to greater depth, often to mineral soil, providing conditions that favour recruitment of deciduous species that in some regions of the North American boreal forest replace what was previously evergreen conifer forest. Fire-mediated composition changes in postfire succession influence a host of ecosystem feedbacks to climate, including changes in net ecosystem carbon balance as well as albedo and energy balance. The extent to which the net effect of these feedbacks will exacerbate or mitigate additional warming is not well known over the larger geographic domain of the boreal biome.

In summary, an increase in tree mortality is observed in many boreal forests, with the clearest indicators of this in North America. However, tree health in boreal forests varies greatly among regions, which coupled with insufficient temporal coverage means that there is low confidence in the detection and attribution of a clear temporal trend in tree mortality at the global scale.

Temperate Forests

The largest areas of temperate forest are found in eastern North America, Europe, and eastern Asia. The overall trend for forests in these regions has until recently been an increase in growth rates of trees and in total carbon stocks. This has been attributed to a combination of increasing growing season length, rising atmospheric CO2 concentrations, nitrogen deposition, and forest management—specifically regrowth following formerly more intensive harvesting regimes, although the relative contribution of these factors has been the subject of substantial and unresolved debate. Most temperate forests are managed such that any change is and will be to a large extent anthropogenic.

The world's temperate forests act as an important carbon sink (high confidence due to robust evidence and high agreement), absorbing 34% of global carbon accumulation in intact forests and 65% of the global net forest carbon sink (total sink minus total emissions from land use). Recent indications are that temperate forests and trees are beginning to show signs of climate stress, including a reversal of tree growth enhancement in some regions; increasing tree mortality; and changes in fire regimes, insect outbreaks, and pathogen attacks.

These trends threaten the substantial role of temperate forests as net carbon sinks, but it is still unclear to what extent existing observations are representative for temperate forests as a whole. Several studies find that tree growth rates in temperate forests passed their peak in the late 20th century and that the decline in tree growth rates can be attributed to climatic factors, especially drought or heat waves.

Extreme climate events have had a major impact on temperate forests over the last decade – for example the extensive forest fires which occurred in Russia during the exceptionally hot and dry summer of 2010. However, the complex interactions between climate and forest management in determining susceptibility to extreme events make it difficult to unequivocally attribute these events to recent climate warming. There is low confidence (limited evidence, medium agreement) that climate change is threatening the temperate forest carbon sink directly or indirectly.

At the biome level, there remains considerable uncertainty in the sign and the magnitude of the carbon cycle response of temperate forests to climate change. A comparison of Dynamic Global Vegetation Models showed that for identical end of 21st century climate projections, temperate forests are variously projected to substantially increase in total (biomass plus soil) carbon storage, especially through gains in forest cover; or decrease due to reductions in total carbon storage per hectare and loss of tree cover.

There is low confidence (medium evidence, low agreement) on long-term, climate-driven changes in temperate forest biomass and geographical range shifts. There is medium confidence (medium evidence, medium agreement) that temperate tree species are migrating poleward and to higher altitudes.

Tropical Forests

Climate change effects on tropical forests interact with the direct influences of humans and are understood largely through field studies of the responses of forests to extreme weather events and through models that are able to simulate a growing number of ecological and atmospheric processes. A key uncertainty in our understanding of future impacts of climate change on tropical forests is the strength of direct CO2 effects on photosynthesis and transpiration. These responses will play an important role in determining tropical forest trends as temperatures and atmospheric CO2 concentrations rise.

Whilst there is new evidence of more frequent severe drought episodes in the Amazon region there is low confidence that these droughts or the observed sea surface temperatures can be attributed to climate change. Networks of long-term forest plots reveal that lianas and fast-growing tree species are increasing, as is forest biomass, with low confidence (limited evidence, medium agreement) that the composition and biomass of Amazon and African forests are changing through the rise in atmospheric CO2. The potential suppression of photosynthesis and tree growth in tropical forests through rising air temperatures is supported by physiological studies but is not yet observed as changes in forest biomass.

There is new experimental and observational evidence of ecological thresholds of drought and fire in moist tropical forests that points to an important indirect role of climate change in driving largescale changes in these ecosystems, and to the importance of extreme drought events. There is high confidence (medium evidence, high agreement) that moist tropical forests have many tree species that are vulnerable to drought- and fire-induced mortality during extreme dry periods. There is also a growing body of evidence that severe weather events interact with land use to influence moist tropical forest fire regimes.

Many moist tropical forests are not susceptible to fire during typical rainfall years because of high moisture content of fine fuels. Selective logging, drought, and fire itself can reduce this fire resistance by killing trees, thinning the canopy, and allowing greater heating of the forest interior, and land use also often increases the ignition sources in tropical landscapes. There is high confidence (robust evidence, high agreement) that forest fire frequency and severity is increasing through the interaction between severe droughts and land use.

