Forest Ecology and Management 352 (2015) 35–46

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Protective functions and ecosystem services of global forests in the past quarter-century ☆

Satoru Miura [a,*], Michael Amacher [b], Thomas Hofer [c], Jesús San-Miguel-Ayanz [d], Ernawati [e], Richard Thackway [f]

[a] Graduate School of Agricultural and Life Sciences, University of Tokyo, 1-1-1, Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan
[b] Logan Forestry Sciences Lab, Rocky Mountain Research Station, US Forest Service, 860 N 1200 E, Logan, UT 84321, USA
[c] Watershed Management and Mountains, Forestry Department, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, Rome 00153, Italy
[d] Unit Forest Resources and Climate, DG Joint Research Centre, European Commission, Via Fermi 2749, I-21027 Ispra, Italy
[e] Data and Information of Forest Management Unit and Land Preparation at Forestry, Ministry of Forestry, Block VII Floor V, Indonesia
[f] Planning and Environmental Management, School of Geography, University of Queensland, Brisbane St Lucia, QLD 4072, Australia

ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form 22 March 2015
Accepted 24 March 2015
Available online 7 September 2015

Keywords:
Sustainable forest management
Multiple functions
Forest conservation
Ecosystem value
Criteria
Indicator

ABSTRACT

The world's forests provide fundamental protection of soil and water resources as well as multiple ecosystem services and cultural or spiritual values. We summarized the FRA 2015 data for protective functions and ecosystem services, and analyzed increasing or decreasing trends of protective areas. The global forest area managed for protection of soil and water was 1.002 billion ha as of 2015, which was 25.1% of all global forested areas. Protective forests have increased by 0.181 billion ha over the past 25 years mainly because more countries are now reporting protective forest areas (139 in 2015 vs 114 in 1990). However, average percentage of designated for protective forests did not change significantly from 1990 to 2015. Global forest area managed for ecosystem services is also now at 25.4% of global total forest area and has changed little over the past 25 years. Among the twelve categories of protective forests, flood control, public recreation, and cultural services increased both in terms of percentage of total forest area and the number of reporting countries. Public awareness of the importance of forest resources for functions and services other than production continues to increase as evidenced by the increase of protective forest designations and reporting in many countries. Percentages of total forest area designated for both protective forests and ecosystem services show a dual-peak distribution of numbers of countries concentrated at 0% and 100%. This suggests a socio-economic influence for the designations. We examined five case study countries (Australia, Canada, China, Kenya, and Russia). The most dramatic changes in the past 25 years have been in China where protective forests for soil and water resources increased from about 12% to 28% of forest area. The Russian Federation has also increased percentages of forest area devoted to soil and water resource protection and delivery of ecosystem services. Australia is now reporting in more protective forest categories whereas Kenya and Canada changed little. These five countries have their own classification of forest functions and recalculation methods of reporting for FRA 2015 were different. This demonstrates the difficulty in establishing a universal common designation scheme for multi-functions of forest. Production of more accurate assessments by further improvements in the reporting framework and data quality would help advance the value of FRA as the unique global database for forest functions integrated between forest ecosystems and social sciences.

1. Introduction

The world's forests provide fundamental protection of soil and water resources and provide multiple ecosystem services as well as cultural or spiritual values. The Food and Agriculture Organization (FAO) of the United Nations reported in Global Forest Resources Assessment (FRA) 2010 that 8% of the world's forests had been primarily designated for protection of soil and water (FAO, 2010b). The public awareness of these forest functions has been growing over last few decades (WHO, 2005; Collaborative Partnership on Forests, 2014). The Earth Summit (United Nations Conference on Environment and Development, UNCED) in Rio de Janeiro in 1992 was a turning point in this awareness trend. The

☆ This article is part of a special issue entitled "Changes in Global Forest Resources from 1990 to 2015".

* Corresponding author. Tel.: +81 3 5841 8636; fax: +81 3 5841 8193.
E-mail address: a-miura@mail.ecc.u-tokyo.ac.jp (S. Miura).

http://dx.doi.org/10.1016/j.foreco.2015.03.039
0378-1127/© 2015 Published by Elsevier B.V.

conference spurred people to promote a variety of activities for sustainable forest management. Chapter 11 of Agenda 21 (''Combating Deforestation'') is particularly relevant in this context. In the summary of this chapter, Keating (1993) writes: ''forests are a source of timber, firewood and other goals. They also play an important role in soil and water conservation, maintaining a healthy atmosphere and maintaining biological diversity of plants and animals... there is an urgent need to conserve and plant forests in developed and developing countries to maintain or restore the ecological balance, and to provide for human needs''.

It is generally accepted that forests and trees, in undisturbed form, provide the greatest vegetative protection against erosion from rain, wind, and coastal waves (Broadhead and Leslie, 2007; Hamilton, 2008). Accordingly, they also significantly contribute to the reduction of downstream sedimentation (Fu, 1989). The root system of the trees creates increased soil strength (Greenwood et al., 2004; Reubens et al., 2007). Forests and trees contribute to the preservation of a good soil structure thanks to the protection against splash erosion (provided the litter layer and the understory vegetation are maintained) and maintenance of robust biological activity in the soil (Binkley and Fisher, 2013). In this context, forests and trees also contribute to the mitigation of risks of shallow landslides. However, deep-rooted mass movements triggered by tectonic events cannot be prevented by forests and trees (Hamilton, 1986; Government of Japan, 2002; Dolidon et al., 2009).

Clean water is becoming more recognized as one of the most important environmental services provided by forests and trees (FAO, 2013). At least one third of the world's largest cities draw a significant proportion of their drinking water from forested areas (FAO, 2013). It is also well established that forests play a crucial role in the hydrological cycle. Forests influence the amount of water available and regulate surface and groundwater flows while maintaining high water quality (Aust and Blinn, 2004; Hamilton, 2008). Forests and trees contribute to the reduction of water-related risks such as floods and droughts and help prevent desertification and salinization (FAO, 2013). However, there is sufficient scientific evidence that forests are not able to prevent or even reduce medium to large scale floods (FAO and CIFOR, 2005; Hofer and Messerli, 2006; Hamilton, 2008). Policy makers have voiced concern about the effectiveness and limitation of these regulating and provisioning services of forests (Cubbage et al., 2007; Collaborative Partnership on Forests, 2014).

In the context of climate change and the resulting increased incidence of natural hazards, the soil and water protection function of forests and trees is becoming increasingly important. For the maintenance and sustainability of this function, forest management through a watershed (landscape) approach is very important (Kammerbauer and Ardon, 1999; Postel and Thompson, 2005). Watershed management includes the management of all available natural resources (including forests) in a comprehensive way and makes the link between natural resources management and the improvement of livelihoods. It provides a framework to organize different land-uses (forestry, pasture, agriculture) in an integrated way (Turner, 1989). Watershed management contributes to the reduction of risks of natural hazards, such as landslides and local floods, and creates local resilience against climate change as well as adaptation options (FAO, 2006b, 2007).

The soil and water protection function of forests and trees offers significant scope for the establishment of payment for ecosystem services (PES) schemes. PES has been developing rapidly under the framework of the Convention of Biological Diversity (CBD) supported by Millennium Ecosystem Assessment and environmental economics (ex. Costanza et al., 1997; Kumar, 2010). In the context of large economic losses by floods and sediment disasters, the calculation of ecosystem values of services related to soil and water protection provided by forests and trees is getting increased attention and importance. FAO (2008) conducted an interesting practical experience of compensation mechanisms for water services provided by forests in Central America and the Caribbean, however its calculation remains a challenge (FAO, 2004b). Recent advances in Clean Development Mechanism (CDM) and Reducing Emissions from Deforestation and Forest Degradation (REDD) in the 2000s under the UN Framework Convention on Climate Change (UNFCCC) also require a reliable reporting of objective forests (REDD Research and Development Center, 2012). Demand for reporting multiple functions of forests has increased in importance based on these rising social concerns in the field of environmental economics.

FRA, the only statistical forest database covering the whole globe, has attempted to assess the extent of protective forests in the world. The inclusion in FRA of the protective function of forests gradually developed in parallel with the increasing importance for the global community assigned to this function. FRA first introduced a concept of 'protective function' of forest as non-wood benefits in FRA 1990 only for developed countries (FAO, 1995) and made the first comprehensive report of protective functions of forest in FRA 2005 as ''More than 300 million hectares of forests are designated for soil and water conservation'' (FAO, 2006a). In the report of FRA 2015, FAO created separate main categories for protective functions and selected ecosystem services since 1990 (FAO, 2012). An initial evaluation of the status and trend of forest protective functions over the past twenty-five years can provide the basis for further detailed analysis of the importance of these forest functions to the international forestry community and other related environmental sciences.

In this paper we analyze the FRA reported data in two main categories of protective functions and selected ecosystem services. In addition, we analyze the status and trend data in several protective forest sub-categories. We tested the effects of sub-regional, latitude-affected climatic, and socio-economic differences and temporal changes on the main category and sub-category protective forest variables according the FRA reporting framework (FAO, 2014a). The trend analyses are based on percentages of total forest area or total land area and not on absolute forest area. We also discuss, as case studies, the status and trend of protective forests in selected countries located in different regions and climatic domains. Finally, we discuss key findings and future recommendation to FRA for improving the reporting of protective functions and ecosystem services.

