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Climate and ecosystem services

The potential of Norwegian ecosystems for climate mitigation and adaptation

Graciela M. Rusch

Norwegian Institute for Nature Research

Cooperation and expertise for a sustainable future

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Abstract

Rusch, G. M. 2012. Climate and ecosystem services. The potential of Norwegian ecosystems for climate mitigation and adaptation - NINA Report 791. 43 pp.

The concept of ecosystem services encompasses the many benefits that society receives from nature and that are often taken for granted. The conceptual framework highlights the connection between ecosystems and its components, and human well-being, and aims to complement current conservation measures and practices which have turned to be insufficient to achieve the 2010 targets of controlling the drivers of biodiversity loss. Ecosystem services are the aspects of nature that society uses, consumes, or enjoys. In some cases, i.e. when individuals or the society make choices that imply the allocation of resources, the benefits from nature have an economic dimension and can potentially be attached an economic value. At the same time many other aspects of nature are valuable but cannot be valued in an economic sense because they are not associated with social or individual economic choices.

This report is about some of the benefits that society receives form nature and that are linked with the challenges that society faces regarding climate change. Two areas in which nature brings benefits to society are highlighted and supported with examples which show the ecological and biological characteristics and processes that underpin the level of service supply. The first one is associated with the capacity of nature to counteract or mitigate the increase in global greenhouse gas emissions. This benefit is ultimately delivered by the growth of plants and the processes that accumulate carbon in biomass and in the soil. In addition, natural vegetation and undisturbed soil in terrestrial ecosystems form large reservoirs of carbon that are released as carbon dioxide when the vegetation cover and the soil are transformed through burning, tillage and draining, or through soil erosion. A second group of benefits is related to the capacity of nature to buffer against hazards produced by climatic extremes, for example, events with high rainfall which are often the cause of floods and higher soil erosion. These challenges will likely be of more concern in the future according to the projected changes in the climate.

The impacts of human activities on the capacity of ecosystems to provide services are emphasized as well as the potential benefits that can be obtained both by incorporating the multiple values of nature into planning and by improving the management of live systems. There is a strong weight of examples from boreal forest because of the extent and economic importance of this nature type in Norway, and because decisions about land-use and forest management have important consequences for the provision of many benefits. There are also examples from floodplains and riparian ecosystems because of their value in water flow and flood control. Green infrastructure is presented as a complementary resource to other proposed climate change adaptation measures. Finally, some additional benefits are highlighted and used as examples of trade-offs and synergies among the multiple services associated with climate change, underscoring the value of the ecosystem service framework to inform decision-making.

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Sammendrag

Rusch, G. M. 2012. Klima og økosystemtjenester. Norske økosystemers potensial for tilpasning til og reduksjon av klimaendringer – NINA Rapport 791, 43 s.

Økosystemtjenester er et samlebegrep for alle de grunnleggende goder som naturen forsyner oss med, og som vi ofte har en tendens til å ta for gitt. Det teoretiske rammeverket understreker sammenhengen mellom økosystemer, dets bestanddeler og menneskevelferd. Det innebærer også et forsøk på å supplere eksisterende forvaltningstiltak og praksis, da disse har vist seg å være utilstrekkelige i forhold til å nå 2010-målene om å stoppe tap av biologisk mangfold. I noen tilfeller har økosystemtjenestene et økonomisk omfang og kan potensielt gis en økonomisk verdi. Dette gjelder for eksempel når individer eller samfunnet tar avgjørelser angående ressursfordeling. Samtidig er mange andre aspekter av naturen verdifulle, uten at de kan verdsettes i et økonomisk perspektiv, da de ikke er koblet til sosiale eller individuelle økonomiske avveiinger.

Denne rapporten fokuserer på noen av de godene vi får fra naturen, som er knyttet til utfordringene klimaendringer medfører. Rapporten fokuserer på to grupper av økosystemtjenester, med eksempler på økologiske og biologiske egenskaper og prosesser som belyser tjenestene. Den første gruppa går på naturens evne til å motvirke og redusere effekten av økningen i globale klimagassutslipp. Denne økosystemtjenesten omfatter plantevekst og prosessene som tar opp karbon i biomasse og i jord. Naturlig vegetasjon og uforstyrret jord danner store karbonreservoarer i terrestriske økosystemer, som slippes ut i form av karbondioksid når vegetasjonsdekket og jorden omdannes gjennom brenning, jordbearbeiding og drenering, eller gjennom jorderosjon.

Den andre gruppa økosystemtjenester går på naturens evne til å motstå negative konsekvenser av ekstremvær, for eksempel i situasjoner med mye nedbør som kan gi flom og økt jorderosjon. Slike episoder vil ifølge gjeldende klimascenarier sannsynligvis bli mer alvorlige i framtida. Den menneskeskapte påvirkningen på økosystemenes evne til å yte tjenester er vektlagt. Rapporten framhever også de potensielle fordelene som kan oppnås ved å inkludere flere aspekter av naturverdier i planlegging og forvaltning av naturområder. Det er en overvekt av eksempler fra boreal skog på grunn av omfanget og den økonomiske verdien denne typen natur har i Norge. Endringer i arealbruk og skogsdrift har viktige konsekvenser for økosystemtjenestene. Eksempler fra økosystemer som elvesletter og elvebredder er tatt med på grunn av deres betydning for vannføring og flomkontroll. Grønn infrastruktur er lansert som en komplementær ressurs til andre foreslåtte klimaendringstilpassingstiltak.

Til slutt er betydningen av de ulike dimensjonene av naturressursforvaltning framhevet. Naturen gir mange tjenester og varer, og ytelsen kan bedres med god planlegging. Å bare ta hensyn til et snevert formål, for eksempel karbonbinding, er ikke tilstrekkelig for å håndtere den naturlige kompleksiteten. I slike tilfeller kan høyere samlet effektivitet og kostnadseffektivitet oppnås når alle viktige mål blir integrert i en helhetlig planlegging.

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Contents

Foreword

This report was commissioned by the Norwegian Directorate for Nature Management (contract nr 11040046) with the aim of highlighting the linkages between climate and ecosystem services with a special focus on how good management practices of ecosystems in Norway can mitigate climate change and increase the Norwegian society's capacity to cope with climate change. The project will contribute to the Directorate's work to insure that nature is managed in the best way considering projected changes in the climate.

The focus of the report is primarily on regulating services linked to the capacity of ecosystems to mitigate climate change (i.e. carbon storage and sequestration) and of Society to cope with natural hazards which are expected to occur as a consequence of global warming. I summerize the mechanisms by which ecosystems provide these services, describe how human activities can modify the capacity to provide services and discuss some alternatives about how ecosystem services can be enhanced through wise planning and managed.

I thank Jon Museth who facilitated references and material about flood regulation capacity of wetlands. Annika Hofgaard and Erik Framstad made many thoughtful comments to report drafts. Thank you to Kari Sivertsen for the drawings and to Per Arild Aarrestad for thoughtful editing. The report has benefitted from discussions with the 'ecosystem services group' at NINA.

February 26th 2012, Graciela M. Rusch

1 Introduction

The benefits that nature provides to human populations are often referred to as ecosystem services (Daily 1997, Millennium Ecosystem Assessment 2005). They are ecological components, processes, and functions that are valued by people (Boyd 2007). Despite its development from ecology, the term “services” originates in economics and has been adopted in ecology to highlight the connection between ecosystems and human well-being. The framework was conceived to raise awareness about the importance of nature and natural processes to society; and as a paradigm that would encourage reflection about the impacts that human activities have on natural systems. In many cases, human activities pose severe threats to the maintainance of life systems and their functions. At present, the approach is aimed to complement current conservation measures and practices which have turned to be insufficient to achieve the 2010 targets of controlling the drivers of biodiversity loss.

After the introduction of the concept (Daily 1997), the global initiative of the Millennium Ecosystem Assessment (MA 2005) assessed the consequences of changes in ecosystems for human well-being and established the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems (MA 2005, **Table 1**).

Some benefits derive from ecological functions that are directly related to organisms that form ecosystems. For example, soil microorganisms and plants regulate fundamental biogeochemical processes involved in the cycling of nutrients in the soil and the production of biomass and carbon capture on land and water (Mace et al. 2011). Also, benefits from nature derive from ecological functions that rely on interactions among species. For example, soil fertility and the maintenance of a variety of soil functions involve multiple interactions between plants, herbivores, carnivores and soil biota (Wardle et al. 2004). Likewise, pollination of crops and pest control, rely on biological interactions (predation, herbivory, feeding, parasitism, mutualism) between different species and organism groups. Other benefits of nature include many forms of recreation, aesthetic enjoyment, commercial and subsistence harvests, damage avoidance, human health, and enjoyment of life's diversity (Boyd 2007).

Ecosystem services are the aspects of nature that society uses, consumes, or enjoys to experience those benefits (Boyd 2007). In some cases, the benefits from nature to society can be assessed in terms of their economic value. These are, in economic terms, the ones associated with social or individual choices that involve the allocation of resources. Some benefits are private, they are received by individuals or companies, and others are public goods. At the same time, there are many aspects of nature that are valuable and fundamental to well-being, but that cannot be valued in economic sense.

The benefits produced by nature are unevenly distributed in space; because of they are based on spatially-variable underlying ecosystem processes (Balmford et al. 2008). The use of these benefits is spatially heterogeneous too, depending critically on the patterns of distribution of end users (e.g., cities, or agricultural areas), which creates substantial spatial variability in the value of benefits even within areas with similar natural production and flow (Balmford et al. 2008). Pollination is an example of highly spatially structured ecosystem service. The benefit of enjoying high levels of pollination will depend on the quality of habitats that provide alternative sources of feed for pollinators (Hegland & Bøke 2006), of the availability of nesting habitats, and of the distance between nesting habitats and the crop (Kremen et al. 2007, Lonsdorf et al. 2007). Therefore, the decisions about the benefits and the trade-offs among them take place on physical space (Troy & Wilson 2006, Nelson et al. 2009, Tallis & Polasky 2011). Some of the important benefits that society receives from nature play an important role in coping with climate changes (EU 2010, **Table 1**).

***Table 1**: Proposed basic structure of the international catergorisation of ecosystem services according to the Common International Classification of Ecosystem Services (CICES). Basic structure and relationship to TEEB[1]classification. Three major ecosystem service themes (provisioning, regulating and maintainance processes and cultural services). Haines-Young and Potschin 2011 (Update). Boxes in orange show the services illustrated in this report.*

CICES theme	CICES classes	Examples from TEEB categories			
Provisioning	Nutrition	Food	Water		
	Materials	Raw materials	Genetic resources	Medicinal resources	Ornamental resources
	Energy				
Regulating and Maintainance	Regulation of wastes	Air purification	waste treatment (esp. water purification)		
	Flow regulation	Disturbance prevention or moderation	Regulation of water flows	Erosion prevention	
	Regulation of physical environment	Climate regulation (incl. C-sequestration)	Maintaining soil fertility		
	Regulation of biotic environment	Gene pool protection	Lifecycle mainenance	Pollination	Biological control
Cultural	Symbolic	Information for cognitive development			
	Intellectual and experimental	Aesthetic information	Inspiration for culture, art and design	Speritual experience	Recreation & tourism

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[1] TEEB project: The Economics of Ecosystem Services and Biodiveristy (Balmford et al. 2008).

2 The scope of the report

The scope of this report is about the benefits that society receives form nature and that are related with the challenges that society faces regarding climate change. The report focuses on three important areas in which nature brings valuable benefits to society.

The first area is associated with the capacity of nature to counteract or mitigate the increase in global green house gas (GHG) emissions that are caused primarily by the use of fossil fuel, but also by changes in the land cover. This benefit is ultimately produced by the growth of plants or the process of primary production. In addition, natural vegetation and undisturbed soil in terrestrial ecosystems also form large reservoirs of carbon (C) that are released as carbon dioxide (CO_2) and hence, contribute to increase GHG emissions when the vegetation cover and the soil are transformed through burning, tillage and draining.

A second group of benefits is related to the capacity of nature to buffer against hazards produced by climatic extremes, for example, events with high rainfall which are often the cause of floods and higher soil erosion. These problems will likely be of more concern in the future, since current predictions about rainfall in Northern hemisphere (Scandinavia, Norway) point to higher frequency of events with high rainfall. The vegetation cover has the capacity to absorb peaks, having a regulating function against floods and controlling erosion and thus soil loss. Also related to climatic phenomena are the benefits from nature associated with the capacity of complex natural systems to reduce risks of losses in the production of food, fibres and timber.

3 The C cycle and greenhouse gases emissions

Through the process of photosynthesis, terrestrial plants capture atmospheric CO_2 and chemically transform CO_2 molecules into organic carbon compounds that form plant tissues and reserves (starch and sugars). The rate of carbon sequestration, or in other words, the rate at which CO_2 is removed from the atmosphere and bound in plant biomass is directly related to the processes of photosynthesis and primary productivity (**Fig. 1**). Plants return some amount of CO_2 back to the atmosphere through respiration, and the difference between the CO_2 that is captured through photosynthesis and that is released back through respiration results in accumulation of biomass (**Fig. 1**). Hence, the importance of plants in the carbon cycle is vital. In addition to the emissions by respiration, biological systems release CO_2 back to the atmosphere through the process of decomposition of organic matter (**Fig. 1**). Fires and burning of organic material (wood, peat) are also processes that release CO_2.

