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A Global Conservation Assessment of Temperate Forests: Status and Protection

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A GLOBAL CONSERVATION ASSESSMENT OF TEMPERATE FORESTS: STATUS AND PROTECTION

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ABSTRACT

Global biodiversity protection requires the development of protected areas that include representative samples of different ecosystems and their associated biodiversity (Dudley 1992, Scott et al. 2001a). I compared long-term decline and protection of forests in three major biomes; boreal, temperate and tropical. I found that forests in the temperate biome are less abundant and less protected than forests in the boreal and tropical biomes. I conducted regional analyses for five continents on the degree of protection of temperate forests across naturally occurring geographic and elevational ranges. My results indicate that protected temperate forests do not represent the full geographic and elevational range of naturally occurring temperate forests. Bias in location, elevation and slope of protected areas are present at both the regional and global scale. Better protection of temperate forests is needed if the diversity and resources associated with these forests types across their geographic range is to be preserved.

INTRODUCTION

One of the most dramatic global changes in the 21st century has been deforestation (Cassel-Gintz and Petschel-Held 2000, Skole and Tucker 1993). Since the end of the last ice age, about half of the earth's forests were lost to human activities (Rosen and Roberts. 2000, Bryant et al. 1997). Of the remaining forests, 60% are highly disturbed, fragmented or degraded, and can no longer support their indigenous plants and animals without careful management and intervention (Bryant et al. 1997).

Much of the attention over the last decades has been placed on the dramatic declines in tropical forests, despite the fact that temperate forests may have declined more in recent centuries and may be more threatened than any other forest ecosystem. Temperate forests simply were the first to be cleared (Bryant et al. 1997), and may be the most degraded, because many areas with high human densities historically occurred in temperate regions (Williams 2003). The large forests in Europe were cleared by the Middle Ages, for agriculture, or by intensive harvests for fuel wood and building material (Bryant et al. 1997, Williams 2003). As early as the late 1500s, cities in England and the Netherlands were experiencing timber shortages (Williams 2003). Temperate forests have also declined as pollution in the form of acid rain has degraded the integrity of forest ecosystems in Europe, North America and China (Dudley 1992).

It seems intuitive that temperate forests would have been reduced at significantly higher rates than other forests considering a) the longer time spans of human use; b) the greater density of human populations in temperate zones, historically; c) the faster and greater industrialization of many countries in the temperate region; and d) the high potential for agriculture that soils in lowland temperate regions represent. However, the degree to which temperate forests have been reduced as well as the value of the remaining temperate forest lands for global biodiversity protection have been poorly documented. In addition, current global biodiversity strategies such as Conservation International's hotspot analysis seem to be based on the assumption that tropical forest ecosystems have declined faster and more dramatically than any other forest ecosystem.

Several authors have suggested that global forest protection is strongly biased across biomes (Pressey 1994), and that temperate forests are less protected than tropical forests (Dudley 1992). Tropical forests--rainforests in particular--have been the focus of many international conservation efforts (Redford et al. 1990), and receive more attention from conservationists than temperate forests (Dudley 1992). For example, publications on biodiversity often focus solely on the tropical region, such as The World Conservation Monitoring Center's (WCMC) publication on Global Biodiversity (Groombridge 1992). There are at least 50 articles on tropical deforestation research per year (Rudel et al. 2000), while the state of non-tropical forests has been neglected (Dudley 1992). As a result, several authors maintain that temperate forests are among the least protected and also the most threatened forest ecosystems (Bryant et al. 1997, Dudley 1992).

To date, there have been no global forest assessments that have specifically compared long-term forest decline and protection across boreal, temperate and tropical biomes, or assessed the adequacy of temperate forest protection for the preservation of global biodiversity. These trends need to be researched and documented on a global or continental scale to determine overall patterns and identify potential biases in forest protection that may negatively affect global biodiversity conservation.

Of equal concern are continental biases in the protection of the few remaining temperate forests. To ensure long-term survival of a representative sample of the natural biodiversity in temperate forests, variation in species distribution along geographic and elevational gradients needs to be considered. It is unlikely that currently protected temperate forest areas provide a large enough sample of temperate forest biota to assure that the full range of temperate forest biodiversity will be preserved into the future.

Existing research indicates that forest protection is often biased towards areas of temperate forest that are of less value to agricultural societies. Protected areas are often established on higher elevation land (Awimbo et al. 1996) of little commercial value (Norton 1999, Scott et al. 2001a, Pressey 1994, 1995, Dudley 1992, Shands and Healy 1977). Elevation and slope bias in protected areas has been reported in parts of Australia (Pressey and Tully 1994, Pressey 1995), Africa (Rebelo 1992, Pressey 1994,), and North America (Scott et al. 2001a, Shands and Healy 1977). This may also be true for the few areas protecting temperate forests and may further exacerbate the neglect of temperate forest ecosystems.