2. Methods

2.1. Data source and compilation

The FRA 2015 dataset (http://www.fao.org/forestry/fra/fra2015/en/) is described by MacDicken (2015). We used FRA 2015 data submitted by countries in response to the question ''How much forest area is managed for protection of soil and water and ecosystem services?''

There are two main categories and ten sub-categories of protective forests designated for specific purposes of providing protection against events that damage forest resources as well as for providing various types of ecosystem services. The main categories are protective forests for soil and water resources and protective forests for delivery of ecosystem services. Within the soil and water resource protection category are protective forests for the sub-categories of (1) clean water, (2) coastal stabilization (3) desertification control, (4) avalanche control, (5) erosion and flood control, and (6) other control. Within the ecosystem services category are protective forests for the sub-categories of (1) public recreation, (2) carbon storage, (3) cultural services, and (4) other services (excluding Table 6 for conservation of biodiversity).

2.2. Data analysis

Protective forest area data are reported in kilohectare (kha) units for each country that provides such information. These area data range more than six orders of magnitude because of the large variation in land area and forest areas within a country and are non-normally distributed. To compare protective forest areas among countries of such large size variability, area data were calculated as percentages of total land area (remains invariant over total 25-y reporting period) for each country and as percentages of total forest area (which may change over reporting period). This enabled us to avoid too much influence by a few large countries. Protective forest areas were also calculated on a per capita basis. Expressing the protective forest area data as a % of total land area or forest area basis allows for comparisons among countries of vastly different sizes and has the added advantage of producing a more normal data distribution. We referred to sum of areas of main or sub-categories of protective forests and its proportion to total forest area or land area in those cases where we need to clarify the absolute status of protective forests.

Statistical data analysis for this paper was generated using SAS software, version 9.4 of the SAS System (© 2013, SAS Institute Inc., Cary, NC, USA). The SAS generalized linear mixed model (GLIMMIX) software was used to test for differences among global sub-regions (northern Africa, eastern and southern Africa, western and central Africa, western and central Asia, east Asia, south and southeast Asia, Europe, Caribbean, Central America, North America, South America, and Oceania), climatic domains (polar, boreal, temperate, subtropical, and tropical), income level (low, low middle, high middle, and high), and report years (1990, 2000, 2005, 2010, and 2015) for each protective forest sub-category with the data expressed in terms of % of total land area, % of forest area, and on a per capita basis. Normal distribution of the residuals was tested using the Pearson graphs panel. The Tukey option was used to test for statistically significant differences among the least-square computed means. Because the various forest area categories were expressed in terms of ratios (% of land area, % of forest area, per capita), any countries with blank values for the denominator values (land area, forest area, or population) result in an undefined ratio. These were omitted from the data analysis. Some countries report 0 values in the various protective forest categories. Since these are real data entries, these were included in the data analysis.

Income level classification for testing protective forest differences among income class is from the 2013 World Bank dataset and is based on per capita annual income (MacDicken, 2015). Income classes are low ($1035 USD or less), lower middle ($1036–$4085 USD), upper middle ($4086–$12,615 USD), and high ($12,616 or more).

We acknowledge that there is considerable variation in data quality from all the reporting countries. FAO has addressed this problem by data quality tiers to all the main category data from each reporting country (MacDicken, 2015). Two types of tier evaluation were introduced. One is status of reliability of data acquisition and the other is reported trend over 5 report years. Tier 1 data are the least reliable, tier 2 data are considered moderately reliable, while tier 3 data are considered the most reliable. Countries were asked to assign tier values for each of the main protective forest categories (soil and water resources and ecosystem services) in the country reports, which were independently peer-reviewed by FAO staff, partners and external experts (MacDicken, 2015). We used the tier data of status and we summarized the number of countries in each tier category by domain.

To provide detailed examples of the reporting of protective forest data into the FRA database, we selected five large area case study countries to represent a cross-section of the major global regions and climatic domains. These are Australia (Oceania region, subtropical domain), Canada (North and Central American region, boreal domain), China (Asian region, temperate domain), Kenya (African region, tropical domain), and the Russian Federation (Europe region, boreal domain). Russia is a special case, geographically. It is included in the global region of Europe in the FRA database, but because it stretches across a wide longitudinal area, it also includes large land area in Asia. All five countries report data quality in the tier 2 or 3 reliability categories. Thus, countries with the least reliable data tier were excluded from these detailed case studies.

3. Results

3.1. Protective forests for soil and water resources

Globally, the Earth has about 3.999 billion ha of forest area as of the 2015 report year, a decline of about 0.129 billion ha since 1990 (Fig. 1 top). Of this total forest area, as of 2015, about 1.002 billion ha (25.1% of global total forest area) has been designated by the various countries and territories for the protection of soil and water resources, an increase of 0.181 billion ha since 1990. At least part of the increase is due to more countries reporting protective forests (114 in 1990 vs 139 in 2015 out of 234 recognized countries and territories) (Table 1 and Fig. 1 top). In percentage terms, global forest area has still declined (Keenan et al., 2015) from 32.3% of total land area in 1990 to 31.3% of total land area in 2015 (Fig. 1 bottom). On the other hand, protective forest area remained fairly constant over the same time interval with a mean of 35.9% of total forest area (Table 2 and Fig. 1 bottom). Values of the percentage for each country showed a U-shaped histogram polarized to 0 or 100%

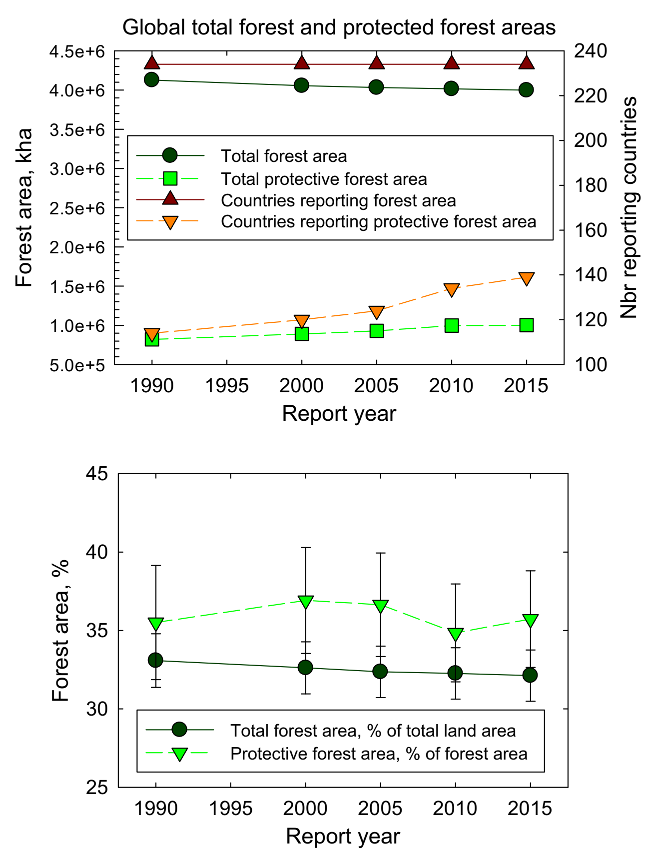

Fig. 1. Global forest area, forest area designated for protection of soil and water resources, and numbers of reporting countries by report year (top). Mean ± std err global forest area as % of total land area and mean ± std err soil and water protective forest area as % of forest area by report year (bottom).

Table 1
Summary of number of reporting countries in each protective forest main category and sub-category for each report year. Nbr > 0 = number of reporting countries with forest area great than 0 in each category or sub-category.

Report year	Soil and water		Clean water		Coastal stabilization		Desert control		Avalanche control		Flood control		Other control	
	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0
(a) Protective forests for														
	Number of reporting countries													
1990	114	90	47	15	56	14	60	10	68	3	55	20	47	5
2000	120	98	50	19	59	16	59	10	68	3	56	22	49	8
2005	124	102	50	19	61	17	61	10	69	3	57	23	49	7
2010	134	113	61	30	68	25	62	10	71	4	63	28	55	12
2015	139	117	62	32	70	27	64	12	74	6	67	32	58	15

Report year	Ecosystem services		Public recreation		Carbon storage		Cultural services		Other services		Forest area	
	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0	Total	Nbr > 0
(b) Protective forests for												
	Number of reporting countries											
1990	64	44	51	25	42	3	42	11	37	7	234	224
2000	67	47	54	30	44	4	45	13	38	8	234	224
2005	73	54	59	36	45	6	47	15	41	11	234	224
2010	79	61	63	40	47	6	51	19	45	17	234	224
2015	83	65	65	42	48	10	51	19	45	17	234	224

Table 2
Global mean ± std err protective forests (as % of total land area and % of forest area) by category and sub-category for all report years (1990–2015) and proportions of land and forest area in each category and sub-category as of 2015 (e.g., Total ha for protection of soil and water resources/total global land area or forest area in ha × 100). Total hectares were obtained by summing the corresponding hectares for all reporting countries.