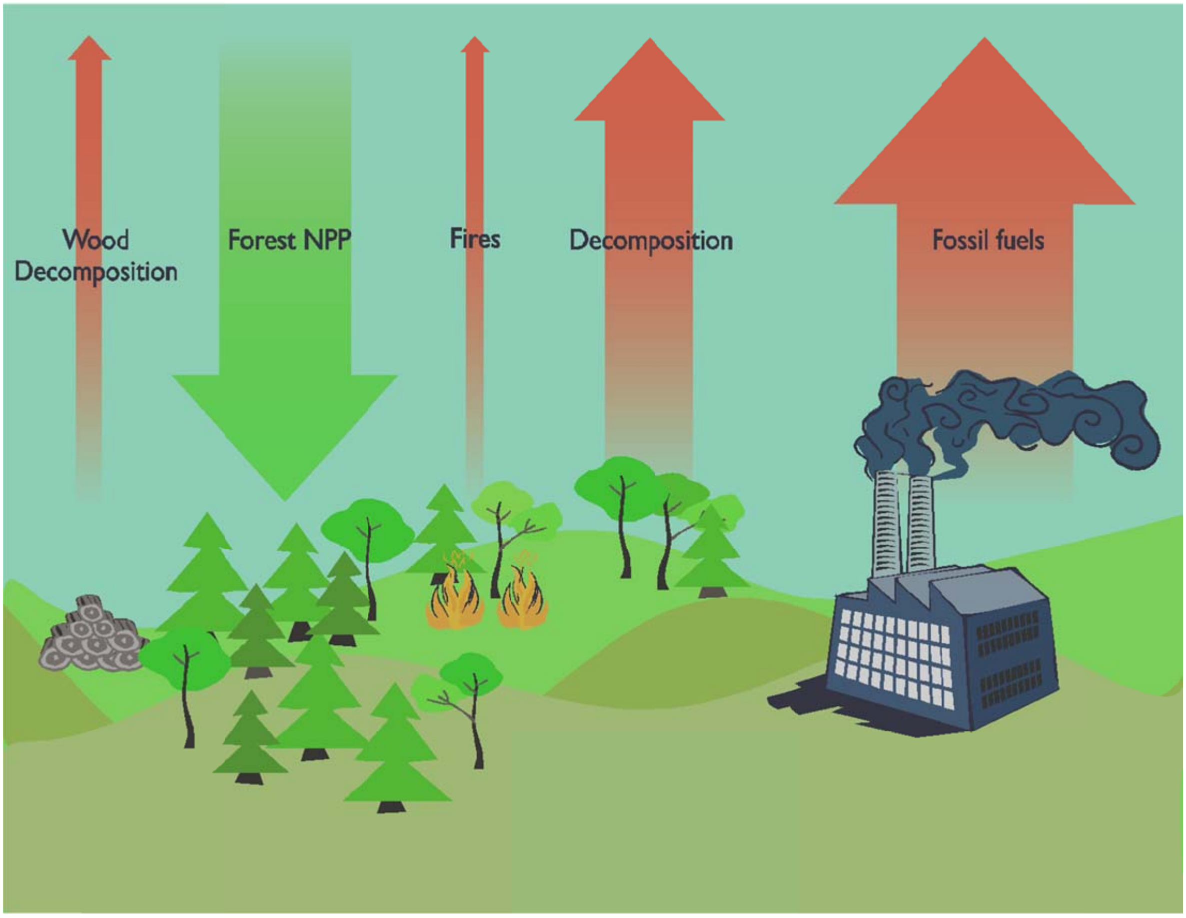

Figure 1*: Diagram illustrating the processes in the bio-geo-atmosphere that are involved in the carbon cycle. The green arrow indicates net carbon sequestration function from the atmosphere by plants. Red arrows indicate emissions of greenhouse gases to the atmosphere through biomass decomposition, fire and combustion of fossil fuels. The size of the arrows is scaled to indicate the magnitude of the flow.*

Fossil fuels are composed by organic C compounds that plants have produced and accumulated during a very long time-span (in the order of hundreds of millions years) and are stored under the Earth surface primarily as coal and oil. Hence, when burned, these fuels release a large amount of accumulated CO_2 and other GHG back to the atmosphere. The magnitude of the release is evidenced by the amount of CO_2 in the atmosphere since the start of the industrial era, when these sources started to be extensively exploited (**Fig. 1**, **Table 2**). An additional source of CO_2 released to the atmosphere is caused by land conversion, e.g. the replacement of natural vegetation to arable land. This release results from the combustion of organic material when burning and from increased decomposition rates of biomass detritus and soil organic matter when the soil is ploughed. The release is of considerable magnitude, because it converts biomass and soil organic matter accumulated over longer periods of time (in the order of magnitude of 100s to 10 000 years). Measurements of the global atmospheric concentrations of GHG show marked increases since pre-industrial times, with levels of CO_2 far exceeding the natural range of the past 650000 years. The concentration of atmospheric CO_2 has increased from a pre-industrial level of about 280 ppm to more than 387 ppm in 2008 (**Fig. 2**).

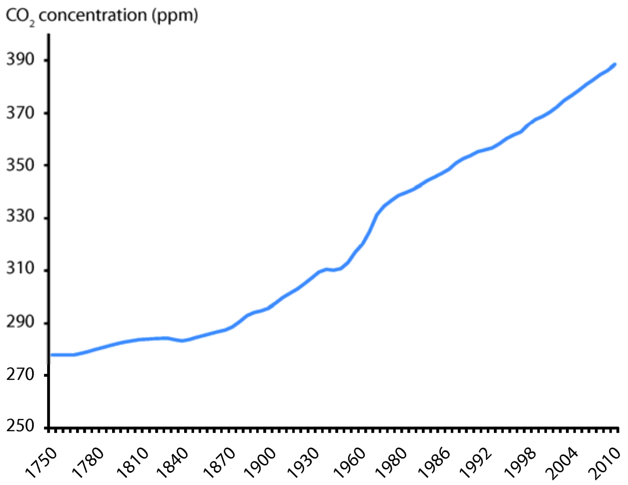

***Figure 2**: Historic development of atmospheric CO2 concentrations (ppm). Source: European Enviormental Agency (EEA) http://www.eea.europa.eu/data-and-maps/figures/atmospheric-concentration-of-co2-ppm accessed 2011-12-20*

***Table 2**: Emissions from fossil fuels and land-use change (millions of metric tons of C per year). Source: Oak Ridge National Lab, Carbon Dioxide Information Analysis Center in Stavins & Richards (2005)*

	1850	**1900**	**1950**	**1960**	**1970**	**1980**	**1990**	**2000**
Fossil Fuel	54	534	1612	2535	3998	5177	5969	6385
Land-use Change	503	697	935	1302	1537	1608	2158	2081

The emissions in Norway have increased in the past 20 years, primarily in the energy sector, and have had with a small decline in recent years, mainly due to a reduction of emissions in the industry sector (**Fig. 3**).

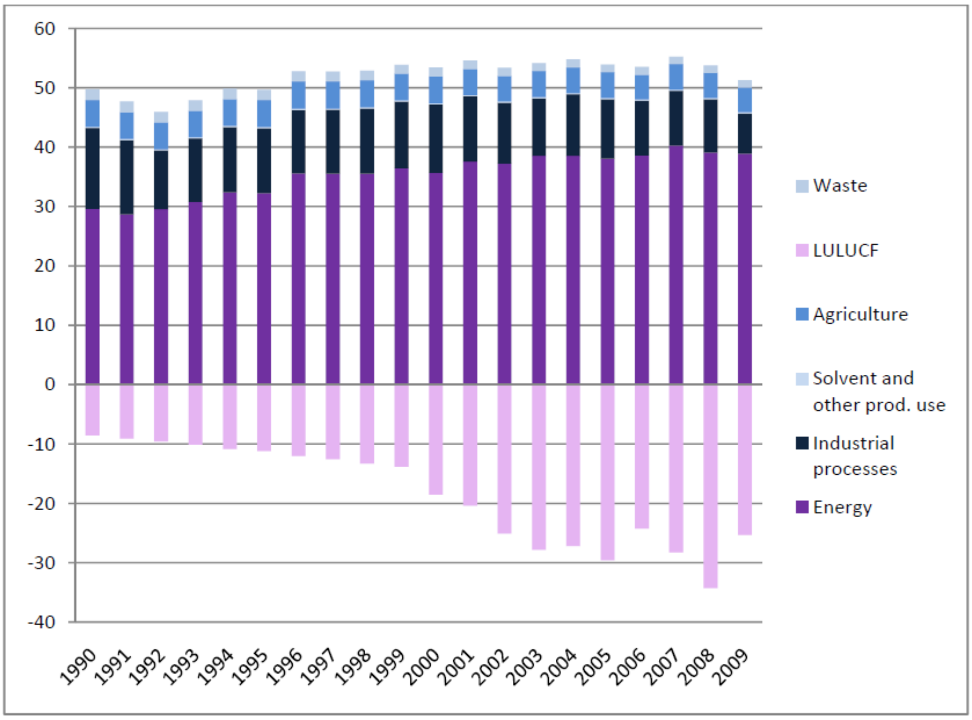

***Figure 3**: Total emissions of all GHG in Norway from 1990 to 2009 calculated as Mtonnes CO_2 equivalents from the different sectors. LULUCF: Land use, Land-Use Change and Forestry. Source: Norwegian Climate and Pollution Agency (2011).*

4 Climate change projections for Norway

4.1 Features of the Norwegian climate

4.1.1 Temperature and plant growth season

The Norwegian climate has considerable geographical and temporal variation, and it is relatively warm compared to other regions at the same latitude due to the influence of air and sea currents (Hanssen-Bauer et al. 2009). Shifts in these currents cause important variation in the local climate. The annual mean temperature ranges from +6 °C at the coast in Vestlandet to –4 °C in the high alpine zone. In parallel, the length of the growing season, estimated by the number of days with mean temperature above 5 °C, varies from 225 days in Vestlandet to below 70 days in the high alpine zone (Hanssen-Bauer et al. 2009).

The ranges in latitude, altitude and the degree of proximity to the sea determine the variation in mean temperature, the length of the growing season and the seasonal variability in temperature.

4.1.2 Rainfall and hydrology

The proximity of land to the sea defines an important climate gradient, from maritime in coastal areas to continental climate in the mountains with a strong influence on the amount of rainfall, whether it falls as water or as snow, on runoff and the hydrological cycle.

The hydrological cycle describes how water falls on land as rainfall, how it accumulates as snow and ice, or infiltrates and is stored as soil- and ground-water, how it goes back to the atmosphere through evapo-transpiration and how it is transported as surface water to the sea (Hanssen-Bauer et al. 2009).

Mean annual rainfall in Norway is estimated to 1486 mm of which 346 mm (ca 25%) go back to the atmosphere through evapo- transpiration and 1140 mm drains (infiltration and runoff) (Wong et al. 2011). Norway has therefore a positive rainfall/evapo-transpiration balance. However, there are large regional differences. According to Hanssen-Bauer et al. (2009), the mean annual precipitation ranges from approximately 300 to 3500 mm, with the highest precipitation amounts found in western and northern Norway. Øvre Gudbrandsdalen and Inland Troms are the driest regions (with less than 300 mm rainfall) and small areas in Vestlandet, the wettest (over 5000 mm rainfall on certain localities). Also mean one-day rainfall event varies between dry and wet areas, ranges from 15 mm to ca 150 mm, respectively. These day mean values are exceeded 3-4 times per year. These rainfall patterns largely determine the magnitude of runoff, which is largest at Ålfotbreen (ca 5400 mm), and lowest at the higher Gudbrandsdalen watershed (ca. 350 mm).

Watersheds close to the coast have in average only few days with snow cover, whereas high alpine areas are covered with snow more than 300 days per year, and the glaciers have permanent snow or ice cover. Whether the climate is maritme or continental has a strong effect on seasonal stream-flows (Beldring et al. 2003). Streamflow in continental or mountain type regimes show low flows in the winter and dominant spring and summer high and predictable flows caused by seasonal snow melt (Poff 2002, Beldring et al. 2003, and **Fig. 4a**). At the other extreme, catchments in the coastal type have less predictable high flow patterns with dominant autumn and winter high flows caused by rain, and summer low flows (**Fig. 4b**). Many catchments have varing degrees of dominance of spring snowmelt and autumn rain high flows (Beldring et al. 2003, Hanssen-Bauer et al. 2009).

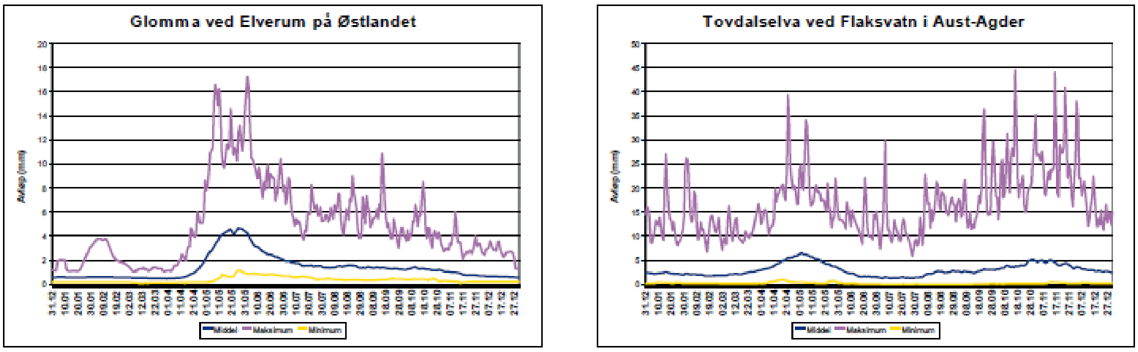

Figure 4*: Normal flow (mm/day) (blue line), highest (purple line) and lowest (yellow line) observed flow per day and year in the Glomma river at the Elverum watershed in the Østlandet region (a) and at the Tovdal river vid Flaksvatn in the Agust-Agder region (b). (a) and (b) correspond to mountain and coastal runoff regimes (Beldring et al. 2003). Source: Hanssen-Bauer et al. 2009).*

4.2 Climate change projections in Norway

Knowledge about future climate change – how fast and to what extent the climate will change – is neither complete nor certain. However, there is a general consensus among scientists that the emissions of GHG to the atmosphere will have significant consequences on the climate and life on Earth. Current climate research does not provide any definite answers, but do give an indication of the direction in which the climate will change (Flæte et al. 2010).

Hansse-Bauer et al. (2009) describe climate changes that have been observed in the past centuary. Despite large variations between years and decades observed on continental Norway, there has been a clear increase in the amount of rainfall during the past 100 years, particularly from the end of the 70'ies (**Fig. 5**). In the past centuary, the yearly rainfall has increased almost 20 %, with the increase being largest in the west coast region (Vestlandet). Their analysis also shows that the increase in rainfall during this period has been largest during the winter and lowest in the summer (24% and 8% increase in 100 years, respectively) but there is a considerable variation among climate regions in the country. In South-Norway the increase in summer rainfall has been the lowest.

In addition to the observed changes in temperature and in the amount of rainfall, changes in the climate are also reflected in terms of the frequency and intensity of extreme climatic events. Hanssen-Bauer et al. (2009) describe the changes that have been observed in terms of extreme rainfall events during the period 1900 to 2004 in Norway in the following way: The maximum rainfall in 1-day increased in 2/3 of the stations with records during this period, although the trends are only statistically significant in 4 stations. There are also indications of an increase in the frequency of intensive rainfall in short periods (less than one day). In the area of Oslo, for example, there has been an increase in frequency of high 1-hour rainfall values in the period between 1968 and 2008. These observations are in agreement with global trends. A recent report from the Intergovernmental Panel on Climate Change (IPCC, 2011) indicates with quite confidence that climate changes are very likely to increase the occurrence of extreme climatic events.

Records of hydrological patterns show large variability and they are difficult to relate to changes in the climate. However, Hanssen-Bauer et al.'s (2009) report indicates a clear increase in winter runoff in Eastern Norway (Østlandet). This increase is larger in the lowlands than at higher altitudes. The authors conclude that this pattern can be explained by the occurrence of more periods of mild weather with snowmelting combined with rain than in the normal period. They also conclude that the increase in glacial runoff from the summers and autumns 1993 must have been a consecuence of icemelting combined with rainfall in the ice-free portion of the glacial area (Hanssen-Bauer et al. (2009). Both patterns indicate higher temperatures and higher occurences of winter rainfall as rain, and in turn, the occurrence of rain-on-snow events. Rain-on-snow events take place when rain falls onto a frozen ground with a pre-existing snowpack. In this case, runoff is exacerbated because the rain does not infiltrate the soil and can, in addition, cause the snow to melt, creating conditions which in some instances can lead to flooding.

