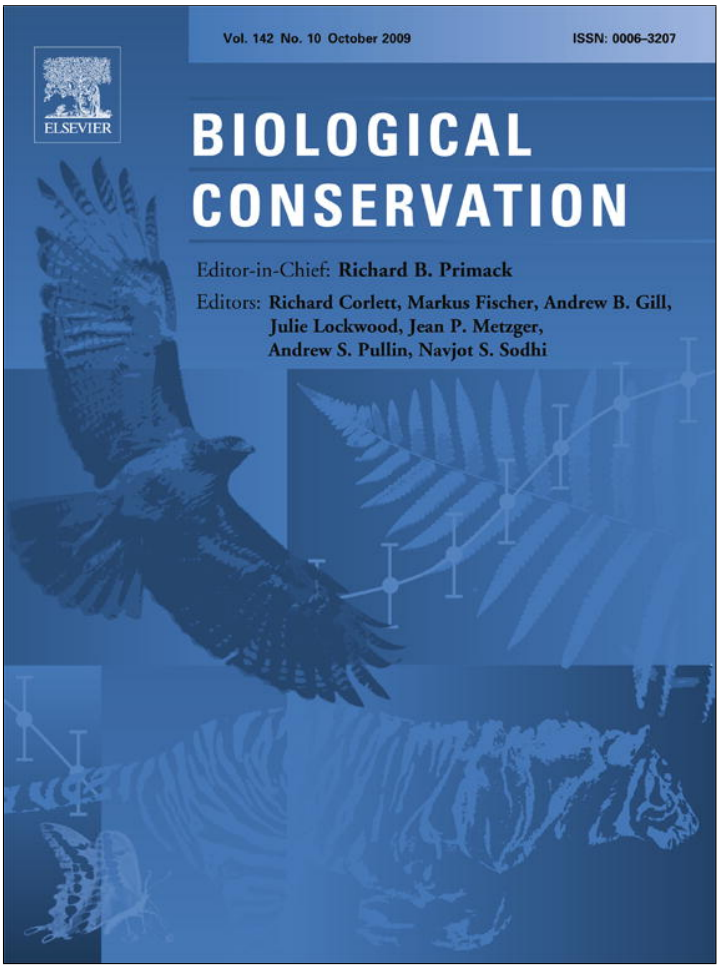

Biological Conservation 142 (2009) 2122–2130

Contents lists available at ScienceDirect

Biological Conservation

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

Global analysis of the protection status of the world's forests

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ARTICLE INFO

Article history:
Received 19 December 2008
Received in revised form 2 April 2009
Accepted 21 April 2009
Available online 19 May 2009

Keywords:
Conservation priorities
Convention on Biological Diversity
Global Forest Map
Global forest types
IUCN management categories
WWF ecoregions

ABSTRACT

This study presents a global analysis of forest cover and forest protection. An updated Global Forest Map (using MODIS2005) provided a current assessment of forest cover within 20 natural forest types. This map was overlaid onto WWF realms and ecoregions to gain additional biogeographic information on forest distribution. Using the 2008 World Database on Protected Areas, percentage forest cover protection was calculated globally, within forest types, realms and ecoregions, and within selected areas of global conservation importance. At the 10% tree cover threshold, global forest cover was 39 million km^2. Of this, 7.7% fell within protected areas under IUCN management categories I–IV. With the inclusion of IUCN categories V and VI, the level of global forest protection increased to 13.5%. Percentage forest protection (IUCN I–IV) varied greatly between realms from 5.5% (Palearctic) to 13.4% (Australasia), and for forest types from 3.2% (temperate freshwater swamp forest) to 28% (temperate broadleaf evergreen forest). Median protection of forest cover in 670 ecoregions (forest above a specified threshold) was 5.9% (IUCN I–IV); at IUCN I–VI, 46% of the ecoregions had less than 10% forest protection. Considering their biodiversity importance, forest protection within global priority areas was insufficient, e.g., median protection of 8.4% in biodiversity hotspots (IUCN I–IV). Results have policy relevance in terms of the target of the Convention on Biological Diversity (CBD), reconfirmed in 2008, to effectively conserve "*at least 10% of each of the world's forest types*". Regular updates of these analyses would allow progress towards achieving that target to be monitored.

1. Introduction

Forests contain high levels of biodiversity, with tropical forests being particularly important in terms of both species richness and their concentration of endemic species (Mittermeier et al., 1998, 2003; Kier et al., 2005; Brooks et al., 2006). The world's forests are also globally important carbon pools and provide a wide variety of other ecosystem services, such as protection of fisheries, watersheds and soils (Millennium Ecosystem Assessment, 2005; Gullison et al., 2007). In particular, forests constitute a vital source of raw materials, both for industry and for rural communities that depend on forest products to meet basic livelihood needs.

Approximately 30% of the global land area is currently forested. At present, more than one-third of all forests are considered primary, but approximately 60,000 km^2 of this primary forest is lost

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doi:10.1016/j.biocon.2009.04.012

or modified every year (FAO, 2006). Globally the annual loss of all types of forest cover was about 130,000 km^2 per year between 2000 and 2005, almost half of which was offset by activities like afforestation, reforestation and revegetation (FAO, 2006). Based on national estimates the accuracy of the FAO data may vary from region to region (Achard et al., 2002; Stibig et al., 2004; Grainger, 2008; Hansen et al., 2008; Potapov et al., 2008; Steininger et al., 2008); however, it is indisputable that the current deforestation rates threaten the biological diversity of forests around the globe, and jeopardise the continued supply of ecosystem services they provide (Brook et al., 2003; Fearnside, 2005; Millennium Ecosystem Assessment, 2005; FAO, 2006).