Protective forest category or sub-category	Mean ± std err (% of total land area)	Proportion of land area in 2015 (%)	Mean ± std err (% of forest area)	Proportion of forest area in 2015 (%)
Soil and water resources	8.67 ± 0.14	7.85	35.92 ± 0.38	25.06
Clean water	1.14 ± 0.13	0.551	3.42 ± 0.26	1.761
Coastal stabilization	0.23 ± 0.03	0.210	0.83 ± 0.08	0.671
Desertification control	0.19 ± 0.00	0.041	3.61 ± 0.09	0.132
Avalanche control	0.04 ± 0.00	0.001	0.36 ± 0.01	0.004
Flood control	1.46 ± 0.07	0.186	5.10 ± 0.33	0.596
Other control	0.98 ± 0.09	1.948	3.13 ± 0.26	6.221
Ecosystem services	7.52 ± 0.12	7.97	29.82 ± 0.60	25.45
Public recreation	1.14 ± 0.08	0.728	4.28 ± 0.19	2.324
Carbon storage	0.60 ± 0.08	0.098	2.63 ± 0.68	0.313
Cultural services	0.56 ± 0.09	1.771	1.94 ± 0.26	5.656
Other services	0.69 ± 0.23	1.267	1.97 ± 0.66	4.047

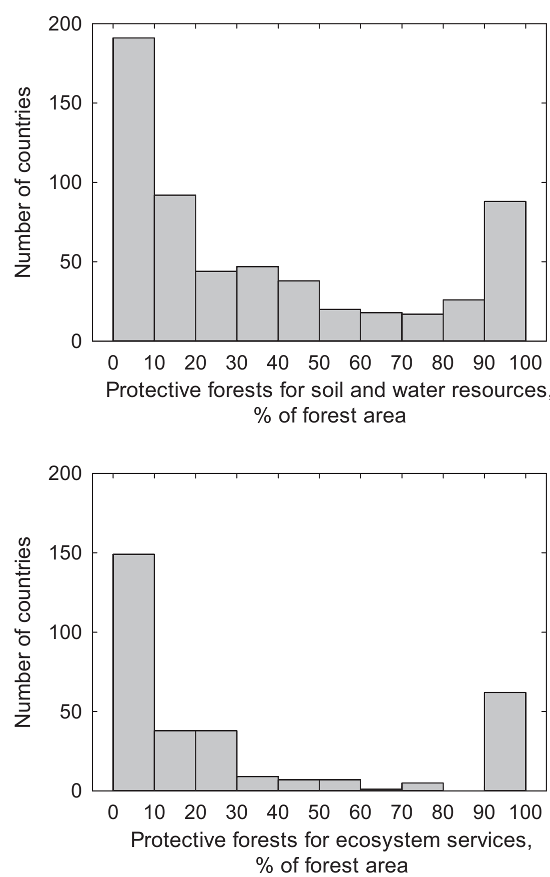

Fig. 2. Histogram distribution of numbers of countries reporting protective forests for soil and water resources as % of total forest area (top) and protective forests for delivery of ecosystem services as % of total forest area (bottom). Number of countries were summed for all five report years.

(Fig. 2). The number of countries reporting a median value around 50% was very small. The U-shaped double peak distribution pattern did not change through 25 years.

Neither main category of protective forests (for protection of soil and water resources (Fig. 3) or for delivery of ecosystem services (Fig. 4)) showed significant trends over the reporting time interval (1990–2015) when expressed as a % of total forest area. Sub-category trends in Figs. 3 and 4 are described below under the various sub-category headings.

No significant differences among global sub-regions for soil and water protective forest area were observed when expressed either as a % of land area or as a % of forest area because of the large variation across countries within a region. Similarly, there were no significant differences among the climatic domains for protective forest area as a % of forest area. Polar countries (only two territories, Greenland (Denmark) and Svalbard and Jan Mayen Islands (Norway), are classified as polar) did not report any forest area. Per capita protective forest area was also calculated and tested for significant differences among global sub-regions. None were

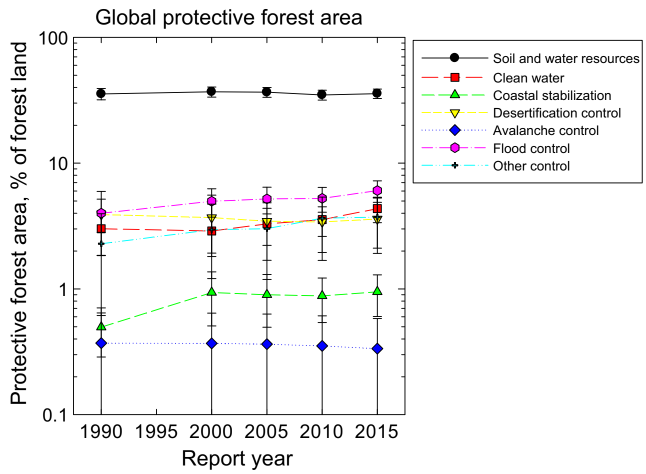

Fig. 3. Mean ± std err global protective forest area (as % of forest area) for soil and water resources (main category) and for sub-categories of clean water, coastal stabilization, desertification control, avalanche control, flood control, and other control by report year.

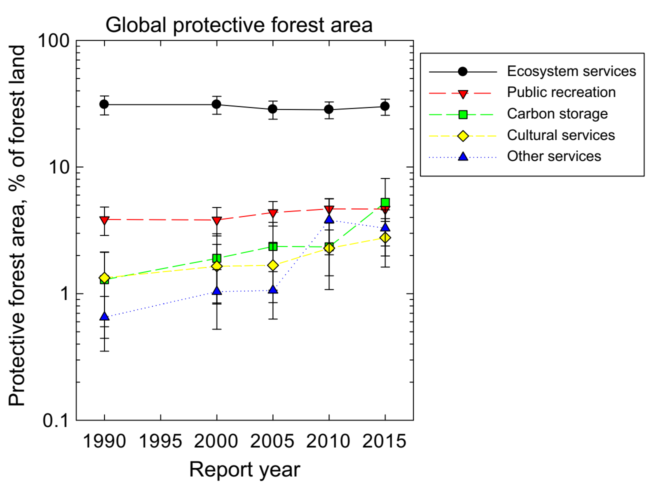

Fig. 4. Mean ± std err global protective forest area (as % of forest area) for delivery of ecosystem services (main category) and for sub-categories of public recreation, carbon storage, cultural services, and other services by report year.

found. Similarly, no significant differences among income class for soil and water protective forest area were found either as a % of land area, % of forest area, or on a per capita basis. Thus, neither sub-regions, climatic domain, nor income class can account for the variation in protective forest area among countries at the main category level.

Relationships between soil and water protective forest area (as % of forest area or on a per capita basis) and a select group of other FRA database variables were explored. No relationships were found between protective forests (% of forest area) and production forest area, cumulative forest area damaged by outbreaks (e.g., diseases, insects, severe weather), or forest areas with management plans. On a per capita basis, no relationships were found between protective forests and non-wood forest products, forest revenue, or public expenditures on forests.

3.1.1. Clean water

Approximately 3.4% of global forest area has been primarily designated for the protection of clean water (Table 2). The number of countries reporting more than 0 ha in this sub-category was 32, which was the one of two largest (along with the flood control sub-category) among soil and water protection sub-categories (Table 1). These forests in this category are found in all the sub-regions except for Central America and North Africa, and most abundant in the European region, where 2.7% of the forest area is primarily designated for water protection. Among them, Japan has designated 24–37% of its forest land area for delivery of clean water from 1990 until 2015 (Table 3). Uruguay ranks second at 20–34% for the same time interval. The most noticeable changes in the reporting period from 1990 to 2015 occur in Europe, Oceania and South America. In Europe, there was a sharp increase in forest for water protection in Russian Federation (from 4.1% in 1990 to 6.3% as of 2015); a small decrease in this forest protection category occurs in Bulgaria. In Oceania, forests designated for water protection were 0.5% in 1990, which increased to 4.8% initiated by sharp increase in Wallis and Futuna Islands and that of newly designated forests by Australia, New Zealand and Tonga in 2010. On the other hand, in South America, forest area in this category showed a decreasing trend because of a substantial decrease from 34% to 20% by Uruguay, and recent small designations in 2000 by French Guiana (2%), and Venezuela (0%).

3.1.2. Coastal stabilization

About 0.83% of global forest area has been primarily designated for coastal stabilization (Table 2). Significant temporal increase of percentage to total forest area ($P < 0.001$) was observed (Fig. 3) and the percentage of Caribbean sub-region was significant higher than that of South America in 1990 and 2000 ($P < 0.001$) but was not significant in the most recent ten years due to the increase of percentage forest area in South American countries.

Few countries in the regions suffering disasters by cyclones, hurricanes, and typhoons, such as Cuba and Jamaica in Caribbean or Bangladesh in South Asia have primarily designated forests for coastal stabilization. Globally, Cuba with its long coastal length has the highest percentage of forest area devoted to coastal stabilization (18–19%) (Table 3). Lithuania ranks second at about 8%.

Table 3
Countries with the highest percentages of forest area in each of the protective forest and ecosystem services main and sub-categories.