The protection of biodiversity at different spatial scales (global, continental regional, etc) and along different spatial gradients (geographic, elevation, slope, etc.) is an enormous task. A large-scale approach based on representation of ecosystems or biomes is an efficient and first step approach to the problem of preserving temperate biodiversity globally

Several studies have used geographic location or elevation gradients in protected areas to assess representation of an ecosystem or communities within the protected area system of a region (Scott et al. 2001b, Awimbo et al., 1996, Hunter and Yonzon 1993), but this has not been done for temperate forests globally.

Global biodiversity protection required the development of protected area networks which include representative samples of different ecosystems and their associated biodiversity (Dudley 1992, Scott et al. 2001a). This research will demonstrate how patterns in temperate forest decline are not balanced by attempts at conservation and protection of temperate ecosystems. My study will also investigate whether current temperate forest protection at global and continental scales provide adequate representation of temperate forest ecosystems. The results from this study will be useful for further policy research on the factors that lead to these patterns in forest decline and protection and how they can be mitigated in the future. However, deforestation patterns and trends in protected area locations are the result of many complex cultural, political, and economic factors. It would be beyond the scope of this study to attempt the analysis and quantification of these cultural and socio-economic factors.

I used several broad-scale data sets and Geographic Information System (GIS) technology to answer the following research questions:

i) Did deforestation in past centuries differ among major global biomes—the boreal, temperate, and tropics?

ii) How much of the boreal, temperate and tropical forest is remaining?

iii) What is the degree of protection in these biomes, relative to the degree of threat?

iv) Are protected areas evenly distributed across the geographic range of current temperate forests?

v) Is protection biased toward higher elevation and steeper slopes?

LITERATURE REVIEW

Global Forest Protection

Political changes, technological advances, and population explosion in the second half of the twentieth century have resulted in severe increases in deforestation and environmental degradation (Williams 2003). Concerns over biodiversity loss and global climate change have brought much attention to global forest decline, especially in the tropics (Dudley 1992, Olsen et al. 2000, Olsen and Dinerstein 1998). Few global analyses of forest protection have been conducted. None have focused on temperate forest. Reports on global forest protection include the following;

- The Frontier Forest Initiative by World Resources Institute (WRI) assessed long term decline, and quality of current forest cover, and protection. This report included percent of Frontier Forest in each biome, but did not report on decline or protection across biomes. In this study biomes were determined by different individual experts for each forest tract (Bryant et al. 1997).
- The Food and Agriculture Organization of the United Nations (FAO) conducted a Global Forest Resources Assessment (FAO 2001), that included remaining forest by biome, but did not report on forest protection

by biome. This report was based on statistics provided by each country, and was not spatially referenced.

- McNeely et al. (1994) published a Regional Review of Protected Areas. The thirteen regions were defined by Udvardy's biogeographical realms, then modified by political boundaries. Number of protected areas, levels of protection as described by IUCN categories, total area protected, and protected area issues were examined for each region. Protected area coverage in each of Udvardy's fourteen biome types was also reported. Temperate broadleaf and temperate needle-leaf forests/woodlands are reported to have only 3.1 and 3.2 percent protection, the lowest of all the biome types, except for temperate grasslands (0.8%) and lake systems (1.3%). Long-term loss within each biome type, elevation, and geographic range of protected areas were not considered.

Focus on Tropical Forests

Much of the conservation effort to date has focused on the tropics (Dudley 1992, Olsen et al. 2000, Olsen and Dinerstein 1998). This is likely because of the increase in tropical deforestation in the last few decades and the higher biodiversity of the tropics (Williams 2003).

Forests in general tend have higher levels of biodiversity than do other environments. Roughly 50% of the earth's diversity can be found in tropical forests (Wilson 1985). However, forests in other biomes are unique and contribute significantly not only to species diversity but also to diversity of ecological processes—such as the

large migration phenomena observed in the boreal zones—and to major biochemical global cycles.

E.O.Wilson (1992) defined biodiversity as:

> The variety of organisms considered at all levels, from genetic variants belonging to the same species through arrays of species to arrays of genera, families, and still higher taxonomic levels; includes the variety of ecosystems, which comprise both the communities of organisms within particular habitats and the physical conditions under which they live, the communities of organisms within particular habitats and the physical conditions under which they live.

Biodiversity includes all levels of organization, and therefore the representation of biodiversity must also be carried out at all levels from ecosystem diversity at a global scale to genetic diversity within species.