The Convention on Biological Diversity (CBD), which has 191 Parties and is thus the most important global agreement on the conservation and sustainable use of biological diversity, considers protected areas as cornerstones of biodiversity conservation (CBD, 2009). In response to the rapidly progressing forest loss and in view of the high biological value of this habitat, the CBD has called for Parties to "*assess the representativeness of protected areas relative to forest types*" and to "*establish biologically and geographically representative networks of protected areas*" (2002 expanded Programme of Work on Forest Biodiversity, decision VI/22). In addition, the 2006 framework for monitoring implementation of the achievement of the 2010 target states that "*at least 10% of each of the world's forest types*" should be effectively conserved (decision VIII/15). In 2008, the 10% protection target for the world's forest types was reconfirmed by the 9th Conference of the Parties to the CBD (decision IX/5).

Internationally recognised political targets constitute an important basis to develop indicators for monitoring and evaluating global conservation efforts and are crucial in guiding conservation policies worldwide (United Nations, 2003; SCBD, 2006); however, they have the danger of being arbitrary and too simplistic. For instance, the 10% protection threshold is not necessarily based on biological evidence and therefore needs to be regarded with caution from an ecological point of view (Soulé and Sanjayan, 1998; Rodrigues and Gaston, 2001; Svancara et al., 2005). Achievement of this target has to be discussed in view of ecological gap analyses, which evaluate if protected areas represent important biodiversity elements at different geographic scales and can provide valuable guidance on the optimal location of protected areas (Rodrigues et al., 2004a,b; Hoekstra et al., 2005; Dudley and Parish, 2006).

This paper presents an up-to-date assessment of the protected area coverage of the world's forests against which the usefulness of the CBD's 10% target can be discussed. The ecological validity of such an assessment strongly depends on the geographic resolution and definition of the global forest types. We used the 20 major forest types of the world, which are represented in the 2000 Global Forest Map (GFM) (UNEP-WCMC, 2000), and updated the global forest cover using MODIS 2005 (Hansen et al., 2006). The 20 major forest types are rather general units (e.g., broadleaf evergreen forest) and can only provide limited information on variations in species diversity and levels of endemism across different biogeographic regions of the world. For this reason, we combined the updated GFM with the WWF ecoregions framework to assess the biological representativeness of the world's forest protected areas. The WWF framework is the most detailed biogeographic classification system at the global level. It distinguishes eight biogeographic realms and 825 terrestrial ecoregions, which were mapped using recognised global biogeographic maps, published regional classification systems and expert consultations (Olson et al., 2001). The WWF ecoregions framework is widely accepted and is often used in biodiversity analyses (Sanderson et al., 2002; Mittermeier et al., 2003, 2004; Magin and Chape, 2004; Hoekstra et al., 2005).

Specifically, this paper explores three main issues related to global forest conservation.

Firstly, it presents an update of the 2000 version of the GFM (UNEP-WCMC, 2000), which provides a recent assessment of global forest cover. The updated GFM is overlaid onto the WWF terrestrial ecoregions dataset to obtain information on forest coverage by ecoregion. Secondly, it assesses global forest protection of each of the world's major forest types, and of forest cover within biogeographic realms and ecoregions, using the 2008 version of the UNEP World Conservation Monitoring Centre (WCMC) World Database on Protected Areas (WDPA). This global overlay analysis measures the degree to which protected areas worldwide provide representative coverage of the GFM forest types and of biogeographically distinct forest ecosystems in WWF realms and ecoregions. Protected area coverage of forests in selected areas of high conservation value are assessed in more detail, i.e., WWF Global 200 ecoregions (Olson and Dinerstein, 2002), Conservation International biodiversity hotspots (Mittermeier et al., 2004) and high biodiversity wilderness areas (Mittermeier et al., 2003).

2. Methods

2.1. Updated Global Forest Map

The 2000 version of the Global Forest Map (GFM) (UNEP-WCMC, 2000) was updated to provide a more recent assessment of global forest cover. This updating process used the 2005 satellite-derived 500 m resolution MODIS Vegetation Continuous Fields Dataset (MODIS05 VCF) (Hansen et al., 2006), and the Global Land Cover 2000 dataset (GLC 2000) produced by the European Commission Joint Research Centre (Bartholomé and Belward, 2005). MODIS05 VCF is the most up-to-date dataset on tree cover globally but includes many areas of woody land cover other than natural forests, especially in the lower tree cover classes. Many of these areas, such as tree plantations, shrublands and some types of agro-ecosystems, were identified and excluded from the updated GFM using the GLC 2000 data. Thus, the updated GFM is primarily a map of relatively natural forest cover.

Since the MODIS data contain information on the percentage tree cover for every pixel, the global forest area can be estimated at different tree cover thresholds. For the following analyses, we defined forest as pixels with more than 10% tree cover, in order to match the tree cover threshold used by the UN Food and Agriculture Organization (FAO) in their Forest Resource Assessment (FRA) products (FAO, 2006) (for limitations related to the 10% tree cover threshold, see Section 4).

2.2. Forest cover within WWF realms and ecoregions

WWF has identified 825 terrestrial ecoregions globally, within 14 major biomes and eight biogeographic realms (seven containing forest), based largely on the biogeographic zones of Pielou (1979), Udvardy (1975) and (White, 1983). The WWF realms recognise large scale biogeographic differences in the distribution of species across the globe (see Fig. 2), and the ecoregions are defined as "large units of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (Olson et al., 2001). The ecoregion delineation is based on the distribution of vertebrate diversity and upon vegetation cover as it would have been 500 years ago, distinguishing 'forest' and 'non-forest' biomes and ecoregions. In order to obtain the current amount of forest area by realm and terrestrial ecoregion, the updated GFM was overlaid onto the WWF ecoregions dataset.

2.3. Protected area data

Protected area data were obtained from the February 2008 version of the UNEP-WCMC World Database on Protected Areas (WDPA), which is the most comprehensive database of protected areas globally holding spatial and attribute information for 102,290 nationally protected sites (http://www.wdpa.org; Chape et al., 2008). For sites where the WDPA contained location and area data, but did not have an actual polygon for the extent of the site, a circular buffer was created around the central point of the appropriate area in hectares. Only nationally designated sites were used in this analysis.