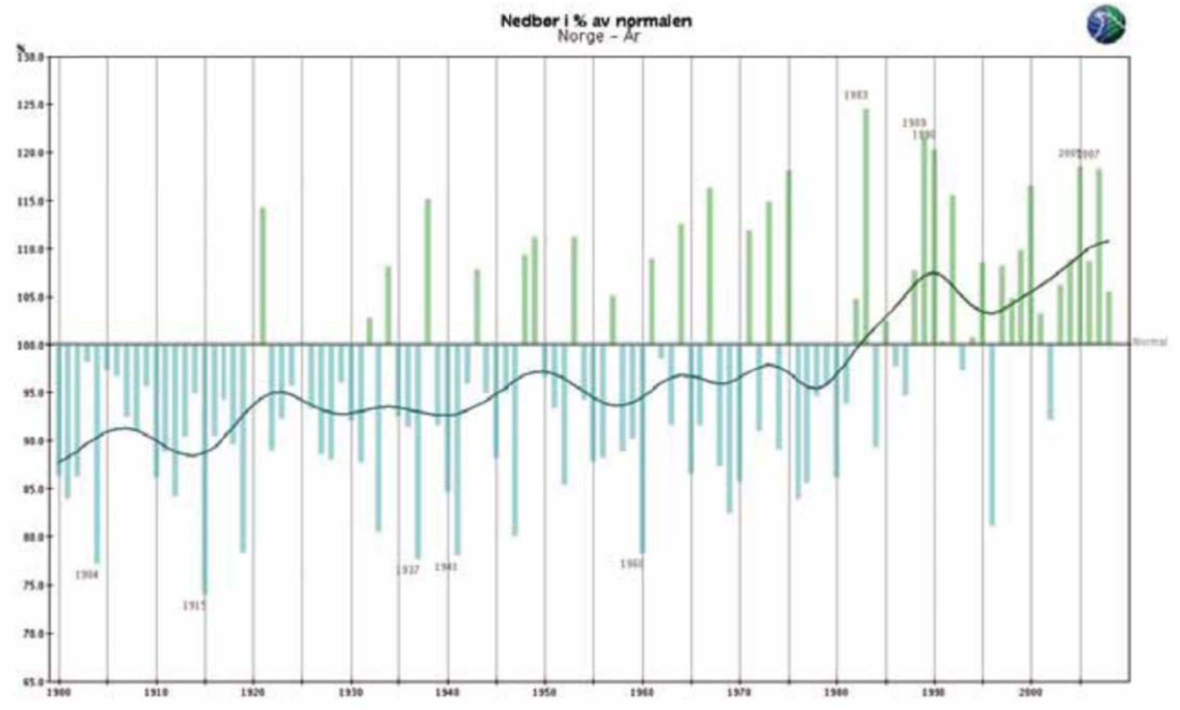

__Figure 5__: Development of rainfall on Norway's mainland 1900-2008. The bars show rainfall as a percentage of the mean rainfall for the normal period 1961-90. Source: Hanssen-Bauer et al. 2009.

Despite the large natural climatic variability, recent analyses of Norwegian climate indicate that the changes that have been observed in the last century are in agreement with what could be expected as a result of human impacts in the form of increased concentrations of GHG in the atmosphere (Hanssen-Bauer et al. 2009). The projections about climate change indicate altered temperature and precipitation in different ways globally. In Norway, recent projections predict in all cases a warmer summer season (15 May–15 October) for the whole country with a temperature increase of 1^{o} – 4^{o}C (Wong et al. 2011). The largest increase can be expected in southeastern and northern Norway, with the smallest increase along the west coast. Also, according to all projections, mid- and northern Norway will experience an increase in future summer precipitation from 100 to over 200 mm; and following the increase in temperature, it is projected general increases in evapotranspiration (Wong et al. 2011).

5 Climate change mitigation services

In response to the concerns about the impacts of human activities on the composition of the atmosphere and their consequences on life systems, the global climate and human-well being in the future, the United Nations Framework Convention of Climate Change (UNFCCC) has set as its ultimate objective: *"the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*" (UNFCCC 1997 Article 2).

Important ecosystem services are linked to this objective. One agreed imitigation strategy for stabilization of GHG in the atmosphere under the Kyoto Protocol is the "*protection and enhancement of sinks and reservoirs of GHG not controlled by the Montreal Protocol*[2]*; promotion of sustainable forest management practices, afforestation and reforestation*" (UNFCCC 1997). In sections 6.1 and 6.2 the factors that underspin the provision of mitigation services are explained. The sections refer to carbon reservoirs or stocks, and to the processes underlying the question about carbon sinks, repectively. In section 7 we address the question about how the management of nature can affect the provision of climate mitigation services.

5.1 Carbon stored in natural and semi-natural vegetation

Ecosystems store a large stock of organic carbon in the vegetation, in peat and in the soil. Soil and biomass contain 3-4 times the amount of C in the atmosphere and therefore play an important role as a regulator of the GHG in the atmosphere (Grønlund et al. 2010). Therefore, one way to stabilize GHG in the atmosphere is to maintain the carbon stored in terrestrial ecosystems, reducing in that way the amount of GHG that passes from terrestrial ecosystems to the atmosphere.

There are large differences, among ecosystems both in the size of the stocks, which depends both on the area covered and on the ecosystem's characteristic; and in how C is distributed between the standing vegetation, debris material and soil organic matter (SOM).

In Norway, forests constitute approximately 38% of the mainland land-cover, mires and wetlands 6 %, agricultural land and pastures 3%. Land that is not covered by any of these cateogories consitutue 43% of the total area, primarily mountain areas without forest cover. The rest of the area (8%) is urban areas, water bodies and glaciers (Grønlund et al. 2010, **Table 3**)

***Table 3**: Land cover types in Norway. Source: Statistics Norway http://www.ssb.no/areal/*

	%	**Km^2**
Total	100.0	323 782
Urban areas & constructions	1.4	4 533
Agricultural land & pastures	3.2	10 361
Mires & wetlands	5.8	18 779
Water bodies & glaciers	7.0	22 665
Forest	38.2	123 685
Alpine	44.4	143 759

The land-cover types that contribute mostly to the C stock are forest, mires and wetlands and the mountain areas above the forest line.

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[2] "Montreal Protocol" means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended (UNFCCC 1997).

In Norway, the carbon stock in forest, including above-ground biomass and root (but excluding soil organic matter (SOM)), has been estimated in 450 mill tons, distributed as 90% in live biomass and 10% in dead trees and debris. Approximately 78% of the forest biomass stock is in above-ground biomass and 22 % in roots (Grøndlund et al. 2010). There is considerable variation, however, in the size of carbon stocks in forest stands with different soil fertility and of different tree species compositon. The amount of carbon stored in boreal forest is higher in sites of high soil productivity (Kranabetter 2009, Grønlund et al. 2010); and Pine forests and mixed Norwegian Spruce and Pine forests have higher carbon stocks than pure stand of Norwegian Spruce.

The carbon stock in a forest stand also varies with age; and generally accumulates along the development of the forest. However, studies of Nordic boreal forests under different disturbance (fire) regimes show that total above-ground carbon storage (including trees and understorey vegetation) is higher in forests that are disturbed more frequently (Wardle et al. 2012). The same studies show that, in contrast to above-ground forest carbon, below-ground carbon stocks are larger in forest with longer time of biomass accumulation. The addition of stocks of above- and below-ground carbon results in higher total carbon stock in forests with long, non-disturbed accumulation periods (Wardle et al. 2012). This is due to a large extent to the stock of soil organic carbon, which in contrast to that in the forest biomass, builds up over longer time. The studies by Wardle et al. (2012) show a continuous accumulation of SOM at least during 5000 years (Wardle et al. 2012) and often a period in the order of 10 000 years is assumed in models of SOM in Scandinavia.

Globally, soils store the largest stock of carbon in terrestrial ecosystems, two to three times larger than the carbon pool of vegetation (Schlesinger 1991, in de Wit et al. 2006). Specifically in the case of the forest in Norway, the carbon stock in SOM is approximately 75 % of the total carbon stock in the forest ecosystem, and it has been estimated to 1 550 mill tons (Grønland et al. 2010). Soil carbon stocks, however, vary considerably with the site physical properties; dry soils have smaller carbon stocks than moist soils, as revealed by a recent study in Sweden (Olsson et al. 2009).

Despite the comparatively smaller area occupied by mires, the carbon stock in open mires in Norway accounts to about half of the stock in forests and forest soils together. The size of the stock depends on the depth of the peat layer (ranging between 0.65 m to 2 m in Norway), the density and the proportion of peat. In Norway, it has been estimated in 950 mill tons carbon (Grønlund et al. 2010).

The alpine area covers 44.4% the majority of the mainland in Norway (**Table 3**). The total C stock in these land-systems is estimated between 500 and 1 500 mill tons C.

5.2 Carbon sequestration

The majority of the GHG that is emitted to the atmosphere through burning of fossil fuels is CO_2, the basic compound which plants use to build their biomass and which, in turn, supports most terrestrial life on Earth. In forests, the CO_2 sequestration rate largely depends on the conditions for plant growth (e.g. climate and soil nutrients), the management practices adopted and the species of trees involved (Stavins & Richards 2005). If the difference between the rate of CO_2 sequestration and release to the atmosphere is positive, there will be a net accumulation of biomass (in the form of leaves, branches, stems, roots and other plant tissues). The ecosystem is then considered to be a 'CO_2 **sink'**, and if the difference is negative, a 'CO_2 **source'.** The proposed GHG stabilizing measure of "*protection and enhancement of CO2 sinks*" (UNFCCC 1997) addresses the maintainance and/or enhancement of CO_2 sequestration by plants, in other words, a service that is provided by nature to counteract the negative effects of human activities on the atmosphere and the global climate. Changes in C stocks are monitored in Norway and reports on GHG emissions and carbon stocks are also submitted to the United Nations Framework Convention on Climate Change (UNFCCC) and to the EU (Climate Pollution Agency 2011, **Fig. 3**).

Stocks of trees in northern Europe (Luyssaert et al. 2010) and in Norway (de Wit et al. 2006) have increased in the past decades, resulting in significantly higher carbon sink strength. In Norway, between 1970 and 2001, an increase of 29% and 4.5% has been estimated for forest biomass and soil carbon in productive forest, respectively (de Wit et al. 2006). Both boreal forests, and mires and wetlands are at present significant carbon sinks in Norway, but they could become net carbon sources as the Earth warms.

There are various factors that determine whether the ecosystem is a carbon sink or a source (whether the difference between CO_2 capture through photosynthesis and release through respiration and organic matter decomposition is positive or negative) (Table 4). These factors are linked to the resources available for plant growth, the climate, and to land-use and management. Therefore shifts in current levels of CO_2 capture and release should be expected as a consequence of changes in these factors.

A critical resource for plant growth is the concentration of CO_2 in the air. There is accumulating evidence that the increased levels of CO_2 concentrations in the atmosphere have a large scale impact on plant growth. Bellassen et al. (2011) indicate that higher levels of atmospheric CO_2 appear to affect carbpm sinks more, indicating large direct impacts of GHG emissions on the carbon cycle and ecosystem functions. Also, site conditions, in terms of water availability, drainage and soil fertility that are important determinants of forest growth affect the capacity of the forest to capture CO_2.

The capacity to capture CO_2 is also determined by the characteristics of the forest stand such as age and species composition. CO_2 sequestration capacity is typically low at early stages of the forest stand, increases with stand age, and declines at stand maturity. However, the time at highest carbon uptake varies considerably among tree species (Stavins & Richards 2005). Bellassen et al. (2011) provide further evidence of the importance of forest stand age on the level of C sequestration. Despite earlier arguments that ageing forests cease to accumulate carbon and reach a zero CO_2 net balance at old age, recent studies show that old- growth forests remove CO_2 from the atmosphere and therefore serve as a global CO_2 sink. Luyssaert et al. (2008) found that in forests between 15 and 800 years of age, net ecosystem productivity (the net carbon balance of the forest including soils) is usually positive, demonstrating that old-growth forests can continue to accumulate carbon. These results are in contrast with the long-standing view that old-growth forests are carbon neutral. In their study, both forest stand age structure and management were responsible for a large variation in the level of carbon capture over the course of a forest rotation, the effect of which was even higher than that of climate fluctuations (600 g C m-2 yr-1 compared to <300 g C m-2 yr-1, for management and climate respectively).

One of the main drivers of organic matter decomposition and soil carbon accumulation is the quality of the litter which depends on the attributes of the plant species in the vegetation (for example, Rothstein et al. 2004, Cornelissen et al. 2004, Cornwell et al. 2008, Weedon et al. 2009, Wardle et al. 2012).Climatic effects on litter decomposition rate can be important, but they appear to be smaller compared to differences due to the quality of the litter (Cornwell et al. 2008). Further, litter quality appears to mediate the accumulation of soil C along forest succession. Studies in northern Scandinavia (Wardle et al. 2012 and references therein) show that soil C accumulates steadily as forest sucession advances and pioneer species are replaced by late successional species (in this case, Norwegian Spruce). Wardle et al. (2012) attribute the increase in forest soil C stock to the low decomposition rates of the litter of late successional species that leads to higher contents of recalcitrant organic matter in the soil.

Table 4*: Factors that affect CO_2 capture and release processes, determining the balance between CO_2 sink and source in forest and forest soils.*

FACTORS	C CAPTURE PROCESSES	C RELEASE PROCESSES
Physical conditions		
Atmospheric CO_2 concentration	Higher photosynthesis rates, higher biomass and soil C accumulation with high CO2 concentration.	
Temperature	Generally, higher photosynthesis rates with higher temperature	Generally, higher respiration and decomposition rates with higher temperature (Cornwell et al. 2008).
Water balance	Plant growth rates determined by water availability, decline with drought.	The largest C stocks in boreal forest occur in poorly drained sites (Rapalee et al. 1998). Soil and wetland drainage is often a major cause of CO2 release.
Site fertility	Higher C storage in sites with higher productivity (Kranabetter 2009, Grønlund 2010).	
Forest stand age	*At stand level*, biomass accumulation rate peaks at intermediate age (Stavins & Richards 2005) but continues in old-growth forest (Luyssært et al. 2008). *At ecosystem level*, projections estimate forest biomass accumulation in Norwegian boreal forest leveling out at 190-340 years (Holtsmark 2011)	*At stand level*, affecting the amount of litter fall and debris. May increase in old-growth forest due to higher debris deposition. *At ecosystem level*, soil C in Nordic boreal forest accumulates steadily at least during 5 000 years (Wardle et al. 2012).
Species composition	Species-specific growth rates affect CO_2 sequestration rates	Plant species litter and wood debris quality affect OM decomposition rates. *Low N, high lignin and secondary compounds reduce decomposition rates (Cornelissen et al. 1999, Cornwell et al. 2008). *Quality of litter can affect decomposition pathways (fungal vs bacterial). Higher fungal-to-bacterial ratio seems to promote C accumulation in soil (Wardle et al. 2004).