Protective forest category or sub-category	Countries with highest % of forest area in protective forest category[†]	% of forest area (report year)
Soil and water resources	Austria, Burundi, Burkina Faso, Bhutan, Isle of Man, Jamaica, Kenya, Libya, Morocco, Martinique, Mayotte, Saint Pierre & Miquelon, Thailand, Tajikistan, Tunisia, Yemen	All at 100% (most to all reporting years)
Clean water	Japan	24–37% (1990–2015)
Coastal stabilization	Cuba	18–19% (2000–2015)
Desertification control	Uzbekistan	80% (1990–2015)
Avalanche control	Tajikstan	14% (1990–2015)
Flood control	Timor-Leste	32% (1990–2015)
Other control	United States	61–68% (1990–2015)
Ecosystem services	Belgium, Bhutan, Isle of Man, Iceland, Jamaica, Kenya, Martinique, Mayotte, United States	All at 100% (most to all reporting years)
Public recreation	Saint Lucia	29–31% (1990–2015)
Carbon storage	Saint Pierre & Miquelon	100% (2015)
Cultural services	Australia	35% (2015)
Other services	Australia	59% (2010), 39% (2015)

[†] See the 2nd and 3rd ranked and subsequent countries in the 'Country sorted' sheet of the supplemental table.

However, many island countries have not always primarily designated forests for that function. The other 26 countries designated less than 10% of total forest area to protect against coastal erosion. Among them, Russia designated 24.3 mil. ha (3.0% of total forest area) forests for coastal stabilization, which occupied 90.5% of global total forest area in this sub-category as of 2015. However, Russia has not shown an increasing trend in coastal forest protection in terms of percentage of total forest area. Other relatively small countries in the Caribbean, South and Southeast Asia regions and other European countries have contributed increased percentages of total forest area to coastal stabilization.

3.1.3. Desertification control

Relatively few countries have protective forests designated for desertification control. All are in arid regions mainly in parts of Africa and in central Asia. About 3.6% of global forest area in the form of protective forests has been used to check the advance of desertification with no significant trend since 1990 (Table 2 and Fig. 3). Uzbekistan, an arid region country in central Asia, has the highest areal extent of forest land designated to arrest the process of desertification (80%) (Table 3). Some other arid region countries designate at least 10% or more of their forests to control desertification (e.g., Mauritius, Mauritania, Oman, Sudan, and Tajikstan). Neither regions nor domains were significantly different regardless of expressing protective forests for desertification control as % of land area, % of forest area, or on a per capita basis.

3.1.4. Avalanche control

About 0.36% of global forest area is primarily designated for avalanche control (Table 2). Tajikstan, a mountainous country also in central Asia, has designated 14% of its forests for avalanche control to protect villages and transportation corridors (Table 3). Switzerland, another mountainous country, ranks second at about 7%. Other countries that designate forests for avalanche control use less than 0.1% of their forests for that purpose. Obviously, the need for this category of protected forests depends largely on the climatology, that is, presence of large and deep layers of snow cover and the topography of the countries. The designation of a forest under this category depends also on the potential avalanche risk to populations and human assets. This is thus a very specific category of protected forests that is present in very few regions and countries in the world and has changed little during these 25 years (Fig. 2).

3.1.5. Flood control

The global mean of percentage of forest area managed for erosion and flood protection has been the largest of ca. 5.1% among this primarily designated sub-category of protection of soil and water (Table 2). Global protective forests designated for erosion and flood protection have increased three times from ca. 7.0 mil. ha (0.17% of global total forest area of 20 countries) in 1990 to 23.8 mil. ha (0.6% of 32 countries) as of 2015 (Fig. 2). The flood control and clean water protection sub-categories have the largest number of reporting countries (32) (Table 1). This rapid increase was due to the increase in Russia in 1990s and is also due to the increase of reporting countries in the 2000s. Countries in temperate to sub-tropical and tropical domains designated larger forest area for erosion and flood control, such as Timor-Leste (32%) (Table 3), Austria (30%) and Switzerland (28%) as of 2015. Tajikistan, a semi-arid country, also designated a high percentage of forest area (25%) for erosion and flood control.

3.1.6. Other control

About 3.1% of global forest area has been primarily designated for other controls within the protective forest soil and water control category (Table 2). No overall global trend in protective forests for other control has been observed (Fig. 2). We note that FAO allowed countries to report a forest area of 'other control' by subtracting the sum of forest area of sub-categories from the forest area of the soil and water protection main category. More than half of all countries reported an identical number of the ratio of the sum of forest area of sub-categories to the forest area of soil and water protection main category. Thus, many countries reported the 'other control' sub-category by means of data subtraction.

3.2. Protective forests for ecosystem services

Globally, as of 2015, about 1.018 billion ha of forest (25.4% of global total forest area) has been designated for ecosystem services, which is almost the same percentage as global protective forest area for soil and water resources (Table 2). Forest area devoted to ecosystem services has continuously increased over the past 25 years mainly because of the increasing number of reporting countries (Table 1) and because of a few countries with distinct net increase of forest area for ecosystem services (e.g. China, Russia, and Ecuador). Of this total forest area managed for ecosystem services, about 48.5% as of 2015 (0.493 billion ha) has been primarily designated for sub-category of public recreation, carbon storage, spiritual/cultural services, and the other services. The average percentage of forest area managed for ecosystem services has not changed from around $29.8 \pm 0.6\%$ during this period (Table 2). However, the proportion of accumulated forest areas primarily designated for delivery of ecosystem services sub-categories was 4.5% in 1990, and then distinctly increased up to 12.3% as of 2015. This increase is about two times larger than the increase in the proportion of accumulated forest areas primarily designated for protection of soil and water.

Canada and United States of America in North America are the top two countries that have the largest forest areas designated for ecosystem services. Canada designates 93% of its total forest area and the United States of America designates 100% of its forests for ecosystem services as of 2015. These two countries also designate high percentages for protective forests of soil and water (Canada, 91%; USA, 61–68%). Another eight countries also designate more than 90% for both two main categories. As a natural consequence, almost all forests for both categories overlap. A definition modification of removing the definitive adverb 'primarily' shifts these countries designation percentages from one end of the percentage scale to the other. Thus, the primary designation issue remains a difficult problem for tracking changes through time.

Percentages of total forest area designated for ecosystem services have not shown significant differences in terms of global regions, climatic domains, or time. Other variables in the FRA dataset such as production forest area, cumulative forest area damaged by outbreaks of insects or disease, or forest areas with management plans, and economic value data on a per capita basis did not have any statistical relationship with forest areas designated for ecosystem services also expressed on a per capita basis. Changing trends also did not any relationships with any of the above variables.

3.2.1. Public recreation

About 4.3% of global forest area is primarily designated for public recreation (Table 2). Forests devoted for public recreation are located in all the regions and sub-regions except North America. The number of reporting countries for this sub-category has been increasing for 25 years, and it was the largest among ecosystem services sub-categories (42 countries reporting more than 0 ha out of 65 total reporting countries as of 2015) (Table 1). Most of protective forests for public recreation are located in South America (43%), Oceania (33%) and Europe (20%) as of 2015. South America, Oceania and Central America were sub-regions which rapidly expanding its recreational forests. Among all the countries, Saint Lucia has designated the highest percentage of its forest area for public recreation (29–31%) (Table 3). Australia is next highest at 21–25% (2010–2015). Forest areas in North America are unquestionably used for public recreation. However, this reported data situation is because of the 'primarily designated' constraint for sub-categories.

3.2.2. Carbon storage

About 1.3% of global forest area was designated for carbon storage in 1990 and this has increased to 5.3% as of 2015 (Fig. 4). Saint Pierre and Miquelon, a self-governing French-aligned territory off the coast of Newfoundland, Canada, designated 100% of its forests for carbon storage – the only country or territory to so designate thus far (Table 3). Iceland is next highest at 28–37% for 2000–2015. The increasing trend is a very positive development for global forests to have an increased role in sequestering more carbon in the future (Fig. 4). However, very few (ten) countries, which was the smallest number among four sub-categories of ecosystem services, reported forest area of more than 0 ha for carbon storage as of 2015 (Table 1). The total global forest area in this sub-category was 12.5 mil. ha (0.3% of global total forest area). Carbon storage has been by far the smallest primarily designated sub-category of ecosystem services (Table 2). Because of the limited dataset, it is difficult to produce a robust statistical analysis.

3.2.3. Cultural services

Forests are an important cultural service resource for many countries. About 1.9% of global forest area is primarily designated for cultural services (Table 2). The forests in this category are distributed in all regions of the globe, except for the African continent. Most protected forest for cultural services are located in South America (48%) and North America (32%) as of 2015. The most noticeable increase in protected forest areas for cultural services occurred in South America, from approximately 11 mil. ha (2.1% of total forest area) in 1990 to 108 mil. ha (16.0%) as of 2015. This sharp increase was driven by a significant enlargement of cultural services areas in Brazil (2–21%), which correspond to approximately 97% of the protected areas in the region. Likewise, most of the protected areas in the region of North America are in the USA (21.0% of total forest area) and Canada (2.0%) where figures have been fairly stable since the 1990s. Significant protected areas for cultural services are also present in Oceania (35% of Australia), which contributes 19.3% as of 2015 to the global figure for this category. Australia began using the primary designation of forests for cultural services in 2000 as the first country in the region to do so. Europe (0.6% of global total forest area) and Asia (1.5%) has contributed to this sub-category in small percentages. The largest global total forest area (5.7%, 226 mil. ha) designated for cultural services among four sub-categories is a consequence of the contributions by a few large countries.

3.2.4. Other services

About 2.0% of global forest area has been designated by countries for delivery of other (unspecified) services (Table 2). No overall global trend has been observed in the past 25 years (Fig. 4). As of 2015, Australia now has the highest percentage of forest area devoted to protective forests for other services (Table 3 and discussion below).