The International Union for Conservation of Nature (IUCN) has defined six protected area management categories (IUCN, 1994; Dudley, 2008), which reflect the conservation management objectives of the protected area. The WDPA stores information on the IUCN management category of each protected area, where this is known. Of the 102,290 national protected areas in the WDPA, 30,685 had no IUCN management category assigned and these were excluded from this analysis. For the remaining 71,605 protected areas, we used the IUCN category to create two sub-divisions of the database: The first sub-division included protected areas with IUCN management categories I–IV, which are typically more restrictive of extraction of natural resources and land use change. The second sub-division included all protected areas with IUCN management categories. With the inclusion of categories V and VI, the second set also considers protected areas that are designated for multiple-use management of forest resources (for limitations of the WDPA, see Section 4).

2.4. Global gap analysis for forest and protected areas

Firstly, the two sub-divisions of the WDPA (see above) were overlaid onto the updated GFM to calculate the level of protection of global forest cover and the different forest types. Secondly, the two sub-divisions of the WDPA and the updated GFM were overlaid onto WWF realms and to determine the amount of forest protected within these biogeographic units of land. Finally, the level of forest protection was calculated for areas of global conservation value as highlighted by three internationally recognised approaches. These three approaches were selected because they use the same WWF ecoregion boundaries and employ complimentary factors for priority setting, i.e., representativeness, threat and intactness (Schmitt, 2007):

(1) Global 200 ecoregions. WWF's Global 200 is a suite of 238 priority ecoregions that together represent the world's marine, freshwater and terrestrial ecosystems (Olson and Dinerstein, 2002). Of the 142 terrestrial Global 200 ecoregions, several are agglomerations of individual terrestrial ecoregions.
(2) Biodiversity hotspots. Hotspots are defined by Conservation International as regions of the world that contain at least 1500 species of vascular plants (>0.5% of the world's total) as endemics, but also where less than 30% of the natural habitat remains (Mittermeier et al., 2004). Hotspots are generally composed of a combination of several WWF ecoregions.
(3) High biodiversity wilderness areas. These are regions of the world larger than 750,000 km^2 with levels of endemism similar to the biodiversity hotspots, but where 70% of the natural habitat remains (Mittermeier et al., 2003). Their boundaries also follow the geographic boundaries of several amalgamated WWF ecoregions.

The results for each one of these different gap analyses are presented in terms of percentage forest protection under IUCN protected area management categories I–IV and I–VI. Where ecoregions and global priority areas contained less than or equal to 100 km^2 of forest area and/or had less than or equal to 0.1% of forest cover, we did not present data on their percentage of forest protection to avoid these areas appearing as a forested area with high levels of protection, when in reality it was only a small portion of the area that was forested and protected (see Section 3).

2.5. Statistical analysis

Protection of forest cover within the various geographic units is presented as percentages. Average percentage of forest cover protection is calculated as mean and median to account for variability in data distribution; non-normal data requires the use of medians, and using the mean can inaccurately report the distribution of the data. Where medians have been used, the mean has been displayed in brackets, and vice versa.

3. Results

3.1. Global forest cover and GFM forest types

The updated GFM estimates global forest cover as 39.0 million km^2 at the 10% tree cover threshold (28.8% of the global land area excluding lakes, rock and ice). If the 30% tree cover threshold had been selected then the area of forest cover would be reduced to 32.0 million km^2 (23.6% of the global land area) (Fig. 1). All the following results in this paper are produced using the forest cover map derived from the 10% tree cover threshold.

The updated GFM assigns 71% of the world's forest cover (i.e., 27.7 million km^2 of forest area) to one of the 20 forest types defined by the original GFM (Table 1). Furthermore it contains 11.3 million km^2 of unresolved tree cover, i.e., additional forest areas identified by MODIS05 VCF that could not be readily integrated with the existing GFM forest types (for additional information see Schmitt et al., 2009).

3.2. Forest cover within WWF realms and ecoregions

The Palearctic realm contains the largest area of forest (11.8 million km^2), followed by the Neotropics (8.7 million km^2), the Nearctic (7.3 million km^2), and the Afrotropics (6.8 million km^2) (Table 2).

Overlay of the updated GFM with the WWF ecoregion dataset shows that 83 of the 825 terrestrial ecoregions do not contain any forest, and furthermore 72 fall below the threshold of a minimum of 100 km^2 of forest area and/or 0.1% of forest cover, including examples from both the predefined 'forest' and 'non-forest' ecoregions (see Section 2). The median percentage forest cover within the remaining 670 (81%) ecoregions is 35% (mean of 38%) with a large range among ecoregions (inter-quartile range of 51.4; $Q1 = 11.1$, $Q3 = 62.5$). Results for the forest cover and forest protection of individual ecoregions can be found online at http://www.unep-wcmc.org/protected_areas/pubs.htm.

3.3. Protection of global forest cover and GFM forest types

Globally, 7.7% of the total forest area is included in more strictly protected areas (IUCN protected area management categories I–IV) (Table 1). When IUCN categories V and VI are added, this value nearly doubles to 13.5%.