Recent discussions of the most effective approaches to the creation of protected area networks favor strategies that assure biodiversity representation over solely capturing the areas with the highest biodiversity (Olsen et al. 2000, Olsen and Dinerstein 1998, Awimbo et al. 1996, Nilsson and Gotmark 1992, Bedward et al. 1992). The inclusion of representative examples of all biodiversity elements is equally or more important than identifying the areas with the highest biodiversity levels (Olsen et al. 2000, Olsen and Dinerstein 1998, Awimbo et al. 1996, Nilsson and Gotmark 1992, Bedward et al. 1992).

This represents a major change from previous approaches, which capitalized on biodiversity hotspots, or from umbrella species approaches, that based protected area

network design on the needs of one or several charismatic species (Franklin 1993, Sisk et al. 1994). Biodiversity hotspot and umbrella species conservation strategies sometimes lack the scale and scope necessary to preserve biological diversity, because:

- They are based on existing knowledge of biodiversity. These data may be inadequate since not all species may have been described (Wilson 1985), and because biodiversity hotspots for some taxa may go unnoticed and unprotected.
- Data on species and biodiversity distribution varies in quality among localities or countries (Ceballos and Brown 1995, Sisk et al. 1994).
- Larger, popular mammals account for most animals on endangered lists, but the majority of animals that have recently gone extinct are smaller, less conspicuous species like rodents, and bats (Ceballos and Brown 1995). Ceballos and Brown (1995) suggest that these smaller species aren't less threatened, only less charismatic, less known, and therefore less likely to make the endangered species list. McKinney (1999) found extinction rates and threat higher in understudied taxa such as insects, and other invertebrates.
- These approaches often ignore ecological processes such as migratory behavior of some of the target taxa (Olsen et al. 2000).
- Biodiversity levels are usually approximated by using selected target taxa. The choice of taxa may significantly bias the selection of future protected areas (Pendergast et al. 1993). For example, biodiversity

hotspots for three groups of animal and plant species in Britain did not coincide (Pendergast et al. 1993).

- The distribution of rare taxa, of special concern to the preservation of biodiversity, often also do not coincide (Pendergast et al. 1993).
- Management for the benefit/protection of one species can threaten another (Scott et al. 1987).
- Protected areas for plant species are often different in size and location than areas needed to represent the diversity of animals (Saetersdal et al. 1993),

In most places there is not enough information on biodiversity to design a protected area network that assures adequate protection of all biodiversity. All forests provide highly valuable ecosystem services such as nutrient cycling, air and water filtration, soil stabilization, and microclimate regulation (Dudley 1992, WRI 2000, Hocker 1979). To preserve the earth's biodiversity, protected area networks should be designed to include and represent all levels and forms of diversity, including the 50% in the non-tropical world (Olson and Dinerstein 1998). Focusing on representing all physical environments in protected areas may be the most effective, and practical approach to preserving biodiversity (Hunter et al. 1988; Olson and Dinerstein 1998).

Geographic Conditions and Representation

Several authors have suggested that since long-term survival of species depends on availability of suitable habitat, representing all physical environments in protected areas is a more effective, and more practical, approach (Hunter et al. 1988). The following

studies at the national level have analyzed the degree of representation by protected areas using various geographic and climatic parameters.

- Crumpacker et al. (1988), assessed representation in the United States according to Küchler potential natural vegetation types.
- Nilsson and Götmark (1992) in Sweden measured representation by landscape type and habitat type.
- Powell et al. (2000) analyzed representation in Costa Rica's protected areas using Holdridge Life zones and the gap analysis approach.
- Scott et al. (2001a) investigated distribution of protected areas in the United States by elevation and soil productivity.
- Pressey (1995) used a combination of slope, fertility, rainfall and temperature to describe the environment and distribution of protected areas in New South Wales.
- Hunter and Yonzon (1993) studied the altitudinal distribution of forests and animals in relation to parks, in Nepal.

Scott et al. (1993) used remote sensing techniques and G I S to identify gaps in the protection of species, and habitat types, on a state-by-state basis.

Several authors have measured protection across geographic and elevational ranges to assess the representation of ecosystems and communities (Scott 2001b and Awimbo et al. 1996). Range is often associated with genetic diversity that enables species to survive stochastic, environmental, and anthropogenic changes (Scott et al. 2001b). Lomolino and Channell (1995) suggest that protection throughout a species' range may be crucial to its long-term survival.

All levels/forms of biodiversity need to be adequately addressed if biodiversity is to be preserved (Scott et al.1999, Sisk et al. 1994). Measures of representation, and scale are issues that must be addressed if the goal of preserving biodiversity is to be met

METHODOLOGY

Approach

My objectives were to assess differences among forest types in long-term global forest decline and protection, and determine whether current protected areas adequately protect temperate forests at the full range of environmental conditions in which they exist.