3.3. Case study countries

3.3.1. Kenya (Africa)

Forest area of Kenya occupies only 7.8% (4.4 mil. ha) of total land area as of 2015 and 70% of land area is grassland (FAO, 2014e). Kenya has designated all forest areas for the protection of soil and water and ecosystem services and cultural and spiritual values for all 5 reporting years. Thus, areas of protective forests change are linked with total forest area. Kenya had decreased forest area in 1990s due to degazettement of forestland to open up areas for agricultural land (FAO, 2014e). Since 2000, there is an increase in forest area both in gazetted and non-gazetted areas due to rehabilitation of degraded forest, especially through carbon credit schemes (Ministry of Environment, Water And Natural Resources, 2014), not reaching, however, the values of 1990. No sub-division was made of the different protection objectives.

3.3.2. China (Asia)

China has dramatically expanded its protective forests over the past 25 years from 18 mil. ha to 58 mil. ha as of 2015 (Fig. 5). The proportion of protective forests to total forest area increased from 12% in 1990 to 28% as of 2015, which is also associated with the increase in total forest area (Fig. 5). This incredible increase contributed a percentage increase in the proportion of protective forests for soil and water resources in East Asia compared to a global no percentage change.

According to the national report on sustainable forest management in China (State Forestry Administration, 2013), areas suffering from soil erosion at the end of 1990s extended to 356 mil. ha and the amount of annual soil losses amounted to 5 billion tons. Water erosion covered 165 mil. ha, and wind erosion damaged 191 mil. ha. The degradation of forests in China had continued for several decades until 1990s, owing to rapid population growth coupled with the over-exploitation of forest resources, and subsequent cultivation on steep slopes (Wenhua, 2004). This caused serious frequent natural hazards and disasters and produced vast human and economic loss. The Chinese government launched a

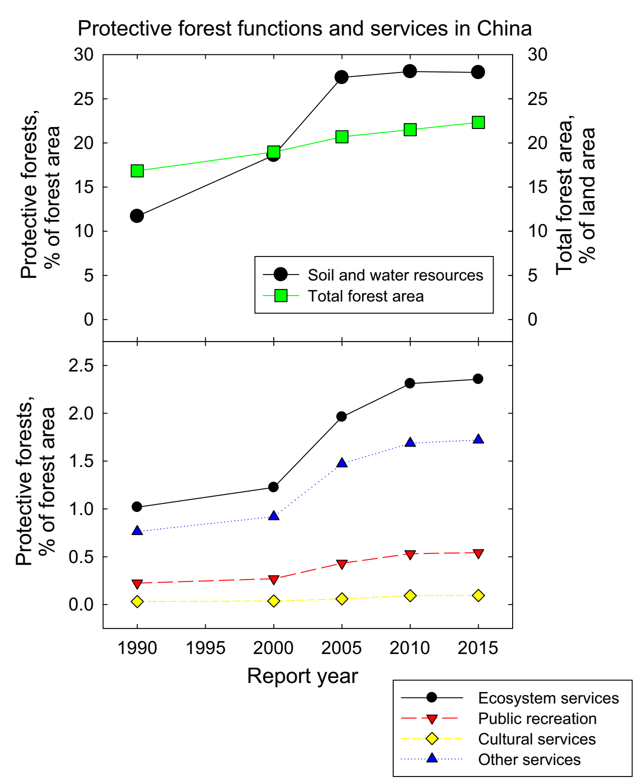

Fig. 5. Mean ± std err protective forest area (as % of forest area) for soil and water resources (main category – top) and for ecosystem services (main category) and subcategories of public recreation, cultural services, and other services (bottom) for China by report year. *Note*: China did not report data in any sub-categories under protective forests for soil and water resources or for C storage under ecosystem services.

series of top-to-bottom afforestation projects and implemented natural forest conservation projects, and increased shelter forests associated with total forest area (State Forestry Administration, 2013). This caused a major annual increase in forested areas from 0.27% (1970s–90s) to 3.27% (6.2 mil. ha/y, 1999–2008) of land area. Areas of shelter forests have reached 83.1 mil. ha in late 2000s, occupying 45.8% of forest area and 8.7% of total national land. Greater parts of shelter forests are for water supply conservation forest (30.6 mil. ha) and water and soil conservation forest (43.7 mil. ha), whereas 3.0 mil. ha are for windbreak and sand-fixing forest. Although the area of shelter forests for arid and semi-arid region is not large, it is apparent that many forests are explicitly managed to control desertification in China, but were not reported in FRA 2015. China stated that it did not report sub-categories of protection of soil and water because of difficulties of translation between the designation system of FAO and that of China own (FAO, 2014d).

3.3.3. Russian Federation (Europe)

Russian territory spreads over the most northern part of the north hemisphere. Thus most Russian forests are located in the boreal domain (88%) (FAO, 2014f). About 50% of land area is covered by forest (815 mil. ha, the world's largest) as of 2015. Russia designated forests by its own classification system, as four main categories: protected forests (2.2%), protective forests (24%), operational forests (50.9%) and reserve forests (22.9%) in 2013 (FAO, 2014f). Protected forests (18 mil. ha) and protective forests (215 mil. ha) correspond to FRA protective forests and conservation forests for biodiversity (main category 6). Russia reclassified and divided these two national categories of forests to adapt FRA definitions of protective forests for soil and water (FAO, 2014f).

According to the new FRA 2015 dataset, forests designated for the protection of soil and water have increased from 7.3% (59 mil. ha) in 1990 to 10.6% (86 mil. ha) as of 2015 (Fig. 6). However, Russia did not show the details of the calculation in the country report (FAO, 2014f). The area under this category comprises forests for clean water protection, coastal stabilization, and flood control (Fig. 6). While small change occurred in area designated for coastal stabilization, protective forests for clean water increased from 4.1% (33 mil. ha) to 6.3% (52 mil. ha) in the period. The most notable increase in the allocation of protective forests is evidenced for erosion and flood protection; the forest area in this category grew from 0.2% (1.6 mil. ha) in 1990 to 1.3% (10.4 mil. ha) as of 2015 (Fig. 6). Forest designated for the protection of ecosystem services, cultural and spiritual values increased from 9.1% (74 mil. ha) in 1990 to 13.4% (109 mil. ha) as of 2015 (Fig. 6). It is interesting to note that the forest designated for public recreation has significantly decreased in the period 1990–2000. In any case, a slight change of percentage for a sub-category in Russia strongly affects any increase or decrease in trend for Europe and even influences the entire global forest assessment as we can see for clean water or flood control.

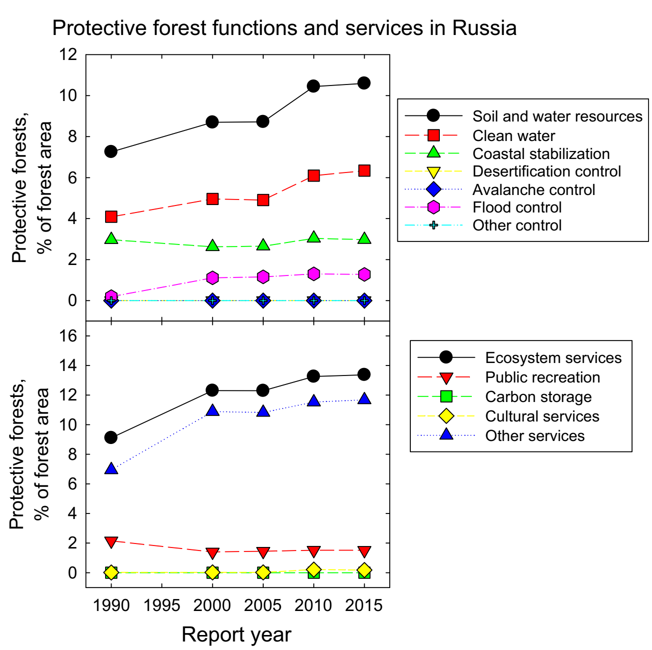

Fig. 6. Mean ± std err protective forest area (as % of forest area) for soil and water resources (main category); for sub-categories of clean water, coastal stabilization, desertification control, avalanche control, flood control, and other control (top); for ecosystem services (main category); and subcategories of public recreation, C storage, cultural services, and other services (bottom) for Russia by report year.

3.3.4. Canada (Americas)

Canada has reported all publicly owned forests as designated for protection of soil and water (FAO, 2014c). At 347 mil. ha (2015 report year), Canada ranks 3rd globally (behind Russia and Brazil) in terms of total forested land area (38% of total land area in Canada is forested). Despite ranking 3rd in total forest area, Canada leads all nations in terms of total forest area designated for protection of soil and water resources (317 mil. ha as of 2015). Canada reported protective forest area in both main categories – soil and water protection (91.4% of forested land area in all report years) and ecosystem services (93.4% of forest area in all report years). Canada only reported protective forest areas in the cultural services sub-category (about 2% of forest areas).