The level of protection varies greatly among the GFM forest types; from 3.2% (temperate freshwater swamp forest) to 28%

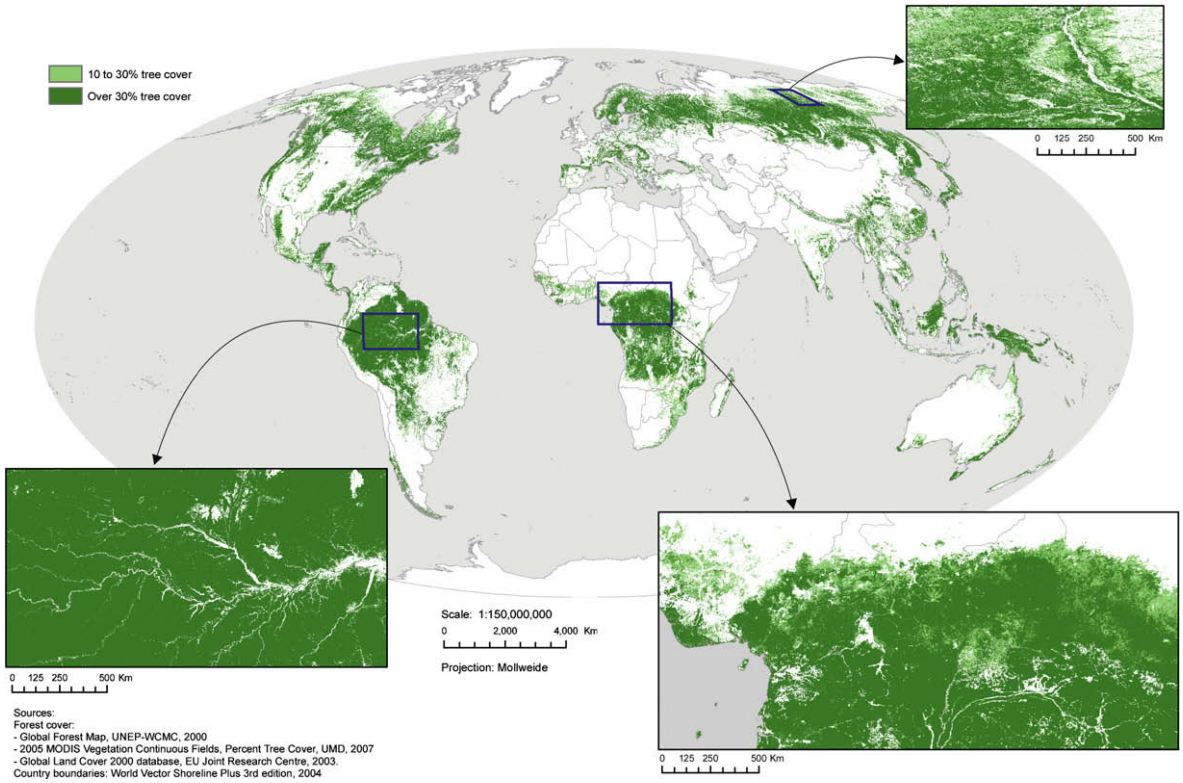

Fig. 1. Global natural forest area at >10% and >30% tree cover as defined by the 2005 MODIS Vegetation Continuous Fields (MODIS05 VCF) and the Global Land Cover 2000 (GLC 2000) datasets, which was used to identify and exclude non-natural forest areas. Analyses in this paper are based on the 10% threshold for tree cover.

Table 1
Area of global forest types (>10% tree cover) as described in the updated Global Forest Map (GFM) and percentage protected under IUCN management categories I–IV and I–VI. Unresolved tree cover comprises a variety of forest types in the Global Land Cover 2000 that could not be assigned a GFM forest type.

Global forest cover and forest types	Forest area ('000 km^2)	% Protected (IUCN I–IV)	% Protected (IUCN I–VI)
Global forest cover	38,998	7.7	13.5
GFM forest types:			
Temperate broadleaf evergreen forest	180	28.0	34.2
Tropical upper montane forest	476	18.2	26.1
Tropical semi-evergreen moist broadleaf forest	843	17.7	26.4
Tropical sclerophyllous dry forest	241	16.0	16.5
Tropical mangrove	119	14.2	20.7
Temperate sclerophyllous dry forest	392	13.1	24.1
Tropical lower montane forest	448	12.7	17.5
Tropical lowland evergreen broadleaf rainforest	6489	10.3	20.8
Tropical thorn forest	10	9.5	22.2
Tropical deciduous/semi-deciduous broadleaf forest	1729	8.9	12.6
Tropical needleleaf forest	32	8.8	13.3
Tropical sparse trees/parkland	1007	8.0	11.0
Temperate evergreen needleleaf forest	6501	7.6	14.1
Tropical freshwater swamp forest	440	6.9	8.6
Temperate sparse trees/parkland	1939	6.1	8.7
Temperate deciduous broadleaf forest	2689	5.7	12.8
Temperate mixed broadleaf/needleleaf forest	1435	4.4	8.5
Temperate deciduous needleleaf forest	2625	4.3	5.8
Tropical mixed needleleaf/broadleaf forest	9	4.3	6.7
Temperate freshwater swamp forest	89	3.2	8.2
Unresolved tree cover	11,305	5.8	10.4
Mean[a] (and median) forest protection per GFM forest type (unresolved cover not included)		10.4 (8.9)	15.9 (13.7)

[a] Percentage data are normally distributed.

(temperate broadleaf evergreen forest) for IUCN categories I–IV. Mean protection across the 20 GFM forest types is 10.4% at IUCN I–IV (median of 8.9%), and many GFM forest types have rather low levels of protection (Table 1).

3.4. Protection of forest within WWF realms and ecoregions

The lowest level of forest protection for IUCN categories I–IV is found in the Palearctic realm (5.5%), which also has the largest area of forest cover (Table 2). Australasia has the highest percentage of strictly protected forest at 13.4% but contains relatively little forest area compared to the other realms. When all protected areas (IUCN I–VI) are considered, all the realms aside from the Afrotropics (9.2%), Palearctic (8.8%) and Oceania (8.2%) have more than 10% of their forest area protected.

The median percentage of forest area that is protected within the selected 670 ecoregions is 5.9% (mean of 10.3%) in IUCN categories I–IV; median percentage protection increases to 11.2%

Table 2
Forest area (>10% tree cover) within WWF realms and percentage protected under IUCN management categories I–IV and I–VI.