Climate change, deforestation, fragmentation, fire, or human pressure place virtually all (97%) of the remaining tropical dry forests at risk of replacement or degradation. There is low confidence in our understanding of climate change effects on dry forests globally.

There is now medium confidence (medium evidence, medium agreement) that climate change alone (i.e., through changes in the climate envelope, without invoking fire and land use) will not drive large-scale forest loss in the Amazon by 2100 although shifts to drier forest types are predicted in the eastern Amazon. There is now medium confidence (medium evidence, high agreement) that severe drought episodes, land use, and fire interact synergistically to drive the transition of mature Amazon forests to low-biomass, low-statured fire-adapted woody vegetation. moving into adjacent savannas and grassland. If recent patterns of deforestation (through 2005), logging, severe drought, and forest fire continue into the future, more than half of the Amazon region’s forests will be cleared, logged, burned, or exposed to drought by 2030, even without invoking positive feedbacks with regional climate.

Plantation Forestry

Plantation forests (7% of the global forest area) are established through afforestation or reforestation, often with tree crop replacement. They differ from natural or semi-natural forests by generally being even-aged, having a reduced species diversity (sometimes of non-native species), and being dedicated to the production of timber, pulp, and/or bioenergy. Low species diversity renders plantation forests less resilient to climate change than natural forests

Afforestation usually results in net CO2 uptake from the atmosphere but does not necessarily result in a reduction in global warming. Growth rates in plantation forests have generally increased during the last decades but the variability is large, with clear attribution being difficult because of the interaction of multiple environmental drivers as well as changes in forest management. Plantations in cold-limited areas could benefit from global warming, provided that increased fires, storms, pests, and pathogens do not outweigh the potential direct climate effects on tree growth rates. How forest pests and pathogens will spread as a result of climate change and other factors is highly uncertain.

Assessments by Region

European Forests

In European forests, climate change is likely to cause ecological and socioeconomic damages from shifts in forest tree species (from southwest to northeast) and in pest species distribution. Observed and future responses of European forests to climate change include changes in growth rates, phenology, composition of animal and plant communities, increased fire and storm damage, and increased insect and pathogen damage. Tree mortality and forest decline due to severe drought events were observed in forest populations in Southern Europe (Italy, Cyprus, Greece, Belgium, Switzerland and the pre-Alps in France between 2006 and 2013. Future projections show that, in Northern and Atlantic Europe, increasing atmospheric CO2 and higher temperatures are expected to increase forest growth and wood production, at least in the short to medium term. On the other hand, in Southern and Eastern Europe, increasing drought and disturbance risks will cause adverse effects and productivity is expected to decline.

By 2100, climate change is expected to reduce the economic value of European forest land depending on interest rate and climate scenario, which equates to potential damages of several hundred billion euros. In Southern Europe, fire frequency and wildfire extent increased significantly after the 1970s compared with previous decades as a result of fuel accumulation, climate change and extreme weather events, especially in the Mediterranean basin. Although the total burned area has decreased in the Mediterranean region as a whole since 1985, future wildfire risk is projected to increase in Southern Europe and megafires, triggered by extreme climate events, have caused record maxima of burnt areas in some Mediterranean countries during the last decades. In Northern Europe, fires are expected to become less frequent due to increased humidity.

Windstorm damage to forests in Europe has recently increased, with boreal forests in the region becoming more vulnerable to autumn/early spring storm damage due to the expected decrease in the period of frozen soil. An increase in the incidence of diseases has been observed in many European forests, with projected increased late summer warming events favouring diffusion of bark beetle in Scandinavia, lowland parts of Central Europe and Austria.

Careful adaptation of forestry and soil management practices will be required to preserve a continental ecosystem carbon sink in Europe despite the vulnerability of this sink to climatic extremes and the first signs of carbon sink saturation in European forest biomass. In areas that are vulnerable to extreme events (such as fires, storms, droughts) or with high water demand, the development of bioenergy production from energy crops and from agricultural residues could further increase demands on adaptation.

Central and South America

Significant trends in precipitation and temperature have been observed in Central America (CA) and South America (SA) (high confidence). In addition, changes in climate variability and in extreme events have severely affected the region (medium confidence).

Two other important contrasting features characterize the region: having the biggest tropical forest of the planet on the one side, and possessing the largest potential for agricultural expansion and development during the next decades on the other. This is the case because the large countries of SA, especially, would have a major role in food and bioenergy production in the future, as long as policies toward adaptation to global climate change will be strategically designed. The region is already one of the top producers and user of bioenergy and this experience will serve as an example to other developing regions as well as developed regions.

However, a substantial amount of forest is gained through (single-crop) plantations, most noticeably in Chile, which has a much lower ecological value than the depleted natural forest.

Soybean and beef production together with palm oil have resulted in widespread deforestation, particularly in Brazil.

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