3.3.5. Australia (Oceania)

Australia (2015 report year) has a total forested land area of 124 mil. ha (16% of total land area) and ranks 7th behind China and Congo. It has reported protective forest area in the two main categories – soil and water protection (23.9% of total forest area as of 2015) and ecosystem services (98.4%) (Fig. 7). Australia is one of the largest dry continent in the world. Most of Australia's land area is classified as rangelands, which encompass some 75% (570 mil. ha) of the continent. One third of the continent has extremely low and variable stream-flow compared to other continents and large areas of the arid hinterland produce almost no run-off. For these reasons, Australia's population is concentrated within 100 km from the coast and much of Australia's drier hinterland is minimally managed.

Public forest excluded from wood harvesting is 29 mil. ha as of 2015. Public forest comprised almost entirely native forest includes forests managed for soil and water protection and ecosystem services, which has remained relatively stable in these reporting period (SOFR, 2013). Australia's forest area designated primarily for protective functions include various public nature conservation reserves. Not all sub-categories of soil and water protection or ecosystem services have been included in any reporting year. Though Australia operates indeed dune protection program for coast care, integrated package for desertification control and managements for erosion and flood controls, it has not provided nationally inconsistent information for these functions (FAO, 2014b).

Ownership of forests affects designation of protective forests in Australia. Importantly, forest areas in public nature conservation reserves are 'managed primarily for protective functions', which includes the conservation of biodiversity as well as protection of soil and water values. It is worth noting that, across most of Australia's forest management jurisdictions, the preservation of soil and water is usually one of several forest management objectives included in the management of multiple-use public forests.

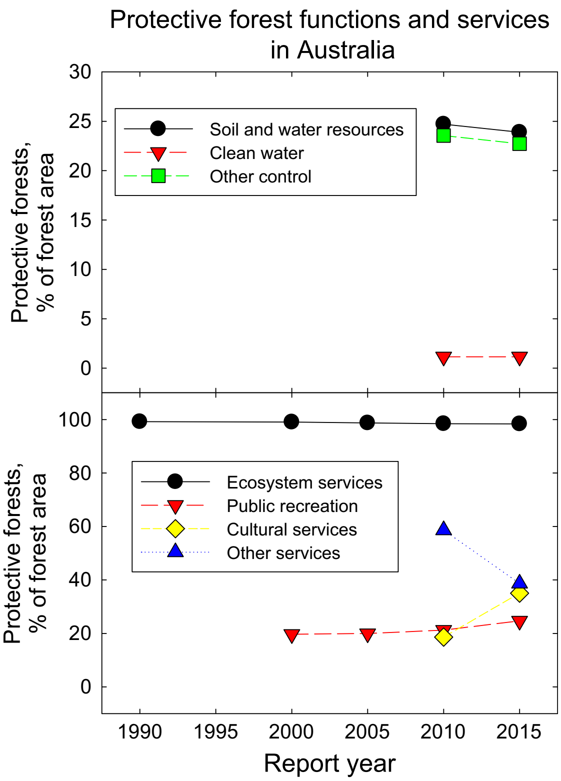

Fig. 7. Mean ± std err protective forest area (as % of forest area) for soil and water resources (main category); for sub-categories of clean water and other control (top); for ecosystem services (main category); and subcategories of public recreation, cultural services, and other services (bottom) for Australia by report year. *Note*: Australia did not report data for protective forests for soil and water resources (or any of the sub-categories) prior to 2010. Australia did not report data in the coastal stabilization, desertification control, avalanche control, flood control, or C storage sub-categories.

4. Discussion

4.1. Global trends of protective forests and selected ecosystem services

Despite a net loss of global forest area over the past 25 years, forest area devoted to protection of soil and water resources has increased by 22%, mostly due to an increase in reporting countries. Some sub-categories such as clean water, flood control, public recreation and cultural services showed clear increased trends both in terms of percentage of total forest area (Figs. 3 and 4) and the number of reporting countries (Table 1). These global trends provide evidence for the continuing increase of public awareness of multiple functions of forests. Various fronts of international cooperation for sustainable forest management, such as regional initiatives (ITTO, FE, MP[1] etc.), UNFF[2], criteria and indicator development (Raison et al., 2001; Diaz-Balteiro and Romero, 2008) and forest certification (Rametsteiner and Simula, 2003; van Kooten et al., 2005) have initiated the current trend associated with UNFCCC and CBD. However, globally, there have been no significant changes in the average of percentages forest area designated for protective forests or ecosystem services. In addition, dual-peak end member distributions of percentages of protective forests or ecosystem services were far from a common one peak natural distribution around a mean. A designation of a forest for protective or ecosystem services purposes could introduce some regulation of productive forest use. Some political regulations or measures likely affect this distribution although we could not clarify the exact reason. A government could hesitate to designate or increase protective forests in such a situation. For instance, stakeholders of forests in the country which has a regulation against production activities may hesitate to designate protective forests. In the opposite case, they have no reason to hesitate to designate 100% of their forests as protective forests. Historical development of forest ownership may also influence this situation such as in Canada or Australia. For example, in Australia, significant proportions of multiple-use forests are informal reserves where wood harvesting is not permitted. In addition, differences among state-based jurisdiction rules in Australia could be obstacles to adjust a unified reclassification of multiple-use forests within one country. Such possible political considerations influencing the designation of protective forests are apparent from country reports for FRA 2015 and other country reports from the Montreal Process for four countries, China, Russia, Canada and Australia. Those countries reports are indispensable sources of understanding the multiple functions of forests in each country.

Although we could not find by SAS GLIMMIX analysis any clear factor affecting percentages of forest area designated for protective functions on a global basis, dramatic change has occurred in China. This Chinese case is not necessary a special case. Excess deforestation has brought about decline of societies (Perlin, 1989). This could happen to other developing countries by rapid increase of its population. A relevant lesson for forest management is how we can set a level of protective functions of forests to maintain sustainable forest management to prevent severe erosion and sediment transport disasters for food production and social infrastructure.

The current reporting of FRA for protective functions or delivery of ecosystem services requires designation of forest areas by governments. No information about the effectiveness of forest protective functions is provided. In the case study of China, one of the current concerns is a verification of actual functioning or effectiveness of increasing protective forests. There are now two challenges in this regard – demonstrating prevention of forest degradation by encroaching sand dunes by means of shelter belts, and not demonstrating its effects (Wang et al., 2010; Yu et al., 2006). Detecting actual change of functions and services could be the next challenge for China to fully utilize FRA. If a future FRA report challenges countries to assess forest protective functioning with measureable variables, this could fill this knowledge gap. To cite a case, a global review of relationships between thinning or clear cutting and water yield (Bosch and Hewlett, 1982) should be a good example. We can introduce such relationships between forest managements and various kinds of functions into FRA reporting.

4.2. FRA definitions and reporting multiple functions

We found both improvement and problems in the reporting variables of "Topic III: Protective functions and selective ecosystem services" in FRA 2015. The improvement was a modification of definition by removing the word 'primarily designated' for the two main categories (5.1 Protection of soil and water, 5.2 Ecosystem services, cultural or spiritual values). This likely produced reported data that was a more accurate reflection of forest protection classifications around the world. The main problem was an insufficient framework for reporting functions of forests. Before we discuss this in detail, we describe the change of definition in recent FRA.

Changes in the past few decades to FRA by FAO have paralleled the global trend of increasing the importance of multiple functions of forests other than production. FAO first introduced a concept of protective forests for soil and water in FRA 1990 (FAO, 1995). However, FRA had not advanced the concept of protective forests as reporting items in subsequent reporting years of 1995 and 2000 (FAO, 1997, 2000, 2001). Then, in FRA 2005, it adopted a percentage of protective forests as a reporting variable (FAO, 2004a).

[1] International Tropical Timber Organization, Forest Europe and Montreal Process.
[2] United Nations Forum on Forests.

Percentage forest area in FRA 2005 was divided into six exclusive categories of functions; (1) Production, (2) Protection of soil and water, (3) Conservation of biodiversity, (4) Social services, (5) Multiple purpose, (6) None or unknown function. Category 1 through 4 was applicable if a forest is primarily designated as one of four functions. Otherwise, category 5 or 6 was assigned. All the forest area must be within one of six categories and the sum of percentages of all six categories must add up to 100%. Using this definition in FRA 2010 (FAO, 2010a), the United States of America did not report in the category of 'primarily function as' and no primarily designated protective forests were reported for the North American sub-region. Reasons how and why this was done were described in the main report of FRA 2010 (FAO, 2010b).

This potentially-misleading definition was modified in FRA 2015. The word 'primarily' designated was not used for the two main categories of protection of soil and water and selected ecosystem services and was applied only to sub-categories. In consequence, the global level of protective forests as a proportion of total forest area abruptly jumped to 25.1% in FRA 2015 from 8% in FRA 2010. Sum of forest area of primarily designated sub-categories of protection forest in 2010 was 369 mil. ha (9.2% of total forest area) in FRA 2015 report. This shows a fairly good correspondence to 8% in FRA 2010 report considering that each country was allowed and encouraged to make a retroactive modified report in previous reporting years of 1990 to 2010.