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5.3 Land use and the capacity of climate mitigation service provision

5.3.1 Carbon storage and forest management

Management practices and land-use change can profoundly affect carbon stocks of terrestrial ecosystems. Deforestation and the conversion of other natural cover are important sources of CO_2, releasing carbon primarily by encreasing the rates of organic matter decomposition and through burning. Since the industrial era, more than a third of anthropogenic CO_2 emissions have resulted from land conversion (Chan et al. 2006 and Houghton 2003[3], **Table 2**) and the current release of stored carbon in living biomass and soil organic matter by deforestation and land conversion is estimated to account for 20% of the total GHG emissions (IPCC 2007).

In Norway, there has been a trend since the mid-90's of negative GHG emissions of atmospheric CO_2 from Landuse, Land-Use Change and Forestry (LULUCF) (Climate and Pollution Agency 2011, **Fig. 3**), or in other words, a net biological binding of C during this period.

However, these patterns could change with more intense harvests, for example for biofuel exploitation. Explorative projections at the national level indicate that higher levels of harvest resulting from biofuel extraction in Norway would have an impact on the area harvested, on the length of the harvest cycles and on the amount of C stored in forest biomass. An extraction level of 9.5 Mm^3 yearly, would allow a rotation cyle of 250 years and an area harvested of 300 km^2/year. Increasing the extraction to 22.5 Mm^3 would reduce the C stock in forest biomass to approximately 50% (Holtsmark 2011, **Table 5**). Even without considering the C stock losses from the soil, the higher level of forest biomass extraction would reduce the stock in about 90 MtC that would stabilize in approximately 150 years (Holtsmark 2011, **Fig. 6**).

Box 1. The national LULUCF emissions and removals in Norway are estimated and reported to the Climate Convention and the Kyoto-Protocol based on data provided by the National Forest Inventory (NFI) and complemented with other data collected by Statistics Norway, Norwegian Agricultural Authority, Food Safety Authority, the Norwegian Directorate for Nature Management, and The Directorate for Civil Protection and Emergency Planning. The calculations of biomass and carbon stock in forest are based on single tree biomass components such as stem, bark, living branches, dead branches, needles, stumps and roots, and other forest stand attributes measured in the permanent sample plots on forest (Climate Pollution Agency 2011).

***Table 5**. Examples of of C stored in forest biomass according to two scenarios of biofuel extraction in Norway. Higher annual harvest leads to shorter rotation cycles and larger area harvested. Source: Holtsmark 2011.*

Length of rotation cycle (years)	Annual harvest (Mm^3)	Area harvested (km^2/year)	C stored in dead and living biomass (MtC)
90	22.5	833	467
250	9.5	300	933

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[3] Global Annual Net Flux of Carbon to the Atmosphere from Land-Use Change: 1850-2000 http://cdiac.ornl.gov/ftp/trends/land-use/houghton/houghtondata.txt

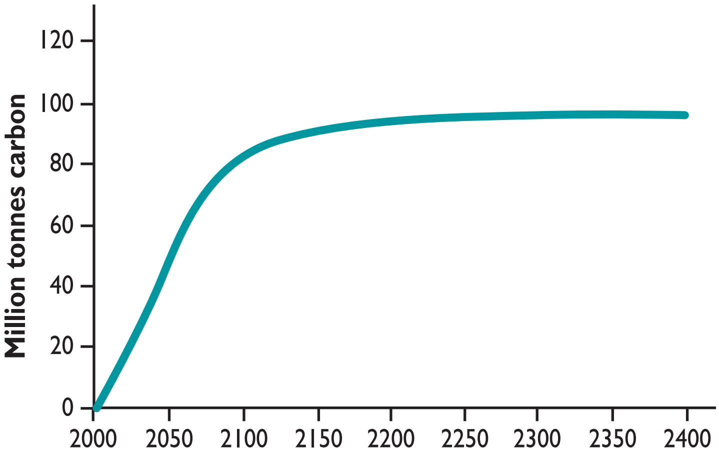

***Figure 6**: Projected drop in the forest carbon stock due to increased logging in Norway. Source: Redrawn from Holtsmark 2011.*

These forestry projections consider forest biomass only and do not assess the impacts of harvest instensity in soil carbon stocks. Hence, it is likely that carbon stock losses are underestimated (Holtsmark 2011). The studies of forests with different fire disturbance regimes support the conclusions that more frequent biomass removal would result in considerably lower soil carbon stocks (Wardle et al. 2012). The removal of biomass as timber and other wood products is likely to have significant consequences on the carbon stock through the reduction in the amount of biomass that enters the soil. However, building up soil carbon stocks does not only depend on the inputs of litter and other plant debris. Other processes that affect organic matter mineralization rates can be even more important and factor out differences in biomass inputs. For example, the harvest of whole trees (Whole Tree Harvesting) appears to have less impact on soil organic carbon loss than practices when only stems are harvested, as shown in a recent long-term study in Sweden. These apparently counterintuitive results were attributed to a complex interplay of factors affecting the activity of soil micro-organisms (Vangelova et al. 2010).

5.3.2 Carbon sequestration and land management

The way the forest is managed determines to a large extent the development of CO_2 accumulation in the forest biomass over time. Holtsmark (shown in Randers (2011) illustrates the differences in CO_2 accumulation in two forestry scenarios in Norway (**Fig. 7**). In alternative a) ‘Harvest’, the mature forest is harvested following the current practice, where the products are one third of fuel-wood, paper and timber each. The time for these products to be burnt or decomposed is estimated to be 1, 5 and 50 years, respectively. In alternative b) ‘No-harvest’ the forest remains standing and the energy needs that arise from the reduction in the amount of fuel-wood is compensated by burning oil. The calculations show that in the ‘Harvest’ alternative the CO_2 stock declines until year 30, when it starts to increase rapidly while the forest matures. In the ‘No-harvest’ alternative, the CO_2 stock increases (after accounting for the emissions from oil burning) until it reaches a plateau between years 20 and 40, after which there is a slow decline. The ‘No-harvest’ alternative results in higher CO_2 stocks in the period from 5 to 55 years after the time the decision about harvest or no-harvest is taken (year 0). More accurate models are needed to predict the CO_2 dynamics in Norwegian forests, however, these results give strong indications that more harvest of forest will reduce the CO_2 stock in the forest, with high certainty in the short term (until ca 2050), but also in the long term (Holtsmark (shown in Randers 2011).

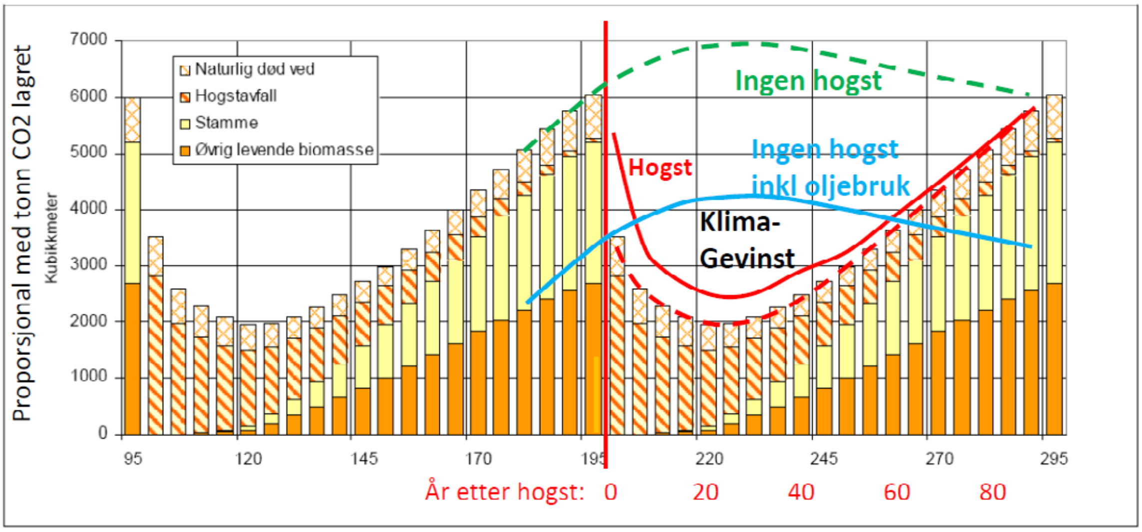

***Figure 7**: Development of biomass on a stand during a period of 100 years. Source: Bjart Holtsmark, SSB, 2010 in Randers (2011). **Alternative 1 'Harvest'**: - - - - CO2 bound in the forest that is harvested in year 0. ——— including CO_2 bound in what results in fuel-wood, paper and timber. **Alternative 2 'No-harvest'**: - - - - No harvest, burning of oil with the same energy content as the fuel-wood that remains unharvested in the forest. ——— Net CO_2 balance after oil burning. The gain in terms of lower CO_2 emissions is represented by the area between the blue and red curves.*

5.3.3 Other climate effects of forest management

The way in which an area and the forest are managed may have other effects on the climate in addition to those that result from the capacity to bind and store carbon. Changes in forest cover, stand age and species composition may also affect the climate by changing the energy budget. In general, forests evaporate more water and more heat is transferred to the atmosphere, compared with open or shrub-covered areas. Forests cover also affects the balance of both long wave and short wave radiation, and it affects the albedo, which is a measure of the reflexion of light from a surface.

The Earth surface and atmospheric albedo varies from 90% for new snow to about 40% for mature boreal forests (Bright et al. 2011). Logging and forestry practices that change the age, density and species composition of a forest stand can change the albedo. The albedo in coniferous forest is lower than in deciduous forest; and that of dense forest is lower than that of clear-cuts. Higher albedo results in cooling, which can counteract the warming effect resulting from GHG emissions (Bright et al. 2011). These factors may affect the local and global climate in different ways, resulting in a net effect on temperature that can be both positive and negative.

6 Impacts of climate change

Increases in temperature over the 20th century have already shifted the timing of floods and future warming may have severe consequences, inducing changes in magnitude, in volume, in frequency, and in duration (Poff 2002). Recent assessments indicate that climate change will likely result in a more extreme events for example, heavier rainfall (IPCC 2011) and flooding patterns (Johnsen et al. 2011).

In a recently released report, the IPCC further stresses the importance of stabilizing GHG concentrations in the atmosphere, by confirming the link between climate change and extreme weather. Based on more knowledge about the causes of climatic hazards, the report presents strong evidence that the patterns of some important climatic extremes have changed and will change more in the future. The conclusions are that it is "virtually certain" that warm weather extreme events will become more frequent this century and that heavier rainfall and fiercer storms are likely to strike the world in the coming decades as climate change takes effect (IPCC 2011).

6.1 Impacts on hydrological cycles

The changes in the climate that have been observed in Norway described in section 5 i.e. the increase in the amount rainfall, in the frequency of short-term high rainfall events, and in the occurrence of rain-on-snow events all point towards changes in hydrological patterns and in an increase likelihood of floods. This means that events that were earlier considered to occur every hundred or two-hundred years (**Fig. 8**) are likely to occur more frequently in the future

***Figure 8**: Historical water level records of the Glomma River at Stev, Elverum. It is worth noticing that the flood that occurred early in the summer 2011, reached only the lower part of the memorial stone. There is strong support for projections that extreme events are likely to occur more often as a consequency of climate change (IPCC 2011, Hanssen-Bauer et al. 2009). Photo: A. Hofgaard.*

Changes in the climate can have significant impacts on hydrological processes and mass transportation associated to these processes. However, the impacts of climate change on hydrological processes and of their consequences on mass transportation and geomorphology are difficult to project. Paleohydrological studies can provide valuable insights about climate change induced hydrology. Several studies using records spanning over a period of 7000 years show that small shifts in temperature (1-2 ^{o}C) and in precipitation (10-20%) can cause important changes in flood magnitude and frequency (Poff 2002). The observed changes in the magnitude and frequency of floods, when matched with geological records, indicate a correspondence between changes in hydrology and important mass transportantion and geomorphological process that could determine rapid changes in river channels (Poff 2002).

6.2 The occurrence of droughts

Even in Norway with its abundant freshwater resources, severe and prolonged water deficit periods have caused major problems in recent years (Wong et al. 2011).The projected changes in temperature and rainfall are likely to result in increased frequency of drought events, However, the occurrence of drought events will be highly dependent on whether precipitation does increase sufficiently to compensate for increased evapotranspiration. Trend studies indicate that summer droughts in southern Norway have become more severe (Wilson et al. 2010, cited in Wong et al. 2011). Generally the droughts related to soil moisture, runoff and groundwater (hydrological droughts) are expected to become more presistent. This is projected both for average and maximum drought durations (Wong et al. 2011). Wong et al. (2011) modelled the occurrence of droughts as a response of projected climate changes. They conclude that despite the projected increase in summer precipitation, the increased summer temperatures are expected to result in longer hydrological droughts (16–60 days) in many parts of Norway. They find that the significant increase in changes in drought refers to both average and maximum drought durations. More persistent hydrological droughts are also projected as a consequence of the effect of increased temperatures on the timing for snowmelt. Earlier onset of the spring will cause earlier snowmelt, resulting in a prolonged summer season.

6.3 Mass movement[4] and avalanches

Mass movement is the process by which soil, regolith[5], and rock move downslope under the force of gravity. Mass movement occurs under the following conditions: i) steep terrain (normally over 30^{o}) ii) loose material that can move, and iii) triggering factors that cause instability in the loose material (www.ngu.no). Triggering factors of mass movement are related to climatic and hydrological processes since the soil water can increase or decrease the stability of a slope depending on the amount of water present. Small amounts of water can strengthen soils because the surface tension of water gives the soil cohesion. This allows the soil to resist erosion better than if it were dry. On the other hand, if too much water is present, the water may act as a lubricant, accelerating the erosion process and resulting in different types of mass wasting (i.e. mudflows, landslides, etc.). Therefore, mass wasting is often related to periods of heavy rain, at water saturation in the soil, when the pressure produced by water in the soil pores is high.

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[4] In Norwegian: løsmasseskred

[5] Regolith is a layer of loose, heterogeneous material covering solid rock. It includes dust, soil, broken rock, and other related materials.

Mass movement, soil erosion, and avalances, the movement of snow downslope, can be triggered by extreme wheather conditions (Kronholm & Stalsberg 2009). Based on the projected changes in the amount of rainfall, increased frequency of heavy rain events, and higher proportion of rain compared to snow in the winter, particularly in the coastal areas, it is likely that the risk of mass movement and avalances will increase in Norway, and that some areas where several enabling climatic and topographical conditions coincide, will be highly exposed.