To analyze and discuss differences in forest decline and protection across the globe, division of forests into categories was necessary. I used three major biomes—boreal, temperate and tropical—because they are the coarsest categories that still reflect differences in forest composition and deforestation patterns. To categorize forests into temperate, boreal, and tropical biomes, I combined a global forest map with a generalized digital map of Holdrige's Life Zones (Leemands 1990, Appendix 1).

To determine differences in remaining forest area, area deforested, and area at different elevations, I needed to be able to accurately measure forest area at a global scale. I conducted all analyses on a continent by continent basis and combined the measurements in the final global analysis to avoid the area distortions inherent in most common global projections and therefore obtain accurate area measurements. By comparing estimates of the world's forested area after the last ice age to current forest and protected forests, I determined long-term forest decline and forest protection on a

global scale (Table 1).

For the final analysis of geographical and elevational biases in temperate forest protection, I utilized a wide range of global data sets (Table1). In this portion of the study I restricted my analysis to currently forested areas within the temperate biome; historically forested areas were not included.

Geographical and elevational gradients capture much of the natural variation in environmental conditions found across landscapes, regions and continents. I compared the geographic distribution, elevation and slope between a random sample of temperate forest areas and protected temperate forest areas.

For all forest mapping and spatial analyses, I utilized Arcview 3.3 (2002), and ArcGIS 8 (2002). For all other data processing and statistical analyses, including the Chi-Square and Kruskal-Wallis tests, I used Microsoft Excel (2000) and Systat 10 (2002).

Table 1. Data Sources

Title	*Date*	*Theme*	*Data type*	*MMU*/Resolution*	*Source*
The World Forest Map	1996	Current forest cover	Raster	1 km^2	The World Conservation Monitoring Centre (WCMC, Cambridge, UK 1996)
Estimated Original Forest Cover Map- A First Attempt	1996	Original forest cover	Raster	1 km^2	The World Conservation Monitoring Centre (WCMC, Cambridge, UK, 1996)
Frontier Forests	1997	Frontier forests	Raster	1 km^2	The World Resources Institute, (Washington D.C., 1997)
Protected Areas Database	1997	Protected areas	Vector	0.4 km^2	United Nations Environment Programme, World Conservation Monitoring center (UNEP-WCMC), the World Commission on Protected Areas (WCPA), and the World Conservation Union (IUCN), 1997
GTOPO30	1993	Elevation	Raster	~1 km^2	These data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey's EROS Data Center http://lpdaac.usgs.gov
Holdridge Life Zones	1990	Biome layer	Raster	0.5 °	Leemans, R., 1990. Biosphere Project, International Institute for Applied Systems Analysis IIASA-Laxenburg, Austria

*MMU = Minimum Mapping Unit: Smallest polygon that can be differentiated in a vector GIS data set.

Data Sources

WCMC original forest map - an estimate of the world's forests at the end of the last major ice age about 8,000 years ago (WCMC 1996). This map represents a forest cover estimate based on climate, elevation and current forest cover. It assumes that forests were not yet exposed to large-scale anthropogenic disturbances.

Current Forest Map – was developed from several country and regional sources, and is accurate to approximately 1:1,000,000 scale. (WCMC 1996).

Frontier Forest Map- the result of a forest fragmentation analysis of the WCMC *current forest map* (WRI 1997). WRI analysts included all areas with closed canopy in the analysis (Bryant et al. 1997). WRI defined *frontier forests* as "...natural, relatively undisturbed and unmanaged forest, large enough to support ecologically viable populations of species native to that particular forest type…" (Bryant et al. 1997).

The Global Landcover Characterization (Loveland 2000) data set—developed from Advanced Very High Resolution Radiometer Imagery (AVHRR) during the International Biosphere Geosphere Project (IGBP)—provided the baseline data for forest distribution in the temperate forest protection portion of this analysis. The GLCC is global land cover data set at 1-km resolution and has been widely used for global and regional conservation studies (Leimgruber et al. 2003)

*GTOPO30 (*USGS, 1993*)*—is a global elevation data set that was developed from a combination of coarse and mid-resolution satellite data (Gesch and Larson 1996, Verdin and Greenlee 1996).

Protected Areas Database (UNEP / WCMC 1997)—is a global data set delineating all areas protected by law. IUCN recognizes five levels of protection ranging

from strict reserves, to those managed for sustainable resource use (Hockings et al. 2000). I included all five protected area categories in my analysis

Data Preprocessing

Combining data sets from different sources requires careful consideration on how to best integrate the data in a meaningful analysis. In the integration process, I transformed all data to a common projection—Lambert Azimuthal Equal-Area. Choosing Lambert Azimuthal Equal-Area projection reduced aerial distortion and facilitated areal calculations. In addition, I resampled all data to a common grid cell size of one kilometer.