The problem of 'primarily' designated for protective forests for soil and water has been resolved as described above for the two main categories. However, the overall strategy of how FRA reflects multiple functions of forests still lacks consistency and harmonization across reporting periods. Ecosystem services of forests are divided into conservation of biodiversity (FRA 2015, Table 6) and other services (FRA 2015, Table 5b) (FAO, 2014a). Carbon storage or sequestration is assigned a sub-category of selective ecosystem services, though biomass carbon and below ground carbon are reported within the main category of production (FRA 2015, Table 3e). In the meantime, there is an opinion such as that of China (FAO, 2014d) and Russia (FAO, 2014f) that all forests make a significant contribution to carbon storage or sequestration because every forest provides a function of carbon sequestration to some extent. Variables reporting multiple functions in FRA 2005 and 2010 showed a clear stance of FAO to report the multiple functionality of forests within a table even if it introduced a new problem as described above. However, in FRA 2015, FAO separated a part of forest functions into three different tables (4. production, 5. protection, 6. biological conservation). Thus, the FAO approach to understand multiple forest functions was still developing.

Forest Europe (FE), the pan-European political process for the sustainable management of the continent's forests, has also been facing to this kind of dilemma of designation between a primary function and multi-functionality of forest. MCPFE, the predecessor of FE, introduced general principles to designate protective functions with legal basis, long-term commitment and explicit designation of biodiversity, landscape, specific natural element or protective function of forest and other wooded land (MCPFE, 2003). This exclusive designation rule for protective functions is similar to the definition of FRA 2005 (FAO, 2004a). This kind of designation scheme was intended to be shared internationally in early 2000's. However, FE also could not completely overcome the problem of overlapping designation for protective forests. FE had to acknowledge that there exists overlapping designations of indicators 5.1 Protective forests of FE – soil, water and other ecosystem functions and 5.2 Protective Forest – infrastructure and managed natural resources in 2011 (MCPFE, 2011). Thus, we can say that there still exists potential to further develop the framework of definitions for reporting multiple forest functions to establish long-term robust variables as a whole forestry sector. Tracing and examining details of recalculation formulas and comments for the three Tables 4–6 of FRA 2015 would be a good start. We could learn from the diversity of the methods and original definitions for designation of protective forests in each country as we illustrated with the five case study countries. On the other hand, movement of developing tools for sustainable forest management is a sweeping trend of forestry sector. Regional initiatives such as ITTO, FE, MP have lead the establishment of criteria and indicators (McDonald and Lane, 2004). Strengthening collaborations with those activities would also be another effective solution for this issue. The beginning of such international collaboration has been seen in the partnership activities of the Collaborative Forest Resources Questionnaire (MacDicken, 2015) for FRA 2015. The overall strategy of FRA for reporting multiple forest functions should be reconciled and improved.

4.3. Data quality

These are largely qualitative designations that while providing a guide to overall data quality, do not facilitate a more quantitative assessment of data reporting errors. For protective forests for soil and water resources, tier 1 countries (least reliable data quality) outnumber tier 3 countries (most reliable data quality) by a large margin (Table 4). For example, there are twice as many tier 1 countries in the protective forests for soil and water category as there are tier 3 countries. Only about 59% of all countries have tier designations for the soil and water resources protective forests category. Only 35% of all countries have assigned data quality tiers in the ecosystem services delivery category. For future editions of FRA, we recommend a renewed emphasis on encouraging countries in the lowest tier 1 to take steps to move to tier 2 and tier 2 countries to move to tier 3. In the current FRA reporting cycle, only about 18% of reporting countries are in tier 3 for the protective forest category and only about 13% are in tier 3 for the ecosystem services category.

Table 4
Numbers of countries (% of total countries) in each data reliability tier for the main protective forest categories of soil and water resources and ecosystem services. Tier 1 = least reliable data quality, tier 2 = moderately reliable data quality, tier 3 = most reliable data quality.

Domain	Soil and water resources				Ecosystem services			
	Tier 1	Tier 2	Tier 3	No tier	Tier 1	Tier 2	Tier 3	No tier
	Number of countries in each tier category							
Polar	1 (0.4)	0 (0)	1 (0.4)	0 (0)	1 (0.4)	0 (0)	1 (0.4)	0 (0)
Boreal	2 (0.9)	1 (0.4)	3 (1.3)	1 (0.4)	1 (0.4)	1 (0.4)	3 (1.3)	2 (0.9)
Temperate	8 (3.4)	5 (2.1)	21 (9.0)	13 (5.6)	5 (2.1)	7 (3.0)	15 (6.4)	20 (8.5)
Sub-tropical	14 (6.0)	2 (0.9)	5 (2.1)	15 (6.4)	8 (3.4)	2 (0.9)	3 (1.3)	23 (9.8)
Tropical	45 (19.2)	16 (6.8)	13 (5.6)	68 (29.1)	17 (7.3)	10 (4.3)	8 (3.4)	107 (45.7)
Total	70 (29.9)	24 (10.3)	43 (18.4)	97 (41.5)	32 (13.7	20 (8.5)	30 (12.8)	152 (65.0)
Grand total (tiers 1 + 2 + 3)			137 (58.5)				82 (35.0)	

All but 10 countries and territories report forest area greater than 0 ha. Half the world's countries now report some forest area (>0 ha) for protection of soil and water resources (117 in 2015) (Table 1). Only about a quarter of all countries (28%) have actual forest area (>0 ha) reported for ecosystem service delivery. In all the protective forest and ecosystem service sub-categories, the number of reporting countries is a minor fraction of all possible reporting countries. It ranges from as few as 6 countries with protective forest areas designated for avalanche control in 2015 to 42 countries reporting forest area for public recreation in 2015. Because of the low numbers of reporting countries with hectares >0 in each of the sub-categories, both the total forest area and percentages of forest area designated as protective forests remains small on a total global basis. There is opportunity for expansion in many of these protective forest sub-categories.

5. Conclusions

FRA was originally founded to build a global inventory of forest resources as the name implies. The global community has come to expect FRA to report forest functions and services other than forest productivities towards the end of the 20th century, where threats of global warming and degradation of biological diversity to human societies became obvious (McCarthy, 2001; WHO, 2005; Kirilenko and Sedjo, 2007). We cannot assess FRA data as a controlled watershed experiment like Bosch and Hewlett (1982). However, FRA data include above and below ground biomass and carbon. Forest soil carbon storage, for instance, could be a good indicator of a development and maturing of a forest ecosystem (Post and Kwon, 2000). FRA 2015 started to provide information about data quality using the tier concept of assessment. We now have foundational information from FRA to assess forest functions, which can lead to implementation of sound forest management. What has happened in the forests of China or Russia where protective forests have increased rapidly? Are the changing directions and strengths in those countries different from changes in Canada where a stable forest management has persisted? Although beyond the scope of this paper, this type of analysis incorporating socio-economic variables in FRA may spur further investigation.

FRA is likely the only and largest database with which we can conduct analysis of the relationships between forest managements and forest functions. We can say that FRA 2015 has succeeded in building a long-term forest database having both socio-economic and environmental aspects. This could be a good start point for a global database for evaluation of the humanities and sciences of the environment. Maintaining and improving this database would contribute immeasurably. Linkage between forestry and social sciences such as environmental economics or behavioral economics would be primarily of importance to utilize FRA data for functional assessment of forest. Devising a sophisticated handling scheme for multiple functions of forest and introducing measurable variables to assess exact functioning of soil and water protection or ecosystem services would provide a breakthrough for sustainable forest management. Improving reliability of reporting through capacity building should be the minimum requirement for future FRA reports. Fostering the database with a long-term strategy is one of the most important missions of the forestry sector.

Acknowledgement

We thank to Kenneth MacDicken and FRA team of Food and Agriculture Organization of the United Nations (FAO) to provide us an opportunity to analyze FRA 2015 data. This paper is a voluntary work of all authors.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foreco.2015.03.039.