6.4 Ecosystem services and climate change adaptation

6.4.1 The role of forests on water flow regulation and flood control

Floods are complex processes of extreme watershed discharge that are strongly connected to the hydrological cycle, which is currently being intensified by changes in temperature, precipitation, glaciers and snow cover, all linked to climate change. However, other factors such as land-use changes can considerably change the natural flows of water. Projected changes in precipitation regimes will contribute to altering the intensity and frequency of rain-fed floods and possibly also of flash floods[6] (EEA SOER 2010b).

Hydrological processes are sensitive to spatial variations in soil properties and vegetation. The regulation of watershed discharge rates and water flows is an important function provided by the vegetation cover. Although soil properties, topographic position, and the underlying geology can often be more important factors than the vegetation, changes in the forest cover can have dramatic consequences on the capacity of rainfall infiltration in the soil and the capacity of the system to regulate water flow (Balmford et al. 2008). In Norway, the capacity for sub-surface storage of water is comparatively small due to moderately shallow surface deposits overlying impermeable bedrock (Wong et al. 2011). Therefore, runoff is comparatively less sensitive to the intensity of evapotranspiration and the occurrence of snow accumulation and ablation and more determined by soil properties that control temporary storage of water and runoff events.These factors are largely affected by the vegetation cover (Matheussen et al. 2000)

Whether the land has forest cover or not affects the amount of water draining from a watershed through various attributes and processes. Forests regulate water flow controlling the amount of runoff and watershed output i) by retaining water in the crowns that returns directly back to the atmosphere through evaporation (Birkinshaw et al. 2010); ii) by increasing rainfall infiltration rates in the soil (Price 2011) through the effect of higher soil porosity caused by deep and extended roots; iii) through enhanced water retention capacity due to higher soil porosity and soil organic matter content, and iv) through higher evapotranspiration rates (Price 2011) due to larger leaf surface and root systems. Cleared land has lower evapotranspiration rates than the forest, causing the soil to be wetter and more responsive to rainfall (Balmford et al. 2008). The forest cover plays an important role in controlling water flow in a watershed by r*educing* the amount of runoff and the water output.

The effect of forest cover on water flow regulation can be summarized as: "*Particularly in areas with seasonal rainfall, forest clearance has important consequences on soil characteristics which in turn affect rainfall infiltration rates in cleared areas and the timing of the provision of water for irrigation, hydroelectric production and transportation (waterways). With clearing, catchment response to rainfall becomes more pronounced and sporadic, resulting in large storm runoff during the rainy season, and lower recharging of the soil and the groundwater reserves. Overall, forest clearance leads to diminished dry season (or 'minimum') flows.*" (Balmford et al. 2008, review by Bruijnzeel 2004).

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[6] A flash flood is a rapid flooding of geomorphic low-lying areas. It occurs when precipitation falls too quickly on water saturated soil or dry soil that has poor absorption capacity. It may be caused by heavy rain or meltwater from ice or snow flowing over ice sheets or snowfields.

Box 2. Watershed flow regulation services by forest

- **Reduce of watershed output** by the interception of rainfall and snow and higher evapotranspiration rates
- **Reduce runoff** through higher infiltration rates due to higher soil porosity.
- **Reduce watershed discharge peaks** through enhanced water storage capacity in the soil and in the vegetation.

6.4.2 The role of wetlands on flood control

The hydrology of wetlands is associated to a wide range of processes including groundwater recharge and discharge, flow alteration and sediment stabilisation. There are many examples where wetlands reduce floods, recharge groundwater or increase low flows. However, the role of wetlands in these processes is difficult to generalise since it varies widely regarding runoff production and water detention. Apparently similar wetlands can be driven by very different hydrological processes (Bullock & Acreman 2003).

There is, however a strong consensus that wetlands significantly affect the water cycle. Bullock & Acreman (2003) reviewed the functional properties of wetlands on hydrocycles and found that the vast majority (ca 80%) of the case studies indicate that wetlands either increase or decrease a particular component of the water cycle. Some wetlands can generate floods whereas others have the capacity to hold water and buffer flow peaks. Floodplains are the wetland type which most consistently shows an effect in the reduction in flood peaks. Most studies (23 of 28) in the review by Bullock & Acreman (2003) including examples from all regions all over the world showed that floodplain wetlands reduce or delay floods. In contrast, headwater wetlands showed increased flood volumes in a large number of cases. This function occurs because headwater wetlands tend to be saturated and convey rainfall rapidly to the river (Bullock & Acreman 2003).

The ecosystems in the riparian zone, i.e. habitats along river margins and banks, are widely recognized to be one of the most important in protecting against flood damage and stream bank erosion. The loss of riparian zone function increases stream flow and erosive forces in downstream areas. Important regulating services of floodplains and other riparian zones are presented in Box 3.

Box 3. Regulation services by floodplains and other riparian zone vegetation formations

- **Reduce flood impacts** by absorbing peak flows, slowing the velocity of floodwaters, and regulating base flow.
- **Contribute to stabilize watercourse banks,** reducing bank erosion and the downstream transport of sediments eroded from watercourse banks.
- **Reduce pollutants in watercourses during periods of high flows** by filtering, and bio-chemically transforming pollutants in watercourses.
- **Reduce pollutants in watercourses** by filtering and bio-chemically transforming pollutants in runoff **before they enter watercourses**.

6.4.3 Soil erosion, mass movement and avalanche control

The probability that an incident takes place is often affected by the combination of different interacting causes. Mass movement is often triggered when the slope is steeper than 25-30 degrees and almost always in periods with extreme rainfall and/or snowmelt. The impact of human activities such as the presence and construction of roads, excavation, forest harvest, can reduce the stability of the mass and hence increase the risk for mass movement and avalanches (DSB 2010).

Blaschke et al. (2008) summerize the following mitigation effects of forest cover on soil erosion i) the soil reinforcing effect of the forest's root network, ii) generally lower soil water balances due to interception and evaporation of rainfall and iii) soil building effects under forest canopy due to the accumulation of soil organic matter which translates in soil aggregate stability.

6.5 Land use and climate change adaptation services

6.5.1 Flood control and forest cover

Floods in Norway are caused by snow melting, snow-melting in combination with rainfall, prolonged periods with rainfall and intense rainfall events. The causes that dominate vary considerably between periods and regions (Hanssen-Bauer et al. 2009).

The potential of land cover to impact hydrological processes has drawn the attention on watershed research in the past 40 years. It was also a matter of concern in Norway after the historical flood in Østlandet in June 1995, which led to the establishment of the HYDRA research program. The HYDRA program had as working hypothesis that the sum of land-use change and other physical interventions had resulted in higher flood risk of water courses in Eastern Norway (Eikenæs et al. 2000).

In general, changes in the structure and the composition of the forest cover can considerable affect hydrological processes, primarily through changes in the Leaf Area Index (LAI: the amount of leaf area per ground unit), the most important vegetation characteristic that affects the prediction of hydrological responses, driving evapotranspiration, snow accumulation and runoff (Rinde 1998, Matheussen et al. 2000). The basin water balance is modified in two ways. First, in the summer, high LAI leads to higher interception and evapotranspiration rates, reducing the amount of water that infiltrates and accumulates in the soil. In Eastern Norway, it has been estimated that ca. 30 % of the rainfall is intercepted by the tree crowns in a dense spruce forest. Drier soils have the capacity to absorbe more rainfall water, and can therefore buffer runoff peaks. In the winter, the amount of LAI affects the proportion of snow that is intercepted by the forest canopy vs. that reaching the ground. At low LAI, more snow reaches the ground and it tends to persist longer than snow that is intercepted in the forest canopy, since the forest reduces sun radiation on the ground, which leads to a delay in snow melting. Therefore, the reduction i LAI tends to increase the accumulation of snow in wintertime. A study by Matheussen et al. (2000) in the Columbia River basin shows the importance of forest age (also determining the level of LAI) at the basin level in controlling hydrological processes. Despite that total forest cover remained unchanged, a decrease in 21% cover of old-growth forest resulted in hydrological alterations that were attributed to significant changes in LAI across the basin.

After clear-cutting there is generally an increase in yearly runoff (up to 30%) compared to fields where the forest cover is maintained (Eikenæs et al. 2000). In Eastern Norway, the impacts of forest cover on watershed runoff patterns have been difficult to establish because the introduction of clear-cutting practices have occurred simultaneously with changes in silvicultural practices which have resulted in an increase in forest growth (Eikenæs et al. 2000). However, simulations of the hydrology of the Osensjøen watershed in Eastern Norway indicate that the total evapotranspiration loss was 14% higher for the land-use situation of selective forest harvest (in 1920) compared to those of clear-cutting harvest (in 1960 and 1990). Deforestation in small watersheds led to increased runoff and higher flood peaks because evapotranspiration was reduced. Deforestation also resulted in earlier onset of spring floods since melt rates were higher in open compared to forested areas (Rinde 1998).

The international literature supports these findings. The synthesis by Stednick (1996) conducted for the Rocky Mountain region also indicates changes in watershed output with changes in forest cover. A change in 15 % forest harvest area resulted in measurable increase in water drainage. However, Stednick (1996) stresses the importance of taking into account other hydrological characteristics to assess impacts of land-cover change and forest management, for example to examine the general ways in which water moves from hillslopes into small stream channels during and between rainfall events and the impacts of peakflow generation (**Fig. 9**). For instance, a study in Coastal Oregon indicates that streamflow generation and the pathways along which runoff flowed were altered by timber harvesting and site preparation; and that the levels did not recover to pretreatment conditions after 28 years after harvesting (Stednick 1995).

The extent of the harvest surface compared to the watershed area is also an important factor when assessing hydrological effects of forest management. For example, a study of two subalpine forests catchments in Colorado, USA, showed that both annual flow and peak flow increased significantly in the watershed with 36 % clearcut area. However, timber harvest did not result in an increase in the annual flow in the mainstraim when the clearcut represented only 10 % of the total area of the larger watershed area (Troendle & King 1987). Some studies indicate that although logging affects runoff in the catchment, the effect of forest cover removal seems to be evident only in small watersheds (Blaschke et al. 2008).

In addition to clear-cutting, the impact of forest roads on water flow speed was considered to be of importance in determining this pattern (Eikenæs et al. 2000). In the case of the Oregon watersheds, an increase in peak runoff of 50% in a period of 50 years was attributed to the effect of forest roads.

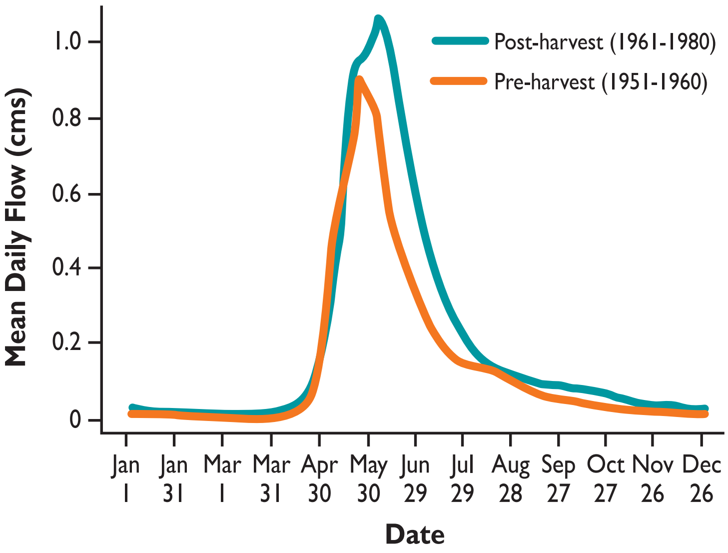

Figure 9: Comparative mean daily streamflow (cubic meters / second) in a subalpine coniferous forest in North Fork of Dry Creek, Utah, USA before and after timber harvest. The two curves indicate both a higher peak at maximum peak flow and a longer peak flow period in the post-harvest situation compared to the pre-harvest forest. Source: Redrawn from Troendle & King 1997.

6.5.2 Mass movement, erosion control and forest management

The lack of vegetation cover with deep roots is also a determinant factor of mass movement. In addition to high soil moisture content, the reduction of deep roots that hold the soil to the bedrock is one important factor that can contribute to initiate slope movement. Also the risk of landslide damage decreases with forest stand age due to increasing forest biomass and canopy cover (Bloomberg et al. 2011).

Further, numerous studies worldwide support the fact that forests protect soils, and reduce erosion rates and sediment delivery to rivers (Blascke et al. 2008). Areas with disturbed vegetation are particularly exposed to soil erosion since the vegetation binds the soil, hence reducing erodability. As explained in the previous section, interception of precipitation and evapotranspiration is highest and runoff lowest when the vegetation cover is high (LAI). Consequently, higher soil erosion and sediment transport occurs when the forest is removed (**Fig. 11**). The mitigating effect of forest cover on soil erosion increases with forest stand age, a fact also associated with high levels of LAI in old-growth forest. Measurements of runoff and sediment yield in Norwegian water courses show that forest rivers carry practically no sediment compared to rivers draining watersheds dominated by glaciers, alpine areas and agricultural land (**Fig. 10**) (Eikenæs et al. 2000).

Forestry operations such as cultivation, drainage, road construction and timber harvesting can increase sediment losses, but best management practices can control this risk (Calder et al. 2007).

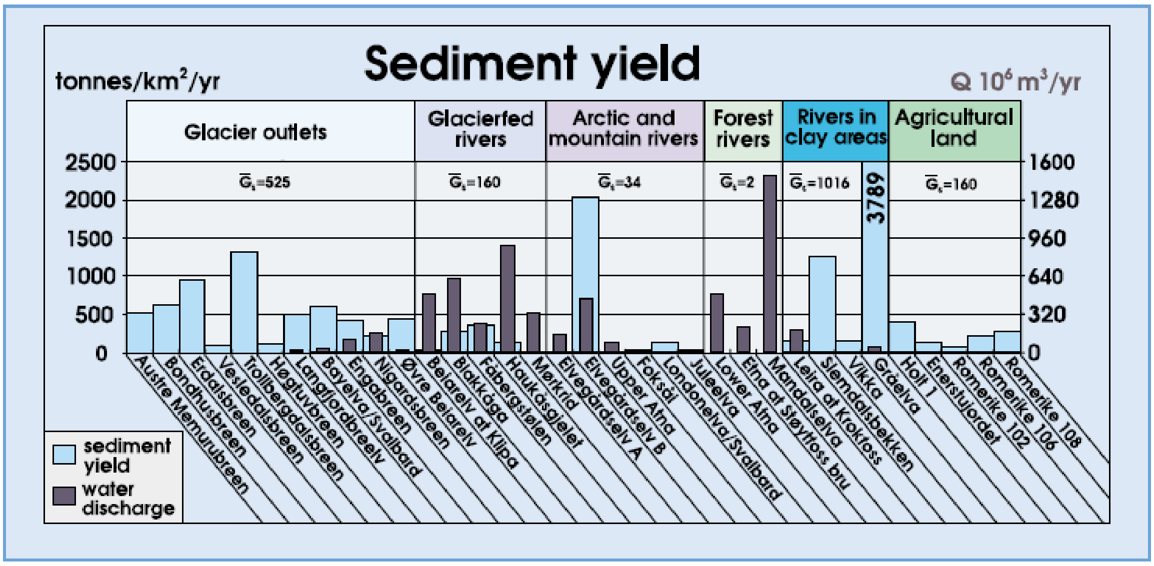

Figure Xt: Norwegian water courses classified according to erosion intensity (Bogen 1996). Source: Eikenæs et al. 2000. Q= Runoff, G= Amount of suspended material.