Data Analysis

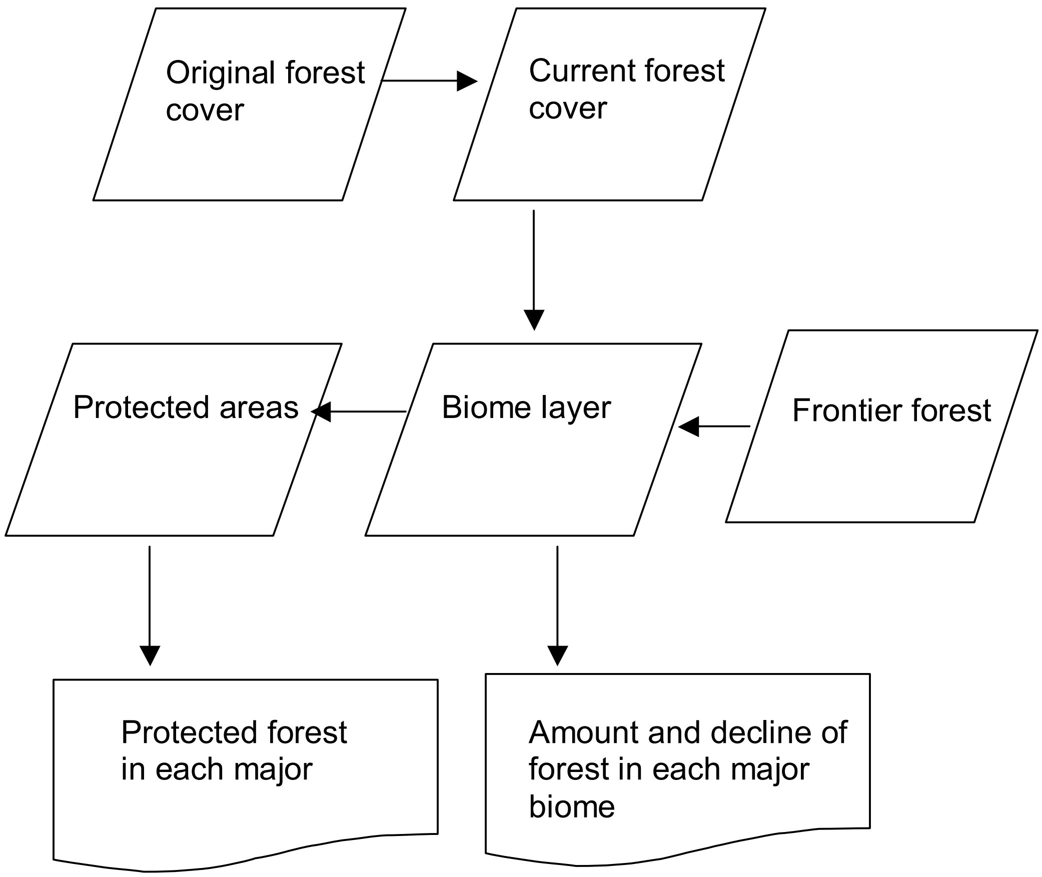
Forest Decline

To analyze forest decline across the earth's major biomes, I divided the original forest layer and the current forest layers into boreal temperate, and tropical. I calculated the relative abundance of each forest type currently, and at the end of the last ice age, and overall decline in forested area for each biome. I used the frontier forest data for a coarse assessment of how much of the current forest in each biome is in good condition (Figure 1).

Forest Protection

I used the protected area data layer to then calculate the forest area in each biome that is currently protected. I repeated this analysis for each of the continental regions (Figure 1).

Figure 1. Data flow for the analysis of global forest decline and protection across biomes.



Elevation and Slope

To determine elevational and slope differences between protected and unprotected temperate forests, I used randomly selected points to sample elevation and slope values. I compared the sample elevation and slope values between protected and unprotected temperate forest areas using chi-square tests.

The elevation and slope data are continuous, 1km^2 grids. Within the temperate forest areas there is an elevation value for each square kilometer. I did not use all of the available elevation data because computational time was a constraint for some

continents in the study. To have consistent methods for every continent in the study, I used randomly generated points to select elevation and slope values from the grids.

I used root mean square error (*RMSE*) to identify an adequate sample size for each continent. By comparing an increasing number of sample elevations (in the temperate forest) to all of the elevation values (in the temperate forest), I was able to determine using *RMSE* when the sample size was large enough to match the range and frequency of all of the elevation values in the temperate forest.