Realm	Forest area ('000 km^2)	% Protected (IUCN I–IV)	% Protected (IUCN I–VI)
Palearctic (Bulk of Eurasia and North Africa)	11,793	5.5	8.8
Afrotropics (Sub-Saharan Africa and Madagascar)	6794	6.4	9.2
Nearctic (most of North America)	7293	6.6	15.2
Oceania (Polynesia, Fiji and Micronesia)	6	7.5	8.2
Indo-Malay (South Asian subcontinent and Southeast Asia)	2571	9.9	13.6
Neotropics (South America and the Caribbean)	8748	10.6	21.3
Australasia (Australia and nearby islands)	1783	13.4	14.8
Lakes, Rock and Ice (Areas across all realms)	9	19.6	25.1

Antarctic not included due to absence of forest cover.

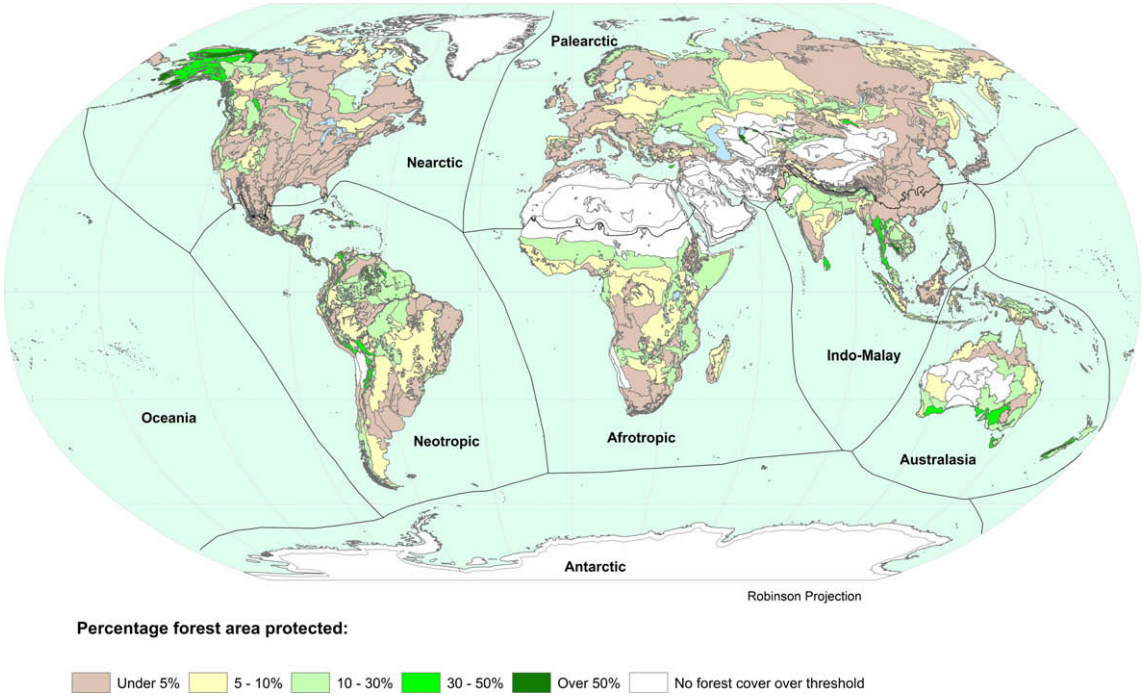

Fig. 2. Distribution of the percentage of protected forest area within WWF ecoregions at IUCN management categories I–IV (forest cover threshold: >100 km^2 of forest area and/or >0.1% of forest cover). The highest levels of protection can be seen in parts of the Amazon, SE Asia and Alaska. It is noteworthy that the ecoregions with high forest protection in the Andes and Australia have below 10% forest cover (see http://www.unep-wcmc.org/protected_areas/pubs.htm). Notable areas of low protection include the Congo basin in Central Africa and Northern boreal forests. Black lines indicate biogeographic realms.

(mean of 17.8%) when all categories of protected area are considered. Individually, 65% of the ecoregions have less than 10% of their forest within IUCN I–IV protected areas. Ecoregions with more than 50% of protected forest cover at IUCN management categories I–IV are found, e.g., in parts of the Amazon, SE Asia and Alaska (Fig. 2). Many of the ecoregions in the Andes and Australia with forest protection between 30% and 50% have only small areas of forest cover (below 10% of the ecoregion; http://www.unep-wcmc.org/protected_areas/pubs.htm).

Even if all protected areas (IUCN categories I–VI) are taken into account, 46% of the ecoregions still have less than 10% of their forest cover protected. Forest cover in North America and Europe is mainly conserved in protected areas with IUCN categories V and VI, while forests in the Amazon, e.g., have a mix of protected areas from all categories (Figs. 2 and 3). The percentage protection of forest areas in Central Africa, the boreal zone and parts of SE Asia remains below 10%, even when all IUCN categories are considered (Fig. 3).

3.5. Protection of global priority areas

3.5.1. WWF Global 200 ecoregions

Of the 142 Global 200 ecoregions, 138 (97.2%) have forest cover, totalling 20.7 million km^2, or 53% of the global forest area. 133 of these contain forest over the threshold of 0.1% forest cover and / or 100 km^2 forest area. The median protection of forest cover within these 133 Global 200 ecoregions is 8.5% (mean of 12.1%) for IUCN management categories I–IV and 12.5% (mean of 18.0%) for all IUCN management categories; 74 (55.6%) have less than 10% of their forest area within IUCN I–IV protected areas (Fig. 4).

3.5.2. Conservation International biodiversity hotspots

All biodiversity hotspots contain forest cover above the selected threshold level. Mean forest cover protection across all hotspots is 10.2% (median of 8.4%) within IUCN I–IV protected areas, but mean protection reaches 15.3% (median of 13.8%) when all categories of protected area are considered (Table 3). Twenty (58.8%) of the 34 hotspots have less than 10% of their forest area within IUCN I–IV protected areas. Forests in the hotspots of Southwest Australia (26%) and New Zealand (40.7%) have high protected area coverage, even within the stricter IUCN categories. At the other end of the scale, data in the WDPA suggest that none of the forest in the Mountains of Southwest China or the East Melanesian Islands is protected. Forest area differs considerably between hotspots, with the largest forest cover in the Sundaland (766,000 km^2), Indo-Burma (742,000 km^2) and Mesoamerica (595,000 km^2) (Table 3).