References

Aust, W.M., Blinn, C.R., 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: an overview of water quality and productivity research during the past 20 years (1982–2002). Water Air Soil Pollut. Focus 4, 5–36. http://dx.doi.org/10.1023/B:WAFO.0000012828.33069.f6.
Binkley, D., Fisher, R., 2013. Ecology and Management of Forest Soils, fourth ed. Wiley-Blackwell, Hoboken, 362 pp.
Bosch, J.M., Hewlett, J.D., 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55 (1), 3–23.
Broadhead, J., Leslie, R., 2007. Coastal protection in the aftermath of the Indian Ocean tsunami: what role for forests and trees? In: Proceedings of an FAO Regional Technical Workshop, Khao Lak, Thailand, 28–31 August 2006, FAO, Thailand.
Collaborative Partnership on Forests. SFM and the Multiple Functions of Forests. <http://www.cpfweb.org/32819-045ba23e53cbb67809cef3b724bef9cd0.pdf> (Retrieved 12.11.14).
Costanza, R., d'Arge, R., de Groot, R., Farberparallel, S., Grasso, M., Hannon, B., Limburg£star, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Cubbage, F., Harou, P., Sills, E., 2007. Policy instruments to enhance multi-functional forest management. Forest Policy Econ. 9, 833–851. http://dx.doi.org/10.1016/j.forpol.2006.03.010.
Diaz-Balteiro, L., Romero, C., 2008. Making forestry decisions with multiple criteria: a review and an assessment. For. Ecol. Manage. 255, 3222–3241. http://dx.doi.org/10.1016/j.foreco.2008.01.038.
Dolidon, N., Hofer, T., Jansky, L., Sidle, R., 2009. Watershed and forest management for landlside risk mitigation. In: Sassa, K., Canuti, P. (Eds.), Landslides – Disaster Risk Reduction. Springer, pp. 633–649.
FAO, 1995. Forest Resources Assessment 1990 – Global Synthesis. FAO Forestry Paper 124. Rome, Italy.
FAO, 1997. State of the World's Forests, 1997. Rome, Italy.
FAO, 2000. On Definitions of Forest and Forest Change. FRA Working Paper 33. Rome, Italy. 14 p.
FAO, 2001. Global Forest Resources Assessment 2000 – Main Report. FAO Forestry Paper 140. Rome, Italy. <http://www.fao.org/forestry/site/7949/en/>.
FAO, 2004a. Global Forest Resources Assessment Update 2005. Terms and Definitions. FRA Working Paper 83. Rome, Italy. 34 p.
FAO, 2004b. Payment for Environmental Services in Watersheds. Land and Water Discussion Paper 3. Rome, Italy. 74 p.
FAO, 2006a. Global Forest Resources Assessment 2005 – Progress Towards Sustainable Forest Management. FAO Forestry Paper 147. Rome, Italy. <http://www.fao.org/forestry/fra2005/en/>.
FAO, 2006b. The New Generation of Watershed Management Programmes and Projects. Forestry Paper #150. Rome. 128 p.
FAO, 2007. Why Invest in Watershed Management? Rome. 31 p.
FAO, 2008. Practical Experiences of Compensation Mechanisms for Water Services Provided by Forests in Central America and the Caribbean. National Forest Programme FACILITY. Rome, Italy. 51 p.
FAO, 2010a. Global Forest Resources Assessment 2010. Terms and Definitions. FRA Working Paper 144. Rome, Italy. 27 p.
FAO, 2010b. Global Forest Resources Assessment 2010 – Main Report. FAO Forestry Paper 163. Rome, Italy. <http://www.fao.org/forestry/fra/fra2010/en/>.
FAO, 2012. Terms and Definitions. Forest Resources Assessment Working Paper 180. Rome, Italy. 31 p.
FAO, 2013. Forests and Water – International Momentum and Action. Rome, Italy. 76 p.
FAO, 2014a. Guide for Country Reporting for FRA 2015. On-line FRA 2015 Working Paper. <http://www.fao.org/forestry/fra>. Rome, Italy. 52 p. 5 appendices.
FAO, 2014b. Country Report: Australia. Global Forest Resources Assessment 2015. Rome, Italy. 130 p.
FAO, 2014c. Country Report: Canada. Global Forest Resources Assessment 2015. Rome, Italy. 94 p.
FAO, 2014d. Country Report: China. Global Forest Resources Assessment 2015. Rome, Italy. 111 p.
FAO, 2014e. Country Report: Kenya. Global Forest Resources Assessment 2015. Rome, Italy. 78 p.
FAO, 2014f. Country Report: Russian Federation. Global Forest Resources Assessment 2015. Rome, Italy. 87 p.
FAO and CIFOR, 2005. – Drowning in Fiction or Thriving on Facts? RAP Publication 2005/03. Bangkok. 30 p.
Fu, B., 1989. Soil erosion and its control in the loess plateau of China. Soil Use Manage. 5, 76–82. http://dx.doi.org/10.1111/j.1475-2743.1989.tb00765.x.

Government of Japan, 2002. International Expert Meeting on Forests and Water, Shiga. Proceedings of the meeting. Tokyo. 361 p.
Greenwood, J.R., Norris, J.E., Wint, J., Greenwood, J.R., Norris, J.E., Wint, J., 2004. Assessing the contribution of vegetation to slope stability. Proc. ICE – Geotech. Eng. 157, 199–207. http://dx.doi.org/10.1680/geng.2004.157.4.199.
Hamilton, L.S. 1986. Towards clarifying the appropriate mandate in forestry for watershed rehabilitation and management. East-West Environment and Policy Institute, Reprint No 94, East-West Center, Honolulu. 51 p.
Hamilton, L.S. 2008. Forests and water – a thematic study prepared in the framework of the Global Forest Resources Assessment 2005. Forestry Paper #155. Rome, Italy. 78 p.
Hofer, T., Messerli, B., 2006. Floods in Bangladesh – History, Dynamics and Rethinking the Role of the Himalayas. United Nations University Press, Tokyo, 468 p.
Kammerbauer, J., Ardon, C., 1999. Land use dynamics and landscape change pattern in a typical watershed in the hillside region of central Honduras. Agric. Ecosyst. Environ. 75, 93–100. http://dx.doi.org/10.1016/S0167-8809(99)00071-7.
Keating, M., 1993. The Earth Summit's Agenda for Change – A Plain Language Version of Agenda 21 and the Other Rio Agreements. Published by the Centre for Our Common Future, Geneva, 35 p.
Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J., Grainger, A., Lindquist, E., 2015. Dynamics of Global Forest Area: Results from the FAO Global Forest Resources Assessment 2015. Forest Ecol. Manage. 352, 9–20.
Kirilenko, A.P., Sedjo, R.A., 2007. Climate change impacts on forestry. Proc. Natl. Acad. Sci. U.S.A. 104, 19697–19702. http://dx.doi.org/10.1073/pnas.0701424104.
Kumar, P. (Ed.), 2010. The Economics of Ecosystems and Biodiversity: ecological and economic foundations. UNEP/Earthprint.
MacDicken, K.G., 2015. Global Forest Resources Assessment 2015: What, why and how? Forest Ecol. Manage. 352, 3–8.
McCarthy, J.J. (Ed.), 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
McDonald, G.T., Lane, M.B., 2004. Converging global indicators for sustainable forest management. Forest Policy Econ. 6, 63–70. http://dx.doi.org/10.1016/S1389-9341(02)00101-6.
MCPFE, 2003. State of Europe's Forests 2003. Ministerial Conference on the Protection of Forests in Europe, Liaison Unit, Vienna.
MCPFE, 2011. State of Europe's Forests 2011. Ministerial Conference on the Protection of Forests in Europe, Forest Europe, Liaison Unit, Oslo.
Ministry of Environment, Water and Natural Resources, 2014. Forest Policy, 2014. Ministry of Environment, Water and Natural Resources, Republic of Kenya, 13 p.
Perlin, J., 1989. A Forest Journey: The Role of Wood in the Development of Civilization. W.W. Norton & Company, New York, p. 445.
Post, W.M., Kwon, K.C., 2000. Soil carbon sequestration and land-use change: processes and potential. Glob. Change Biol. 6, 317–327. http://dx.doi.org/10.1046/j.1365-2486.2000.00308.x.
Postel, S.L., Thompson, B.H., 2005. Watershed protection: capturing the benefits of nature's water supply services. Natl. Resour. Forum 29, 98–108. http://dx.doi.org/10.1111/j.1477-8947.2005.00119.x.
Raison, R.J., Flinn, D.W., Brown, A.G., 2001. Application of criteria and indicators to support sustainable forest management: some key issues. In: 'Criteria and Indicators for Sustainable Forest Management'. IUFRO Research Series No. 7, CABI, Wallingford, pp. 5–18. doi: http://dx.doi.org/10.1079/9780851993928.0005.
Rametsteiner, E., Simula, M., 2003. Forest certification—an instrument to promote sustainable forest management? J. Environ. Manage. 67, 87–98. http://dx.doi.org/10.1016/S0301-4797(02)00191-3.
REDD Research and Development Center, 2012. REDD-plus cookbook – How to measure and monitor forest carbon. In: Hirata, Y., Takao, G., Sato, T., Toriyama, J. (Eds.), Forestry and Forest Products Research Institute, Japan, 151pp.
Reubens, B., Poesen, J., Danjon, F., Geudens, G., Muys, B., 2007. The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review. Trees 21, 385–402. http://dx.doi.org/10.1007/s00468-007-0132-4.
SOFR (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee), 2013. Australia's State of the Forests Report. Canberra: ABARES; 2013. <http://www.daff.gov.au/ABARES/forestsaustralia/Documents/sofr2013-web2.pdf> (accessed 23.07.14).
State Forestry Administration, 2013. National Report on Sustainable Forest Management. China Forestry Publishing House, Beijing, China, 232 p.
Turner, M.G., 1989. Landscape ecology: the effect of pattern on process. Annu. Rev. Ecol. Syst. 20, 171–197. http://dx.doi.org/10.1146/annurev.es.20.110189.001131.
van Kooten, G.C., Nelson, H.W., Vertinsky, I., 2005. Certification of sustainable forest management practices: a global perspective on why countries certify. Forest Policy Econ. 7, 857–867. http://dx.doi.org/10.1016/j.forpol.2004.04.003.
Wang, X.M., Zhang, C.X., Hasi, E., Dong, Z.B., 2010. Has the Three Norths Forest Shelterbelt Program solved the desertification and dust storm problems in arid and semiarid China? J. Arid Environ. 74, 13–22. http://dx.doi.org/10.1016/j.jaridenv.2009.08.001.
Wenhua, L., 2004. Degradation and restoration of forest ecosystems in China. For. Ecol. Manage. 201, 33–41. http://dx.doi.org/10.1016/j.foreco.2004.06.010.
WHO, 2005. Ecosystems and human well-being: Health Synthesis. Island Press, Washington, DC.
Yu, K., Li, D., Li, N., 2006. The evolution of greenways in China. Landsc. Urban Plann. 76, 223–239. http://dx.doi.org/10.1016/j.landurbplan.2004.09.034.