This method entailed generating increasing densities of random points within the total temperate forest area for each continent. Then dividing the elevation values into categories 1-300, 300-1000, and >1000 meters. I divided values from all of the elevation pixels in the temperate forest area into the same categories, and I compared the number of random points in each elevational category with the number expected based on the percentage of total elevation in each category. I calculated this as:

$$RMSE = \sqrt{\frac{1}{k}\sum_{i=1}^{k}\left(yi - \hat{y}i\right)^2}$$

Where
y = observed value
$\hat{y}$ = expected value
k = number of bins

As the random point density rose, *RMSE* decreased, down to a point density where the *RMSE* began to level out (Figure 2). This density varied between continents (Table 2). To combine the results for a global analysis a common density was necessary. A point density of .05 per km^2 provided an adequate sample size for every continent. I used the same density for random sampling within the temperate forest area and

protected areas. Figure 2 illustrates the results of *RMSE* performed once for elevation data in North America. The slight increase in error at the higher point density is likely due to a random fluctuation.

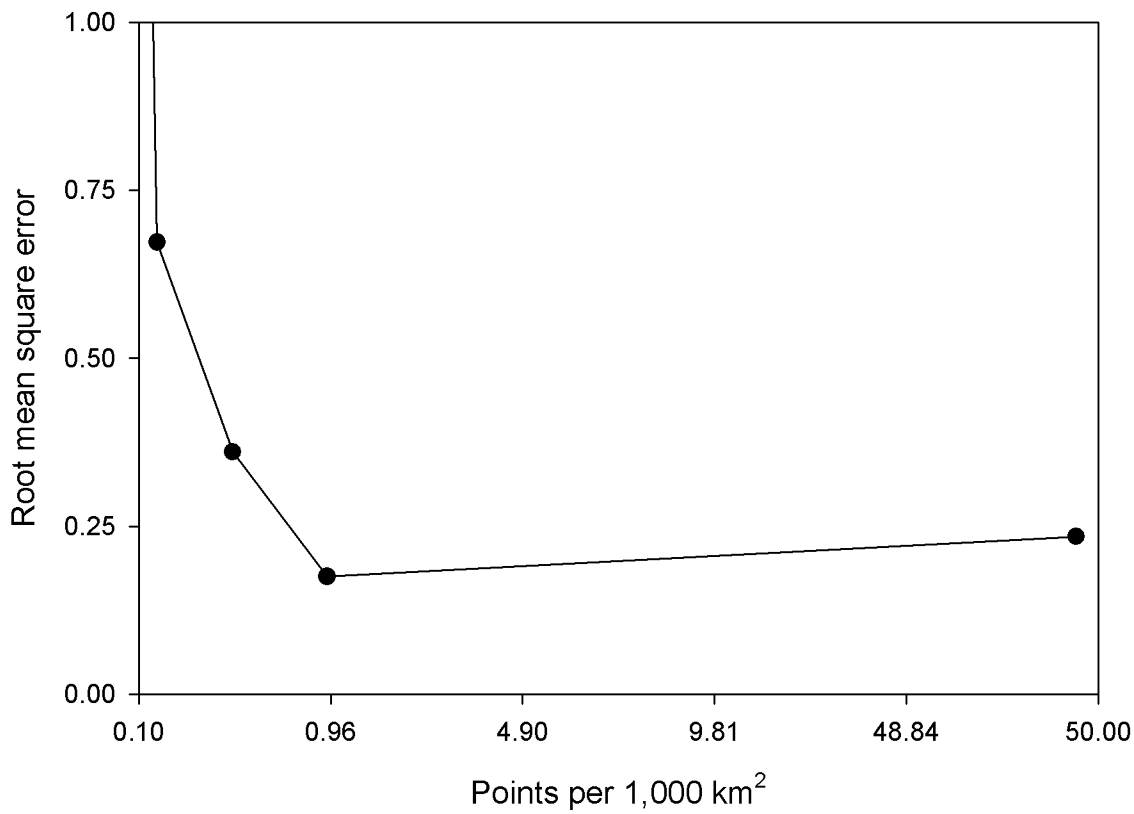


Figure 2. Root mean square error and point density (number of random samples).

Table 2. Density at which the rmse began to level out

	Africa	Australia	Eurasia	North America	South America
Points per 1,000 km^2	6.68	5.45	1.51	4.90	10.68

I divided the elevation values into three major categories (0-300, 301-1000, >1000 m). The categories are coarse in keeping with the scale of the analysis and the detail of the data available. I chose these categories after visually inspecting histograms of the distribution of temperate forest and protected temperate forest across elevation values for each continent. I chose classes that most concisely illustrated the pattern of the distribution for all the continents in the study. I used chi-square to test whether the elevation in the two groups (protected and unprotected) differed significantly.

I used the same random sample as in the elevation analysis to compare slope in both groups (protected and unprotected). I divided the slope categories into ≤3 degrees and >3 degrees. I used chi-square to test whether the slope in the two groups (protected and unprotected) differed significantly.