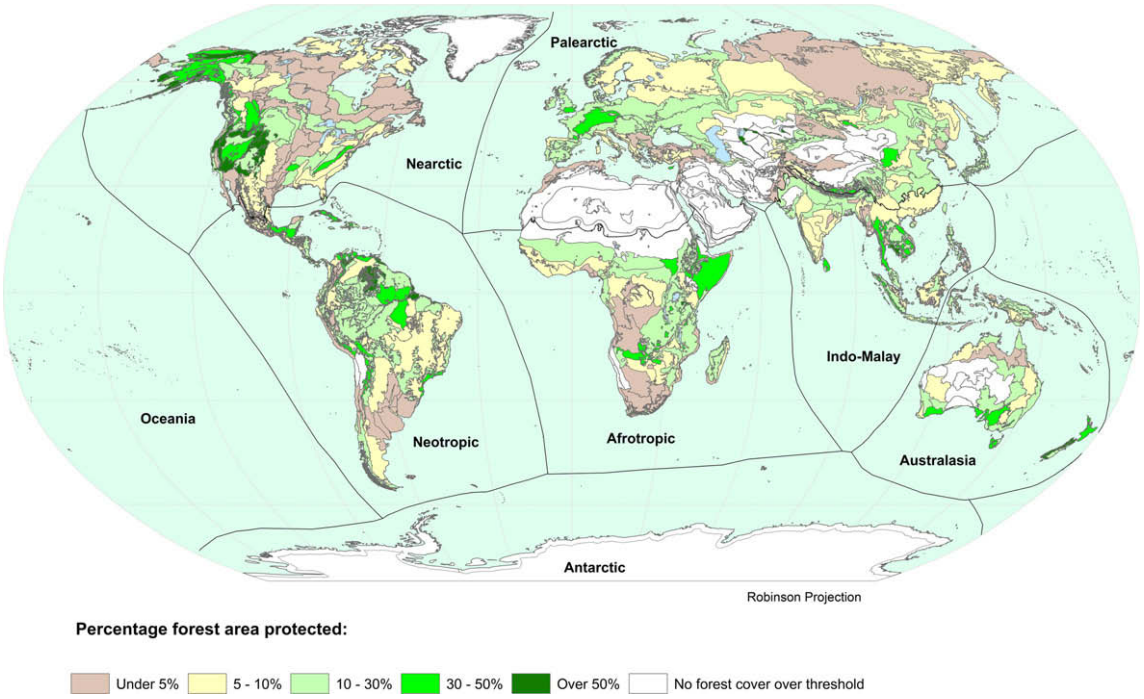

Fig. 3. Distribution of the percentage of protected forest area within WWF ecoregions at IUCN management categories I–VI (forest cover threshold: >100 km^2 of forest area and / or >0.1% of forest cover). Forest cover in North America and Europe is mainly conserved in protected areas with IUCN V and VI, while forests in the Amazon, e.g., have a mix of protected areas from all categories (compare Fig. 2); however, many ecoregions with high levels of protection in North America have forest cover below 10% (see http://www.unep-wcmc.org/protected_areas/pubs.htm). Black lines indicate biogeographic realms.

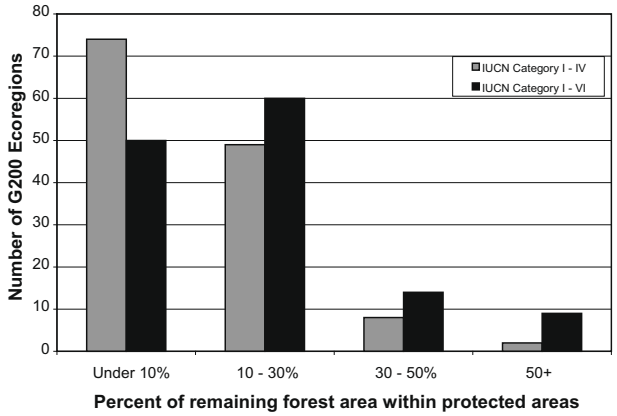

Fig. 4. The number of Global 200 ecoregions with different levels of forest protection at IUCN categories I–IV and I–VI; in total 133 Global 200 ecoregions with forest cover above the threshold of 0.1% forest cover and/or 100 km^2 forest area.

3.5.3. Conservation International high biodiversity wilderness areas

Of the five high biodiversity wilderness areas, the highest protection of forest within more strictly protected areas is within the Miombo-Mopane Woodlands and Savannas (14.1%), followed by Amazonia (11.1%), New Guinea (9.5%), and the Congo Forests (7.2%) (Table 4). The small area of forest within the North American Deserts wilderness area is the least well protected (4.2%). When all protected areas (IUCN I–VI) are considered two of the wilderness areas have more than 20% of their forest area protected; Amazonia (25%) and Miombo-Mopane (20.2%).

4. Discussion

In this paper we have presented a global map of current forest cover, sub-divided into 20 forest types. By overlaying this map with WWF realms and ecoregions and the world's protected areas we have generated statistics on the protected area coverage of the various forest types and biogeographic units. Below, we discuss these results, but also outline some of the caveats in our analysis, which need to be understood when the results are being interpreted.

4.1. Updated Global Forest Map and WWF ecoregions as tools for assessing global forest conservation

The analysis of forest conservation at the global scale is challenging because it requires a globally applicable definition of forest cover and forest types. In this paper we have used a 10% tree cover threshold for forest cover within the MODIS 2005 dataset. This corresponds with the FAO definition of forest cover, and our estimation of 39.0 million km^2 of global forest cover is close to the latest estimate from the FAO, which was 39.5 million km^2 of forest, derived mainly from national scale inventories (FAO, 2006).