6.5.3 Flood control and wetland management

Floods are ubiquitous in Norway and also flood prevention measures which are based on the construction of technical infrastructure such as levees and flood walls are common. At the same time, the storage capacity of rivers to absorb flood waters has been strongly affected by severing flood plains from main water channels in most of the developed world (Poff 2002), also in Norway. Paradoxically, technical flood mitigation structures can increase flood magnitude and frequency by preventing the lateral movement of water across floodplains and wetlands (Johnsen et al. 2011). An example provided by Poff (2002) is the Mississippi River basin, in the USA. In the last half of the 20th century, floods in the basin have increased as a direct result of the increased disconnection of the flood plain from the river by extensive leveeing (USGS 1999). At the same time, larger river systems in the basin that have not experienced such degree of floodplain disconnection have not flooded so severely during the same time period (Criss & Shock 2001).

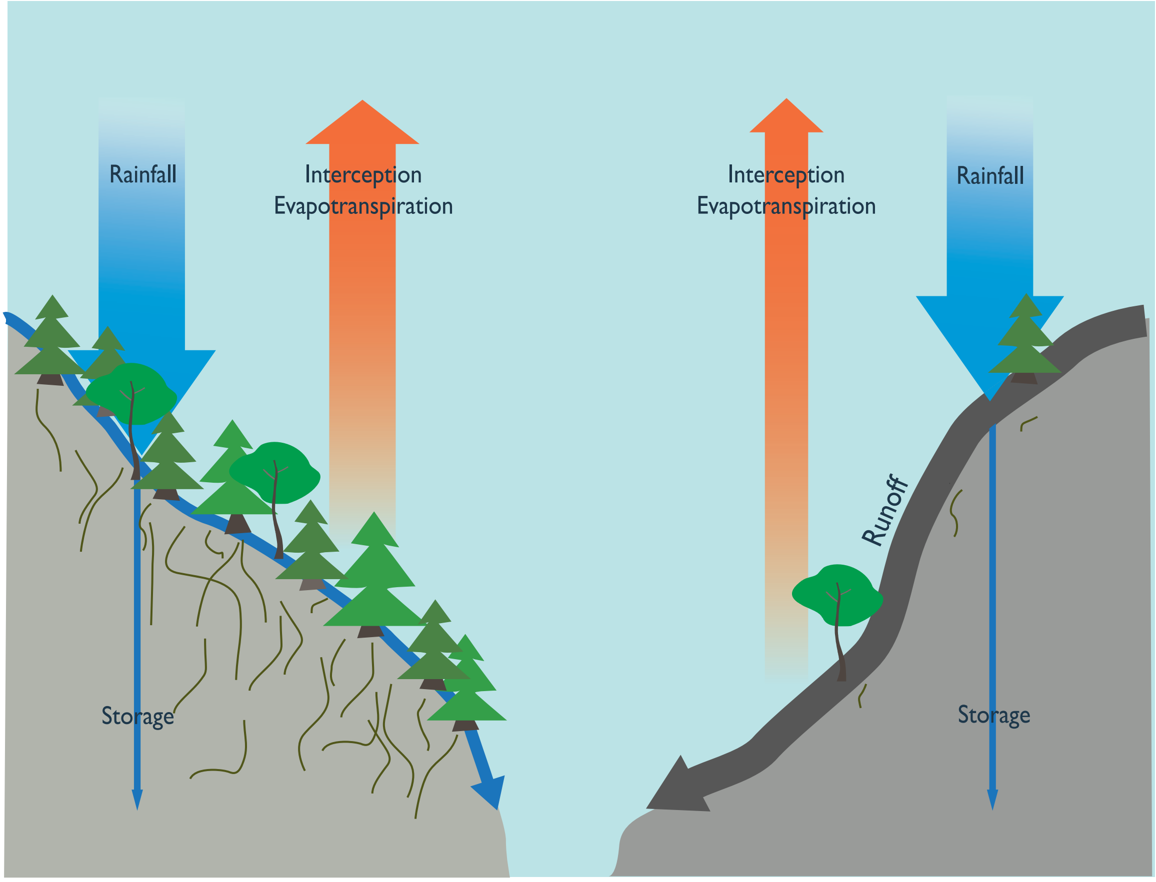

Figure 11. *Hydrological processes that affect the water cycle in summer in boreal forest. Rainfall interception and evapotranspiration is highest and runoff is lowest in areas with high vegetation cover (high leaf area index, LAI). When the forest is removed, the higher runoff results in soil erosion and high sediment transport. The size of the arrows show the relative magnitude of the processes. The figure is based on data and models in Neff (1996) and Eikenæs et al. (2000).*

7 Planning of ecosystem services for climate change mitigation and adaptation

7.1 Challenges for adaptation to climate change

As presented in the previous sections, it is clear that climate change is happening, and in addtion, it is expected to have far-reaching consequences for human and natural systems. Even without any increase in current emission levels, temperature is expected to increase this century due to past emissions. An average global temperature rise of 2° C or more are likely to have major societal, economic and environmental consequences, making it challenging for human and natural systems to adapt at affordable costs. Further, climate change exacerbates the impacts of other key drivers of global environmental change. For the boreal region, projections include less amounts of rainfall as snow and higher risk of damages by winter storms and increased river flows. For mountain areas, higher risk of rock falls and soil erosion are two of the highlighted impacts (**Fig. 12**).

At the European level, the EU has developed an adaptation framework aiming at developing a comprehensive strategy by 2013 to be supported by a clearinghouse for sharing and maintaining information on climate change impacts, vulnerability and adaptation. Various adaptation options have been identified, including those that take into account the “precautionary principle”[7] in planning such as no-regret measures[8], which are relevant under all plausible future scenarios.

Compared with most other countries, Norway is both less vulnerable and better equipped to meet climate change. However, to adapt to yet rather unpredictable changes in the climate is a considerable challenge for Norwegian municipalities. To prepare for today’s climate can be a good start for adaptation in the future[9].

Changes in hydrological processes as a result of a higher occurrence of torrential rains and massive snow fall should be expected. The committee appointed by the Ministry of the Environment to conduct an assessment on Norway’s vulnerability and on the need to adapt to the impacts of climate change (Flæte et al. 2010) concludes that changes in the climate in Norway are inevitable and the need to adapt to projected changes need to be part of a planning excercice with long-term objectives. The committee belives “*that it is necessary to work towards establishing a broad understanding and consensus of the need to include a long-term perspective in all planning within the public administration sector, as well as among politicians, in order to enable society to adapt to climate change*”.

7.2 Eco- engineneering for climate change adaptation and preparedness

As shown in the examples in the previous sessions, land-cover and land-use practices can determine the potential for ecosystems to contribute to climate change adaptation and prepared-

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[7] The Precautionary Principle helps to make decisions about whether an action should, or shold not be done, without knowing the risks with certainty.

[8] ‘no regret measures’ are measures that turn out to be of benefit no matter how or if the predicted climate change impacts materialise. Proactive 'no regret' strategies aime at maximizing positive and minimizing negative outcomes for communities and societies in climate-sensitive areas such as agriculture, food security, water resources and health

[9] Klimatilpassning i norske kommuner http://www.klimakommune.no/

ness. They also illustrate that the provision of ecosystem services can be enhanced if wise territorial planning is put into practice.

Since its inception in the mid-1990s in the USA, the concept of “**green infrastructure**” has gained much attention in the area of policy development to support long-term sustainability of natural resources. The concept highlights the importance of the natural environment in decisions about land-use planning, and it is closely interlinked with the concept of ecosystem services. In particular, there is an emphasis on the "life support" functions provided by networks of ecosystems that underpin long-term sustainability. The concept has been increasingly used in the context of environmental hazards prevention such as the control of stormwater runoff and treatment of polluted runoff (US Environmental Protection Agency, EPA). In Europe, green infrastructure is also understood as strategically planned and managed networks of lands that conserve ecosystem values and functions and provide associated benefits to human populations (EEA 2011). Green infrastructure addresses the protection and restoration of ecosystems with the ultimate aim of insuring the long-term provision of services. It has become a cornerstone of the EU’s environmental strategy towards the 2020 biodiversity target, and for the development of a green and more sustainable economy (EEA 2011). The EU Environmental strategy towards year 2020 recongises the multiple benefits delivered by nature and integrates them through spatial planning into broader objectives of sustainable management and use of nature.

Green infrastructure adds the value of ecosystem services to technical solutions to address challenges in society (EGU 2012). In this context, green infrastructure is being promoted as an effective and efficient response to projected climate change, primarily for climate adaptation, but also, although to a less extent, to mitigate climate change (i.e. carbon sequestration and storage, storing floodwater and ameliorating surface water runoff to reduce the risk of flooding) (EEA 2011).

Box 4. Mitigation services of floodplains (Source: Poff 2002).
In the Boston, MA, area, the Charles River drains a rural but rapidly urbanizing catchment prone to flooding. More than two decades ago, the US Army Corps of Engineers implemented non-structural flood controls by purchasing the development rights to floodplain wetlands in the upper portion of the Charles River catchment. The ca. 3500 ha purchased allowed for a storage capacity of more than $60x10^6$ m^3 *of water, at a cost of less than 10% of the projected cost of the originally proposed dam and levee project. The state compensated local communities for lost tax revenues due to land set-asides and many of these natural valley storage’ areas are managed for recreation and for wildlife habitat. When near-record flooding occurred in 1979 and 1982, the wetlands performed effectively each time, absorbing flood surges and then gradually passing them downstream’ (Faber 1996).*

Effeciency in this context must be seen as gains in terms of the impact of mitigation and adaptation measures against the costs involved in their implementation (**Box 4**). To find artificial solutions to provide the services that nature provides is not only technically challenging, but also costly (EU 2010), and in some cases conventional engineering approaches can increase the risk of hazards and amplify levels of damage (Poff 2002). Flood control infrastructure that protects floodplains along the Glomma River in Eastern Norway can result, locally, in an increase of up to 0.5 m of the water level compared with areas without infrastructure (Eikenæs et al. 2000)

Flæte et al. (2010) make some recommendations to Norwegian municipalities that follow from the recognition that it is usually less costly to prevent foreseeable problems from occurring than to attempt to mitigate the consequences once they have taken place, therefore comprehensive planning is recommended.The Directorate for Civil Protection and Emergency Planning (DSB) in Norway further recommends that municipalities should consider carefully the costs of the construction and maintainance of technical infrastructure. DSB warns municipalities against engaging in costly prevension infrastructure (DSB 2010), proposing that municipalities avoid planning for preparedness measures (e.g. grey infrastructure) if this can be achieved through preventive measures, since “certain choices can lock economic resources and cause expenditures over long time” (**Box 6**). Technical infrastructure has been used extensively as prevension measures in Norway, on the other hand, the use of environmentally sensitive flood protection measures has so far been applied infrequently (Østdahl and Taugbøl 1999, in Johnsen et al. 2011). Rauken and Kelman (2010) point out, for example, that the economic system in Norway leaves municipalities with few economic incentives to leave flood zones undeveloped or to restore the natural dynamic of floodplains, whereas municipalities can receive economic support for the construction of grey infrastructure. Flæte et al. (2010) point to the possibility of reviewing the Planning and Building Act (LOV-2008-06-27-71) to provide a better tool for preparedness and adaptation to climate change.

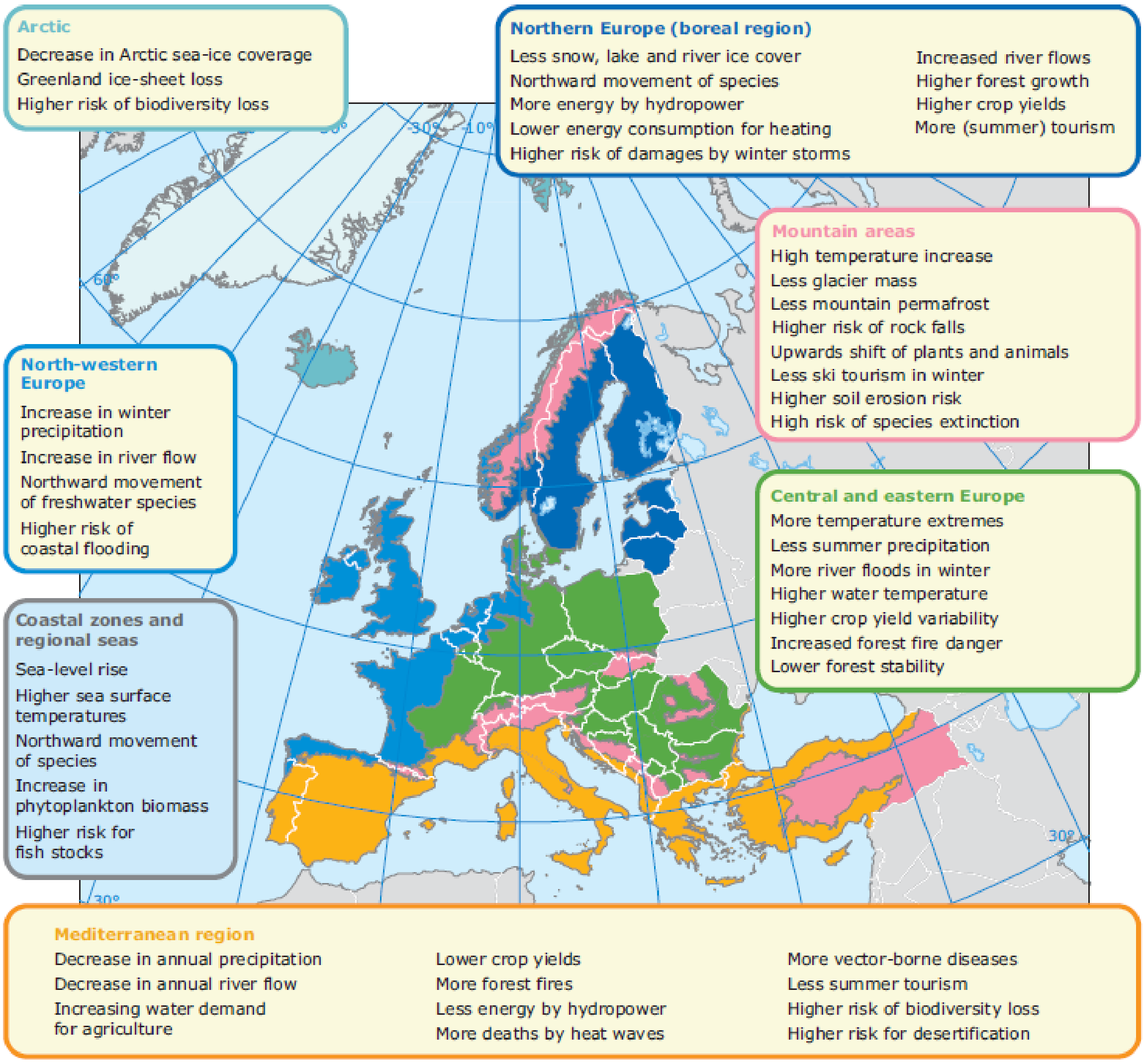
7.2.1 Management of ecosystem services to enhance climate mitigation potential

Norwegian forests are intensively exploited for wood products, and as described in section 6, they are also an important sink of carbon. Compared to the increase in the European forest carbon sink in the past 50 years, timber harvests have grown more slowly (Ciais et al. 2008). However, as explained in section 6, a return to using wood as biofuel, would translate into shorter rotation time in forestry which would cancel out the benefits of carbon storage over the past five decades (Ciais et al. 2008, Holtsmark 2011). Since the carbon debt caused by a more intensified extraction of forest material is estimated to take hundreds of years to restore, the mitigation effects of forests under this exploitation regime are questionable.