Geographic Range

To compare the geographic distribution of protected and unprotected temperate forests, I converted grid data of all temperate forests and protected temperate forests into vector polygons using the Arc/Info “gridpoly” command. I calculated the coordinate at the center location (centroid) of each vector polygon, and compared the locations of the patches in each group (protected and unprotected temperate forest). These analyses were restricted to forest patches larger than $10km^2$.

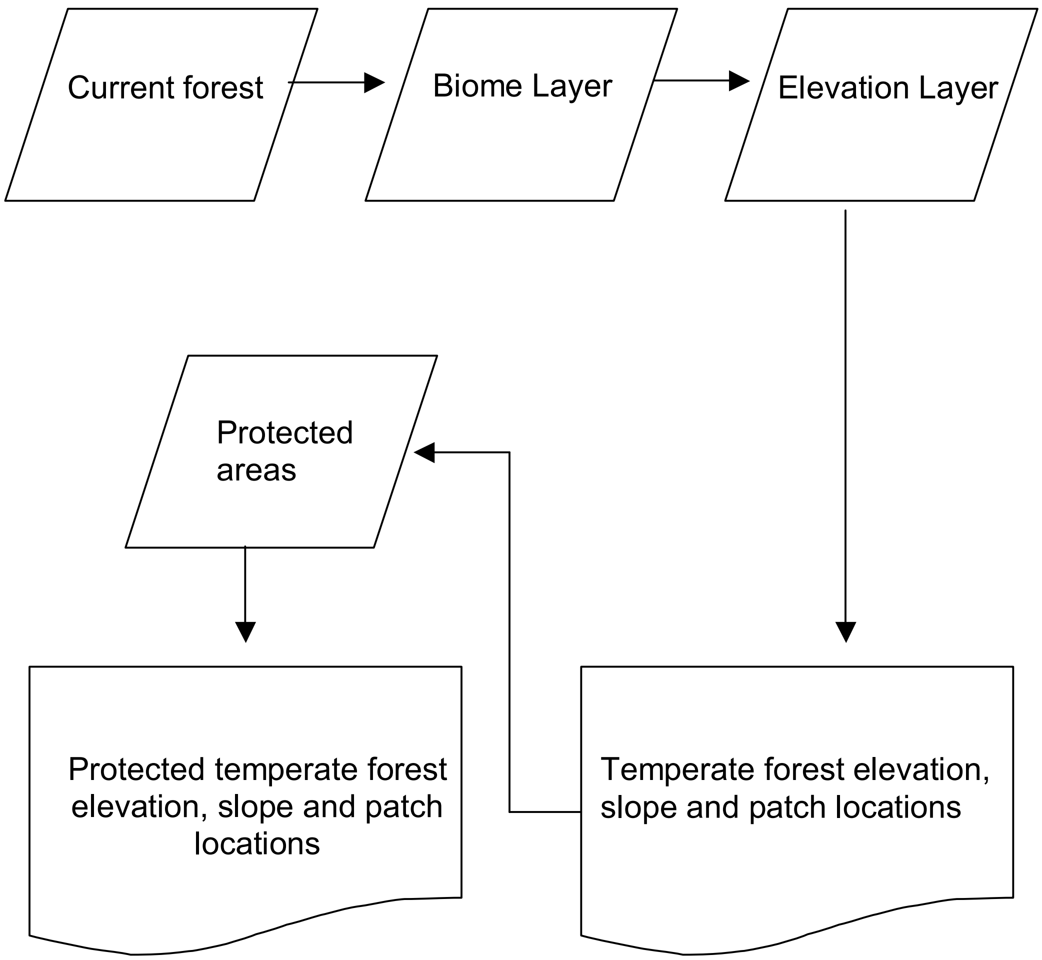
I used a non-parametric Mann-Whitney U test to compare the latitude, and the longitude of the centroids of protected and unprotected temperate forest patches.

Data Limitations

Holdridge life zones data are based on climate and elevation models. Temperate zone category does not always indicate the presence of temperate vegetation. One large area in South America's Amazon Basin was included in the temperate Zone according to the Holdridge data set. I found no documentation suggesting that temperate vegetation occurred there, so I removed it from the analysis. Although the data required some edits for this application, it is a valid and useful means of delineating climate zones (Brown and Lugo 2003, Lugo et al.1999, Powell et al. 2000).

The IUCN Protected areas data set, the only global data set available of protected areas, lacks data for some countries.

Figure 2. Data flow for the analysis of temperate forest protection.



RESULTS

Global Forest Decline

Originally, the world's forests were predominantly tropical (Table 1). Temperate forests were the second most abundant forest type, followed by boreal forest.