One reason for selecting the 10% tree cover threshold was to capture woodland areas in eastern, western and southern Africa, e.g., the miombo and Acacia woodlands, which were not captured using the 30% tree cover threshold in the previous GFM (UNEP-WCMC, 2000). However, it would be possible to re-calculate the forest protection statistics based on different tree cover thresholds. This flexibility makes the updated GFM also useful for analyses in the context of activities under the Kyoto Protocol of the UN Convention on Climate Change (UNFCCC), which allows for individual national forest definitions, with tree cover thresholds from 10% to 30% (Robledo and Blaser, 2008).

Although the updated GFM has a much better resolution and accuracy in the identification of near-natural forest cover than the 2000 GFM, the large amount of unresolved tree cover (Table 1) reduces its utility for tracking protection of forest types. Completing a fully updated GFM, where all forest areas are assigned to a forest type is a significant task, which would involve reviewing

Table 3
Forest area (>10% tree cover) within Conservation International biodiversity hotspots and percentage protected under IUCN management categories I–IV and I–VI.

Biodiversity hotspot	Forest area ('000 km^2)	% Protected (IUCN I–IV)	% Protected (IUCN I–VI)
Mountains of Southwest China	125	0.0	13.8
East Melanesian Islands	72	0.0	0.7
Succulent Karoo	0.1	1.9	1.9
Madrean Pine-Oak Woodlands	281	2.1	6.4
Coastal Forests of Eastern Africa	188	2.2	5.7
Irano-Anatolian	2	2.6	8.0
Japan	244	3.3	15.9
Mediterranean Basin	265	4.2	11.8
New Caledonia	6	4.4	4.4
Maputaland-Pondoland-Albany	124	4.7	4.8
Cerrado	366	5.6	8.7
Guinean Forests of West Africa	223	7.0	7.5
Mesoamerica	595	7.3	16.6
Wallacea	195	7.4	8.6
Polynesia-Micronesia	6	7.5	8.2
Madagascar and the Indian Ocean Islands	129	7.6	9.9
Atlantic Forest	246	7.7	15.9
Sundaland	766	9.0	12.7
Tumbes-Choco-Magdalena	77	9.8	12.0
Eastern Afromontane	295	9.8	13.8
Himalaya	211	10.5	14.8
Cape Floristic Region	15	11.1	11.1
California Floristic Province	155	11.7	50.8
Caucasus	90	12.1	13.8
Philippines	83	12.6	17.6
Indo-Burma	742	14.2	19.2
Horn of Africa	2	15.5	18.4
Caribbean Islands	45	15.6	28.4
Chilean Winter Rainfall and Valdivian Forests	134	17.6	19.6
Mountains of Central Asia	11	17.7	18.4
Western Ghats and Sri Lanka	97	17.8	17.8
Tropical Andes	426	18.3	24.0
Southwest Australia	73	26.0	26.1
New Zealand	76	40.7	54.5
Total forest area within hotspots: 6 364 km^2 Mean[a] (and median) protection of hotspots		10.2 (8.4)	15.3 (13.8)

[a] Percentage data are normally distributed.

Table 4
Forest area (>10% tree cover) within Conservation International high biodiversity wilderness areas and percentage protected under IUCN management categories I–IV and I–VI.

High biodiversity wilderness area	Forest Area ('000 km^2)	% Protected (IUCN I–IV)	% Protected (IUCN I–VI)
North American Deserts	41	4.2	18.7
Congo Forests	1572	7.2	8.4
New Guinea	640	9.5	9.9
Amazonia	5618	11.1	25.0
Miombo-Mopane Woodlands and Savannas	821	14.1	20.2

each area of unresolved tree cover against regional and national forest datasets.

Even if the GFM was fully updated, it does not provide a detailed biogeographic classification, but rather identifies broad forest types at the global scale. It is possible to partly solve this issue by breaking the GFM forest types up according to the WWF biogeographic realms, which do reflect spatial differences in the species composition of forest ecosystems. This approach increases the total number of separate forest units from 20 to 85 resolved GFM forest types, with 8–19 forest types per realm. The area of forest within each forest type within each realm could be easily calculated once the unresolved tree cover has been integrated with the resolved forest types.

However, this exercise would still result in a forest map with a much lower biogeographic resolution than the 670 ecoregions that contain notable amounts of forest cover. As ecoregions were delimited in order to represent specific biogeographic assemblages of plant and vertebrate species (Olson et al., 2001), it is assumed that the greater level of biogeographic resolution afforded by ecoregions – as compared to forest types within realms – will better represent the distribution of forest species across the world. At the same time, ecoregions were not intended for use in vegetation classification, so the ecoregions analysis relied on the updated GFM for information on forest cover. For instance, due to their spatial resolution, ecoregions do not highlight either montane cloud forests or riparian forests. Moreover, a single ecoregion may contain several GFM forest types, especially in the tropical ecoregions. Since the updated GFM is based on the 10% tree cover threshold, which also picks up woodland areas, the predefined 'forest' and 'non-forest' ecoregions were not a useful classification in this analysis.

Our analyses suggest that a combination of the updated GFM and the WWF realms and ecoregions biogeographic framework should be used for assessing progress in global forest conservation. Until the full completion of the updated GFM, ecoregions together with information on global forest cover constitute a suitable surrogate for representing different forest types. Once the updated GFM is fully completed, the GFM forest types could be subdivided by WWF realms to accommodate biogeographic variations at the global level. At a regional scale, the fully resolved GFM forest types could be used for assessing representation of forest protection within each ecoregion.