Forest management measures that increase carbon sequestration in soils are planting or regenerating forest on cultivated land, drained soils; and increasing rotation length (de Wit & Kvindelsland 1999, Wardle et al. 2012) (**Box 5**). Measures that may affect soil carbon stocks negatively are strongly mechanised site preparation, draining and conversion of peatlands, forest land and clearcutting. Particularly in steep terrain, extraction of forest products will considerably affect the carbon stock because of soil losses that generally occur through erosion when the forest cover is removed (**Fig. 11**). Since forest soils in Norway contain a very large proportion of the carbon stock, comparatively small changes in this stock could have important consequences on the national CO_2 budget in Norway.

Box 5. Forestry practices that would increase carbon sequestration or reduce emissions from forests in Norway.

- Implementation of forestry management practices to promote carbon storage / decrease carbon release
- Lengthening forest rotation cycles
- Urban and peri-urban tree cultivation and forestry practices
- Restoration of woodlands
- Maintenance and/or restoration of woodland riparian vegetation



Note: Please note that some of the original biogeographical regions of Europe have been regrouped as follows:
Central and eastern Europe: Continental region minus north/west of Italy plus Pannonian region and Steppic region;
Mountain areas: Alps plus Apennines plus Balkans-Rhodope Mountains plus Carpathian plus Fennoscandian plus Pyrenees plus Anatolian region plus Dinaric Alps;
Mediterranean region: Mediterranean region plus Black Sea region and north/west of Italy;
North-western Europe: Atlantic region;
Greenland does not belong to a biogeographical region of Europe.

***Figure 12**: Key past and projected impacts of climate change and effects on sectors for the main bio-geographical regions of Europe. Source: EEA – SOER 2010 – Adapting to climate change.*

7.2.2 Management of ecosystem services for climate change adaptation

Flood control

An approach based on green infrastructure (also non-structural flood control, Poff 2002) to flood management relies on techniques that involve “little or no channel manipulation, mechanical habitat alteration, or building of structures” and they have been considered as a way to meet societal and ecological goals (Galat *et al*. 1998, in Poff 2002). In this context, the use or restoration of the natural absorptive capacity of wetlands and flood plains as mitigation against future flooding has received some explicit attention.The approach essentially emphasizes basic hydrological and ecological principles to reduce runoff to, and increase natural storage in, rivers to minimize flood damage to humans (Poff 2002). One well-documented example is the case of the Charles River in the Boston, MA, area (**Box 4**).

The recommendations about planning and preparedness for climate change adaptation measures by the Directorate for Civil Protection and Emergency Planning (DSB) (DSB 2010) and by (Flæte et al. 2010) to Norwegian municipalities share many elements with the planning principles of the green infrastructure and ecosystem services frameworks. First, they stress the importance of a comprehensive approach to adaptation where the effects of GHG emissions, pollution and the role of the natural environment are assessed when adaptive measures are planned. Second, the Committee indicates that the Norwegian society ”*can implement changes in land use and natural resource management to minimise the total impact on the natural environment and the ecosystems”*. The Committee considers a strong land use planning system that takes climate change into account as the most important step the Norwegian society can take in order to adapt to a changing climate.

The use of technical infrastructure as flood prevension measure is common in Norway, but there may be a growing awareness of the positive effects of preserving wetlands for flood control (Johnsen et al. 2011). In a questionnaire from 2007 on local adaptation to climate change (Berglund and Nergaard 2008, in Johnsen et al. 2011) in Norway, about 50% of the roughly 190 municipalities that responded had constructed flood mitigation technical infrastructure to a large or to some extent (Johnsen et al. 2011). At the same time, about one-third of the municipalities had conserved wetlands and marsh areas to a large or to some extent.

In addition to the role of floodplains and riparian ecosystems for flood control (see sections 7.4.2) retention in small catchments of runoff that may generate floods can occur with better land-use practices. As described in the examples in the previous sessions, both the amount of forest cover and the management of the forest in terms of the relative composition of yound and old forest in a water catchment, significantly affects the capacity of the land cover to evapotranspirate water, retain rainfall and snow in the forest canopy and ameliorate the effects of rain-on-snow events. These effects of the vegetation on the hydrological properties of watersheds result in measurable impacts on peakflows magnitudes and duration. Reynard *et al*. (2001, in Poff 2002) concluded that a 50% increase in forest cover could counteract the impact of increased flooding during climate change in large British catchments.

Box 6. A summer flood of the river Gaula caused severe damage in the town of Ålen, Holtålen, Sør-Trøndelag in August 2011

The flash damaged the main road, a bridge and public and private buildings in the center of the town. In a recent evaluation, the Norwegian Water Resources and Energy Directorate (SVE) mapped some of the damaged area as a flood prone zone ’200 years flood risk zone’, which sets building restrictions in the area according to the NVE-defined guidelines for land use planning and flood protection in flood prone areas (SVE) (http://www.nve.no/en/Floods-and-landslides/Flood-inundation-maps/). Technical infrastructure to secure the area against a risk of’1000 years flood’ is being considered but it is costly and will take time to construct.

Ålen town centre, September 2011.

Photo: G.M.Rusch

7.2.3 Management of multiple ecosystem services

This report deals primarily with four important services provided by ecosystems which are linked to the mitigation of GHG emissions (carbon storage and sequestration), and to the adaptation capacity of society to climate change (related to the control of water flow, flood and soil erosion). How decisions about land-use and the management of these systems have the potential to enhance or reduce the level of service provision is also illustrated. However, since all ecosystem services are underpinned by life systems, it is likely that most services indicated in **Table 1** (section 1) will be affected in some way or another by the changes in the environment cause by global warming. The impacts of climate are expected to interact with the extensive transformations of ecosystems caused by human activities (Vitousek et al. 1997, Rockström et al. 2009). For example, pollination services depend among other factors, on the pollinator species sensitivity to temperature, to cloudiness (both projected to change in some areas in Norway with global warming), to the availability of food-providing and nesting habitats (largely affected by land management), and to the level of agrochemicals used in crops. Also biological pest control will depend on fine-tuned biophysical requirements of parasite and host species.

The framework of ecosystem services provides a valuable tool for planning the use and enjoyment of life systems by society. It provides a conceptual ground to understand values that are taken for granted, to highlight how human activities impact these values, and it enables to make explicit societal choices about nature and natural resources. The analysis of benefits from nature based on the ecosystem service framework has helped to understand aspects highly relevant to support decision making about the use and managmenet of nature, such as the existence of trade-offs and synergies among services. It has also stimulated the develpment of methodological frameworks to evaluate the relative importance of different alternatives in particular decision making situations.

Trade offs

Almost any decision about the way an ecosystem is managed will involve trade-offs among benefits and although some of these trade-offs are relatively well characterised, there is still much to be explored about multiple ecosystem services and benefits demanded from nature (Mace et al. 2011). In many cases, choice and trade-offs have a spatial component and involves choices about various values of a particular land area. The existence of trade-offs means that either enhancing the provison of one service will impact negatively on the other, or that different services are provided in different areas on which society needs to make choices about. In the cases shown in this report there appears to be trade-offs between carbon sequestration and carbon storage and the intensification of forest explotation for biofuel production (section 6.3). Another example is that of the provision of forest material and the service of soil erosion and avalanche control in forests occurring on steep terrain. Futher, practices to increase CO_2 sequestration such as more densely planted forests, introduction of species with high growth rates and fertilization would result in negative effects of the understorey vegetation and very likely soil carbon storage and on nutrient circulation.

Synergies

On the other hand, in many cases, several services co-occur, so that efforts in maintaining one service will provide a number of additional benefits. Some synergies emerge from the examples provided in this survey.

1. For instance, old-growth forests are carbon sinks, maintain large carbon stocks in forest and in soil that take in the order of hundreds of years to restore if harvested.

2. Aslo, old-growth forests have an important function in the regulation of the biotic environment. They provide habitat for organisms adapted to condictions which occur in only a small portion of the boreal forest ecosystem in Norway (Framstad et al. 2011) since the area of old-growth forest is small.

3. In addition, if located in areas with particular environmental conditions and/or which have been intensively altered by land-use, old-growth forests will be of high value for representing particular portions of forest biodiversity (Framstad et al. 2011).

4. Further, old-growth forests deliver a higher water flow regulation capacity than young forests, both due to the above-ground structure and to the content of soil organic matter.

5. If located in steep terrain, old-growth forest will reduce the risk for mass movement and availanches, and losses of soil and soil C stock by controlling soil erosion.

6. If occuring in urban or peri-urban localities, old-growth forests can, in addition, provide important cultural services (recreation, spiritual experience, inspiration for culture, etc) since a large part of the population that can enjoy these services lives in these areas.

7. Finally, modern forestry uses nursery plants of varieties that have been developed through genetic improvement to maximize forestry products outputs, to reforest after harvesting. Old-growth forests are likely to harbour larger genetic resources since the trees in current old-growht forests have established through natural regeneration from local seeds sources before modern practices were introduced in forestry (Storaunet og Gjerde 2010). In view of the projected increase in the occurrence of droughts, changes in temperatures and possible, different exposure to deaseases as a consequence of climate change, the protection of a diverse genetic pool in species of economic importance is one important measure to increase resilience and adaptive capacity of the system.

Assessment of the relative contribution of ecosystem service provision

The existence of trade-offs between services within particular decision making unit (a farm, a forested land, a municipality, a region or at the national level), makes it necessary to consider all the relevant services within one methodological framework that will enable some form of comparison of the level of service provision among different units. Monetary valuation of services has the advange of providing a common currency between the different services; however, there are many conceptual and technical difficulties with this kind of valuation of nature. With the development of the research field, these challenges are being increasingly understood and considerable advances have been made in identifying the limitations and the potential of monetary valuation in the context of ecosystem services framework. Also, advances have been made in search of alternative, non- monetary, forms of valuation which can enable the assessment of the relative value of multiple services across areas and land uses, informing decisions and contributing to more transparent decision-making processes.

8 Glossary

C	Carbon
CO_2	Carbon dioxide
CPA	Climate and Pollution Agency, Norway
DSB	Directorate for Civil Protection and Emergency Planning, Norway
EEA	European Enviornmental Agency
EGU	European Geosciences Union
EU	European Union
GHG	Green House Gases
IPCC	Intergovernmental Panel on Climate Change
KP	The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC or FCCC), aimed at fighting global warming. The UNFCCC is an international environmental treaty with the goal of achieving the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."
LAI	Leaf area index, the amount of leaf area per ground unit
LULUCF	Land use, Land-Use Change and Forestry
SOM	Soil organic matter
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resource Institute

9 References

Balmford A., Rodrígues A.S.L., Walpole M., ten Brink P., Kettunen M., Braat L. & de Groot R. 2008. Review on the economics of biodiversity loss: Scoping the science. ENV/070307/2007/486089/ETU/B2. Final Report. European Commission European Commission (contract: ENV/070307/2007/486089/ETU/B2), Cambridge, UK, 259 pp.

Beldring S., Engeland K., Roald L.A., Saelthun N.R. & Vokso A. 2003. Estimation of parameters in a distributed precipitation-runoff model for Norway. Hydrol. - Earth Systems Science 7: 304-316.

Bellassen V., Viovy N., Luyssaert S., Le Maire G., Schelhaas M.J. & Ciais P. 2011. Reconstruction and attribution of the carbon sink of European forests between 1950 and 2000. - Global Change Biology 17: 3274-3292.

Berglund, F., Nergaard, E. 2008. Utslippsreduksjoner og tilpasninger - Klimatiltak i norske kommuner. Notat. Norsk institutt for by- og regionforskning (NIBR), Notat, Oslo. (sitert i Johnsen et al. 2011).

Birkinshaw, S.J., Bathurst, J.C., Iroume, A., Palacios, H. 2011. The effect of forest cover on peak flow and sediment discharge-an integrated field and modelling study in central-southern Chile. - Hydrological Processes 25: 1284-1297.

Blaschke P., Hicks D. & Meister A. 2008. Quantification of the flood and erosion reduction benefits, and costs, of climate change mitigation measures in New Zealand. Blaschke and Rutherford Environmental Consultants for MfE., Wellington, New Zealand, 76 pp..

Bloomberg, M., Davies, T., Visser, R., Morgenroth, J. 2011. Erosion susceptibility classification and analysis of erosion risks for plantation forestry. Ministry for the Environment

University of Canterbury, Christchurch, New Zealand.

Bogen, J. 1996. Erosion and sediment yield in Norwegian rivers. In: Walling, D.E., Webb, B.W. (Eds.) Erosion and sediment yield: Global and regional perspectives. IAHS. 73-84 pp.

Boyd, J. 2007. Nonmarket benefits of nature: What should be counted in green GDP? - Ecological Economics 61: 716-723.

Bright, R.M., Strømman, A.H., Peters, G.P., 2011. Radiative forcing impacts of boreal forest biofuels: A scenario study for Norway in light of albedo. – Environmental Science & Technology 45: 7570-7580.

Bruijnzeel, L.A., 2004. Hydrological functions of tropical forests: not seeing the soil for the trees? . Agriculture, Ecosystems & Environment 104, 185-228.

Bullock, A., Acreman, M. 2003. The role of wetlands in the hydrological cycle. - Hydrology and Earth System Sciences 7: 358-389.

Burton T.A. 1997. Effects of basin-scale timber harvest on water yield and peak streamflow. - Journal of the American Water Resources Association 33: 1187-1196.

Chan, K.M.A., Shaw, M.R., Cameron, D.R., Underwood, E.C., Daily, G.C. 2006. Conservation planning for ecosystem services. - PLOS Biology 4: 2138-2152.

Ciais P., Borges A.V., Abril G., Meybeck M., Folberth G., Hauglustaine D. & Janssens I.A. 2008. The impact of lateral carbon fluxes on the European carbon balance. - Biogeosciences 5: 1259-1271.