4.2. The WDPA as source of information on the world's protected areas

The WDPA is the best available database on the global distribution of protected areas (Chape et al., 2008). However, it is well known to contain significant errors for some countries in terms of missing protected areas, inaccurate (or missing) protected area boundaries, and problems with capturing the most updated assessment of the IUCN management categories of individual protected areas (Chape et al., 2005). In particular, 30% of the national protected areas in the 2008 version of the WDPA were lacking an IUCN protected area category. This means, for example, that a large numbers of 'forest reserves', primarily in southeast Asia and Africa were omitted from this analysis because their management objectives were not clear, whereas a number of them are known to function as protected areas on the ground (e.g., Burgess et al., 2007b). In Tanzania, as an example, IUCN protected area categories were recently assigned to 87 forest reserves, covering 6568 km^2 (Burgess et al., 2007a; Marshall et al., 2007). For those regions of the world where this global analysis seems inaccurate we recommend more detailed regional and national scale evaluations that take into account forest reserves and other protected sites in forest habitats that currently do not have any IUCN protected area category assigned.

4.3. Global gaps in forest conservation

Global averages paint quite a bright picture of forest protection, with 13.5% of forest cover protected globally and median protection of forest cover within 670 ecoregions at 11.2%, under all IUCN management categories. However, those figures decline to 7.7% for global forest cover and 5.9% for median forest protection within ecoregions if protected areas with IUCN management categories I–IV are analysed separately. When the global averages are further broken down by individual ecoregions, taking into account the biogeographic differences between forest ecosystems, the results are rather bleak: 65% of the 670 ecoregions with forest have less than

10% of their forest cover protected at IUCN I–IV (Fig. 2). There are many ecoregions with large areas of unprotected forest cover, even in the realms that have good overall protection (Table 2) and many of those ecoregions are recognised global conservation priorities. With a median protection of forest cover at 8.5% within Global 200 ecoregions (Fig. 4) and 8.4% in biodiversity hotspots (Table 3), forests in areas of high biodiversity importance are not much better protected than overall forest cover at IUCN I–IV. This also holds true for high biodiversity wilderness areas (Table 4).

These results clearly show that global averages can mask conservation deficiencies at the regional scale and underline the importance of a multi-layered biogeographic framework when monitoring the global status of forest protection. However, it needs to be underlined that this analysis cannot indicate whether a protected area contributes effectively to forest biodiversity conservation on the ground. Pending the completion of a global databank for protected area management effectiveness scores (UNEP-WCMC and IUCN, 2008), this paper had to rely on solely on IUCN categories to differentiate between protected areas.

4.4. Assessment of global forest conservation and the CBD 10% target

Our analyses show that there remain serious gaps in forest protection worldwide with respect to achieving the CBD 10% protection target for each of the global forest types. While some large tracts of remote forests, especially in boreal regions, may persist without immediate protection, forest areas in more densely populated regions of the world require conservation attention, probably in the form of protected or at least sustainably managed forest areas.

An important feature of the CBD 10% target is the principle of representativeness, because it assigns conservation value to all ecologically distinct forest types, including species-rich tropical forests, vast boreal forests as well as forest remnants in industrialised countries. As a simplistic indicator, however, the arbitrary 10% target does not account for the actual distribution of biodiversity within forests (Rodrigues and Gaston, 2001; Svancara et al., 2005). Species based gap analysis (Rodrigues et al., 2004b) and regional work on designing representative protected area networks (Cowling et al., 1999, 2003) suggest that protecting 10% of the remaining forest will not be adequate to conserve the biodiversity that these forests contain.

This holds true especially for the regions that are globally recognised priorities for biodiversity conservation. For instance, the main feature of high biodiversity wilderness areas is their vast size, and conservation of just 10% of those areas may thus not be an adequate target. Protection of large high-biodiversity tropical forest areas is also important for the mitigation of global climate change (Mittermeier et al., 2003; Saatchi et al., 2007). The same holds true for the vast under-protected boreal forest ecosystems, which belong to the last intact forest landscapes globally (Bryant et al., 1997; Sanderson et al., 2002). In addition, the forests within biodiversity hotspots generally appear seriously under-protected given their global biological importance, in particular for endemic and threatened species (Brooks et al., 2002). Since biodiversity hotspots have already lost a significant proportion of their forested area, the 10% target equates to only a small proportion of the original forest area being protected.

Yet, from a political perspective it will be difficult for the CBD to assign specific conservation targets to different forest ecosystems or countries. It is important to keep in mind that the 10% figure is a politically motivated target, and a compromise achieved by the CBD parties during long negotiations. Notwithstanding the value of such a quantitative target at the global level, it should not distract from the fact that countries or regions need to develop forest conservation targets tailored to their particular ecological setting (Svancara et al., 2005). This can be achieved by systematic conservation planning at a regional scale, a process which considers the detailed distribution patterns of biodiversity within forests, the socio-economic situation in the concerned region and the conservation effectiveness of existing protected areas (Margules and Pressey, 2000; Dudley and Parish, 2006; Langhammer et al., 2007).

Another important issue is the need to define the reference year against which future changes in forest cover and levels of protection should be measured. This reference year is necessary otherwise a decline in forest cover outside protected areas over time would automatically result in an increase of protected forest area (Mulongoy and Chape, 2004). The present analysis uses 2005 forest coverage data, which are the most recent available, and were collected just prior to the adoption of the CBD 10% target for forest protection in 2006. Hence, the data in this paper might be adopted as a suitable baseline reference point for the purposes of the CBD.

5. Conclusions

We developed a systematic and flexible global framework based on forest cover, forest type and biogeographic pattern, against which targets of forest protection and representativeness can be assessed. As the most up-to-date assessment of the protection status of the world's forest globally, our analyses show that there are still large numbers of forest areas with very low levels of protection in the tropics as well as in the temperate and boreal zones, especially if only the more strictly protected areas (IUCN categories I–IV) are considered. These results can be used as an indication of the egions of the world where further investigation of the adequacy of forest conservation measures is urgently needed. Regular updates of these analyses would constitute an important contribution to forest conservation monitoring at the global level and can provide guidance to international and national conservation policy.

Acknowledgements

We thank the German Federal Agency for Nature Protection (BfN) for supporting the majority of this work with funds from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU); thanks also to WWF International for additional funding and to Conservation International for permission to use their GIS layers for High Biodiversity Wilderness Areas and Biodiversity Hotspots.

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