Ciais P., Schelhaas M.J., Zaehle S., Piao S.L., Cescatti A., Liski J., Luyssaert S., Le-Maire G., Schulze E.D., Bouriaud O., Freibauer A., Valentini R. & Nabuurs G.J. 2008. Carbon accumulation in European forests. - Nature Geoscience 1: 425-429.

CPA 2011. Greenhouse Gas Emissions 1990-2009. National Inventory Report - Norway. Climate and Pollution Agency Oslo, 370 pp.

Cornelissen, J.H.C., Quested, H.M., Gwynn-Jones, D., Van Logtestijn, R.S.P., De Beus, M.A.H., Kondratchuk, A., Callaghan, T.V., Aerts, R. 2004. Leaf digestibility and litter decomposability are related in a wide range of subarctic plant species and types. - Functional Ecology 18: 779-786.

Cornwell, W., K., Cornelissen, J.H.C., Amatangelo, K., Dorrepaal, E., Eviner, V.T., Godoy, O., Hobbie, S.E., Hoorens, B., Kurokawa, H., Pérez-Harguindeguy, N., Quested, H.M., Santiago, L.S., Wardle, D.A., Wright, I.J., Aerts, R., Allison, S.D., van Bodegom, P., Brovkin, V., Chatain, A., Callaghan, T.V., Díaz, S., Garnier, E., Gurvich, D.E., Kazakou, E., Klein, J.A.I., Read, J., Reich, P., Soudzilovskaia, N.A., Vaieretti, M.V., Westoby, M. 2008. Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. - Ecology Letters 11: 1065-1071.

Criss, R.E., Shock, E.L. 2001. Flood enhancement through flood control. - Geology 29: 875-878.

Daily G.C. (ed.) 1997. Nature's services: The social dependence of natural ecosystems, Island Press.

de Wit H.A. & Kvindesland S. 1999. Carbon stocks in Norwegian forest soils and effects of forest managmenet on carbon storage. Rapport fra skogsforskningen. Supplement. Skog og landskap, 14: 52 pp.

de Wit H.A., Palosuo T., Hylen G. & Liski J. 2006. A carbon budget of forest biomass and soils in southeast Norway calculated using a widely applicable method. - Forest Ecology and Management 225: 15-26.

DSB (2010). Samfunnssikkerhet i arealplanlegging. Kartlegging av risiko og sårbarhet. TEMA. Direktoratet for samfunnssikkerhet, Oslo, 10: 34 pp.

EEA 2008. Impacts of Europe's changing climate - 2008 indicator-based assessment. Introduction. EEA Report. EEA, Copenhagen, 36 pp.

EEA 2011. Green infrastructure and territorial cohesion. The concept of green infrastrucutre and its integration into policies using monitoring systems. EEA Technical report. European Envioronmental Agency.

EEA 2011b. Opinion of the EEA Scientific Committee on greenhouse gas accounting in relation to bioenergy. European Environment Agency,10 pp.

EEA-SOER 2010. The European environment - State and Outlook 2010. European Envioronmental Agency.

Eikenæs, O., Njøs, A., Østdahl, T., Taugbøl, T (Eds). 2000. Flommen kommer…Sluttrapport fra HYDRA – et forskningsprogram om flom. Norges vassdrag – og energi direktoratet. 108 pp.

EGU 2012. European Geosciences Union. Conference Session: Eco-engineering mitigations against natural hazards: Biological contribution to sustainable soil bioengineering in a changing world, Vienna, Austria, 2011.

EU 2010. Grön infrastruktur. European Commission 2 pp.

Faber S. 1996. On borrowed land: public policies for floodplains. Lincoln Institute of Land Policy., Cambridge, MA, USA.

Flæte O., Bardalen A., Dalen L., Drange H., Gjærum I., Hanssen-Bauer I., Hisdal H., Kaare Hovelsrud G., Karlsen J., Larssen S.A., Nyeggen E., Ottesen P., Pedersen S., Petkovic G., Sundby S., Vennemo H. & Aanestad J. 2010. Adapting to a changing climate. Norway’s vulnerability and the need to adapt to the impacts of climate change. NOU. Norwegian Ministry of the Environment, Oslo, 296 pp.

Framstad E., Stokland J. & Hylen G. 2011. Skogvern som klimatiltak. Verdifulle skogtyper for biologisk manfold og karbonlagring. NINA Rapport. Norsk institutt for naturforskning, Oslo, 752, 38 pp.

Galat, D.L. (and 16 others). 1998. Flooding to restore connectivity of regulated, large-river wetlands. Journal of Bioscience 48: 721-733 (sitert i Poff 2002).

Grønlund A., Bjørkelo K., Hylen G. & Tomter S.M. 2010. CO2-opptak i jord og vegetasjon i Norge. Lagring, opptak og utslipp av CO2 og andre klimagasser. Bioforsk Rapport. Bioforsk, 5, 38 pp.

Haines-Young R. & Potschin M. 2011. Common International Classification of Ecosystem Services (CICES): 2011 Update. European Environment Agency, 1-17 pp.

Hanssen-Bauer I., Drange H., Førland E.J., Roald L.A., Børsheim K.Y., Hisdal H., Lawrence D., Nesje A., Sandven S., Sorteberg A., Sundby S., Vasskog K. & Ådlandsvik B. 2009. Klima i Norge 2100. Bakgrunnsmateriale til NOU Klimatispassing. Norsk klimasenter, Oslo.

Hegland S.J. & Boeke L. 2006. Relationships between the density and diversity of floral resources and flower visitor activity in a temperate grassland community. - Ecological Entomology 31: 532-538.

Holtsmark B. 2011. Harvesting in boreal forests and teh biofuel carbon debt. Climatic Change doi: 10.1007/s10584-011-0222-6

World Resource Institute. 2003. Earth Trends: Country profiles, Norway.

Houghton, R.A., 2002. Global Annual Net Flux of Carbon to the Atmosphere from Land-Use Change: 1850-2000.

IPCC .2007. Fourth Assessment Report. Climate Change 2007: Synthesis Report. Intergovernmental Panel on Climate Change. 73 pp.

IPCC. 2011. Summary for Policymakers. In: Intergovernmental Panel on Climate Change Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Field, C. B., Barros, V., Stocker, T.F., Qin, D., Dokken, D., Ebi, K.L., Mastrandrea, M. D., Mach, K. J., Plattner, G.-K., Allen, S. K., Tignor, M. and P. M. Midgley (eds.). Cambridge University Press, Cambridge, UK and New York, USA. 23 pp.

Johnsen, S., I., Museth, J., Schartau, A.K., Barton, D.N., Fangel, K., Erikstad, L., Dervo, B.K. 2011. Local floodplain management in Norway under climate change: Flood risk reduction and biodiversity conservation. . In: Kelman, I. (Ed.), Municipalities addressing climate change. Nova Science Publishers, Inc.

Klein, C., 2010. Marine conservation planning for a complex world. - Decision Point October 2010, 5-6.

Klif 2011. Skog som biomasseressurs. Klima- og forurensningsdirektoratet, Oslo, 100 pp.

Kranabetter J.M. 2009. Site carbon storage along productivity gradients of a late-seral southern boreal forest. - Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 39: 1053-1060.

Kremen C., Williams N.M., Aizen M.A., Gemmill-Herren B., LeBuhn G., Minckley R., Packer L., Potts S.G., Roulston T., Steffan-Dewenter I., Vazquez D.P., Winfree R., Adams L., Crone E.E., Greenleaf S.S., Keitt T.H., Klein A.M., Regetz J. & Ricketts T.H. 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. - Ecology Letters 10: 299-314.

Kronholm K. & Stalsberg K. (2009). Klimaendringer gir endringer i skredhyppigheten. NORKLIMA. CICERO, Oslo, 3-09: 34-36.

Lonsdorf, E., Kremen, C., Ricketts, T., Winfree, R., Williams, N., Greenleaf, S., 2009. Modelling pollination services across agricultural landscapes. - Annals of Botany 103: 1589-1600.

Luyssaert S., Schulze E.D., Borner A., Knohl A., Hessenmoller D., Law B.E., Ciais P. & Grace J. 2008. Old-growth forests as global carbon sinks. - Nature 455: 213-215.

Luyssaert S., Ciais P., Piao S.L., Schulze E.D., Jung M., Zaehle S., Schelhaas M.J., Reichstein M., Churkina G., Papale D., Abril G., Beer C., Grace J., Loustau D., Matteucci G., Magnani F., Nabuurs G.J., Verbeeck H., Sulkava M., van der Werf G.R., Janssens I.A. & Team C.-I.S. 2010. The European carbon balance. Part 3: forests. - Global Change Biology 16: 1429-1450.

MA 2005. Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Press I. UN, Washington, DC. 86 pp.

Mace, G.M., Norris, K., Fitter, A.H. 2012. Biodiversity and ecosystem services: a multilayered relationship. - Trends in Ecology & Evolution 1445: 8.

Matheussen, B., Kirschbaum, R.L., Goodman, I.A., O'Donnell, G.M., Lettenmaier, D.P. 2000. Effects of land cover change on streamflow in the interior Columbia River Basin (USA and Canada). - Hydrological Processes 14, 867-885.

Neff, T.A.M., 1996. Mesoscale water balance of the boreal forest using operational evapotranspiration approaches in a distributed hydrologic model. University of Waterloo, Waterloo, Ontario, Canada. 206 pp.

Nelson E., Mendoza G., Regetz J., Polasky S., Tallis H., Cameron D.R., Chan K.M.A., Daily G.C., Goldstein J., Kareiva P.M., Lonsdorf E., Naidoo R., Ricketts T.H. & Shaw M.R. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontier in Ecology & the Environment 7: 4-11.

Olsson M.T., Erlandsson M., Lundin L., Nilsson T., Nilsson A. & Stendahl J. 2009. Organic arcbon stocks in Swedish podzol soils in relation to soil hydrology and other site characteristics. Silva Fennica 43: 209-222.

Poff, N.L., 2002. Ecological response to and management of increased flooding caused by climate change. - Philosophical Transactions of the Royal Society A- Mathematical, Physical and Engineering Sciences, 1497-1510.

Price K. 2011. Effects of watershed topography, soils, land use, and climate on baseflow hydrology in humid regions: A review.- Progress in Physical Geography 35: 465-492.

Randers J. 2011. Effekten på CO2-binding i skog av hogst versus å la skogen stå. Teknologirådets høring, Oslo.

Rapalee G., Trumbore S.E., Davidson E.A., Harden J.W. & Veldhuis H. 1998. Soil carbon stocks and their rates of accumulation and loss in a boreal forest landscape. - Global Biogeochemical Cycles 12: 687-701.

Reynard, N.S., Prudhomme, C., Crooks, S.M. 2001. The flood characteristics of large UK Rivers: potential effects of changing climate and land use. - Climatic Change 48, 343-359. (sitert i Poff 2002)

Rinde, T. 1998. A flexible hydrological modelling system using an object-oriented methodology. Institutt for vassbygging. Norwegian University of Science and Technology (NTNU), Trondheim.

Rockström J., Steffen W., Noone K., Persson Å., Chapin F.S.I., Lambin E., Lenton T., Scheffer M., Folke C., Schellhuber H.J., Nykvist B., de Wit C.A., Hughes T., van der Leeuw S., Rodhe H., Sörlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P. & Foley J. 2009. Planetary boundaries: Exploring the safe operating space for humanity. - Ecology and Society 14: 32.

Rothstein, D.E., Vitousek, P.M., Simmons, B.L. 2004. An exotic tree alters decomposition and nutrient cycling in a Hawaiian montane forest. - Ecosystems 7: 805-814.

Schlesinger, W., 1991. Biogeochemistry. An Analysis of Global Change. . Academic Press, Inc., San Diego, CA, USA.

Stavins R.N. & Richards K.R. (2005). The cost of U.S. forest-based carbon sequestration, Arlington, Virginia, US, 52 pp.

Stednick, J.D. 1996. Monitoring the effects of timber harvest on annual water yield. - Journal of Hydrology 176: 79-95.

Storaunet, K.O. & Gjerde, I. 2010. Skog. Naturindeks for Norge 2010. Directorate for Nature Management, Trondheim, 79-93.

Tallis H. & Polasky S. 2011. Assessing multiple ecosystem services: an integrated tool for the real world. Natural Capital: Theory and Practice of Mapping Ecosystem Services. Kareiva P., Tallis H., Ricketts T.H., Daily G.C. & Polasky S., Oxford University Press, New York, 365 pp..

Troendle C.A. & King R.M. 1987. The effect of partial and clearcutting on streamflow at the Deadhorse Creek Colorado. - Journal of Hydrology 90: 145-157.

Troendle C.A. & Stednick J.D. 1999. "Effects of basin scale timber harvest on water yield and peak streamflow," by Timothy A. Burton - Discussion. - Journal of the American Water Resources Association 35: 177-181.

Troy A. & Wilson M.A. 2006. Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. - Ecological Economics 60: 435-449.

UNFCCC, 1997. Kyoto Protocol of the United Nations Framework Convention on Climate Change. United Nations, Kyoto.

Vanguelova E., Pitman R., Luiro J. & Helmisaari H.S. 2010. Long term effects of whole tree harvesting on soil carbon and nutrient sustainability in the UK. - Biogeochemistry 101: 43-59.

Vitousek P.M., Mooney H.A., Lubchenco J. & Melillo J.M. 1997. Human domination of Earth's ecosystems. - Science 277: 494-499.

Wardle D.A., Bardgett R.D., Klironomos J.N., Setälä H., van der Putten W.H. & Wall D.H. 2004. Ecological linkages between aboveground and belowground biota. - Science: 1629–1633.

Wardle D.A., Jonsson M., Bansal S., Bardgett R.D., Gundale M.J. & Metcalfe D.J. 2012. Linking vegetation change, carbon sequestration and biodiversity: insights from island ecosystems in a long-term natural experiment. - Journal of Ecology 100: 16-30.

Wilson, D., Hisdal, H., Lawrence, D. 2010. Has streamflow changed in the Nordic countries? – Recent trends and comparisons to hydrological projections. - Journal of Hydrology 394: 334-346. Sitert i: Wong et al. 2011.

Weedon, J.T., Cornwell, W.K., Cornelissen, J.H.C., Zanne, A.E., Wirth, C., Coomes, D.A. 2009. Global meta-analysis of wood decomposition rates: a role for trait variation among tree species? - Ecology Letters 12: 45-56.

Wong W.K., Beldring S., Engen-Skaugen T., Haddeland I. & Hisdal H. 2011. Climate change effects on spatiotemporal patterns of hydroclimatological summer droughts in Norway. - Journal of Hydrometeorology 12: 1205-1220.

Østdahl, T., Taugbøl, T. 1999. Miljøtilpasninger ved eksisterende og nye flomsikringstiltak - en litteraturstudie Hydra-rapport, Oslo, 71 pp.

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