Today, temperate forests are by far the least common forest type globally (Table 1). Large, undisturbed forest areas, or frontier forests, have become extremely rare. Only 4% of the world's frontier forests occur in the temperate biome. The remaining 96% of frontier forest is almost evenly distributed between tropical and boreal biomes.

Table 1. Total and relative forested area (10,000 km^2) for different biomes after the last ice age and within the last decade

Forest Category	*Tropical forest*	*Boreal forest*	*Temperate forest*
Original	2514 (45%)	1446 (26%)	1609 (29%)
Current	1389 (43%)	1256 (39%)	562 (18%)
Frontier	570 (51%)	496 (45%)	45 (4%)

Temperate forests have declined the most dramatically throughout time and may now be the most threatened forest type globally (Table 2). Inspection of the relative change in forest cover within each of the three biomes demonstrates that all biomes

experienced severe declines in forest cover (Original forest to current; Table 2), but that temperate declines were about 50% more than tropical, and about four times the rate of boreal declines. The proportion of current forests that are frontier is also much smaller in temperate than in either tropical or boreal forests.

Table 2. Forest decline and frontier status of forests in three biomes.

	Tropical forest	*Boreal forest*	*Temperate forest*
Original-current (% decline)	44.8	13.2	65.1
Frontier (% of current)	22.7	34.3	2.8

Global Forest Protection

Temperate and boreal forests are currently under protected (Table 3). Only 4.64% of the temperate forest and only 1.5% of temperate unfragmented frontier forest is protected. Boreal forest is even less protected while tropical forests experience the highest degree of protection. Because of the severe declines in temperate forests, the relatively small area of unfragmented temperate forests and the obvious lack of protection adequate for this ecosystem, temperate forests may be considered the least common, most severely threatened and least protected of the three major forest biomes.

Table 3. Current and protected forest area (km^2)

	Tropical Forest	*Boreal Forest*	*Temperate Forest*
Current	13,887,231	12,562,070	5,617,210
Current protected	2,101,226 (15.3%)	425,367 (3.4%)	260,709 (4.6%)
Frontier protected	1,376,781 (9.9%)	298,583 (2.4%)	81,565 (1.5%)

On a continent by continent basis, continents in the northern hemisphere, which have the most temperate forests, have the smallest percentage of their temperate forests protected (Table 4).

Table 4. Temperate and protected temperate forest on each continent

	Temperate forest (km^2)	Protected (km^2)	Protected (%)
Eurasia	3,845,331	137,404	3.57
North America	2,140,602	26,307	1.23
Australia	341,796	43,788	12.81
South America	212,912	30,311	14.24
Africa	101,291	5,517	5.45

Temperate Forest Protection

Elevation and slope

Based on my statistical analysis of geographic data, I found significant differences in elevation patterns between protected and unprotected temperate forests on every continent. My analysis demonstrates that the most significant differences in elevation for temperate forests occur in Eurasia (χ^2=1378.18, n=198953, p<0.001), and North America (χ^2=375.75 n=162579, p<0.001). The largest differences in mean

elevation between protected and unprotected temperate forests were found in Africa (Δ=1120m), Eurasia (Δ=570m), and North America (Δ=195m) where protection was disproportionately greater at higher elevations (Figure 5).

In North America, 30% the temperate forests are found at 0-300m elevations. Yet, only 11% of the protected temperate forest area occurs at similar elevations. Conversely, 32% of temperate forests and 41% of protected temperate forests were found at elevations greater than 1000m (Figure 5).

In Eurasia, 40% of the temperate forests are located at 0-300m elevation but only 16% of the protected temperate forests are at elevations below 300m. Only 22% of unprotected temperate forest but 44% of the protected temperate forest area stretches over elevations greater than 1000m (Figure 5). In Africa, 62%of temperate forests and 96% of the protected temperate forest was at elevations greater than 1000m (Figure 5). The results of the chi-square test were also significant for Australia (χ^2=43.12 n=20707, p<0.001) and South America (χ^2=14.59 n=12979, p<0.001); however, the differences between temperate forest and protected temperate forest elevation were less pronounced.

Current protection is biased toward steep slopes. Chi-square tests showed highly significant differences in Eurasia (χ^2=1791.34, n=198709, p<0.001), South America (χ^2=204.27, n=12981, p<0.001), North America (χ^2=137.92 n=160993, p<0.001), and Australia (χ^2=101.05 n=20504, p<0.001), where protected temperate forests areas have steeper slopes than the unprotected temperate forest areas. The results for Africa were not significant (χ^2=2.15 n=5624, p>0.2). The largest proportional differences in slope between protected and unprotected temperate forest are in Eurasia, where 48% of the

total temperate forest and 75% of the protected temperate forest had a slope value of >3 degrees (Figure 6).

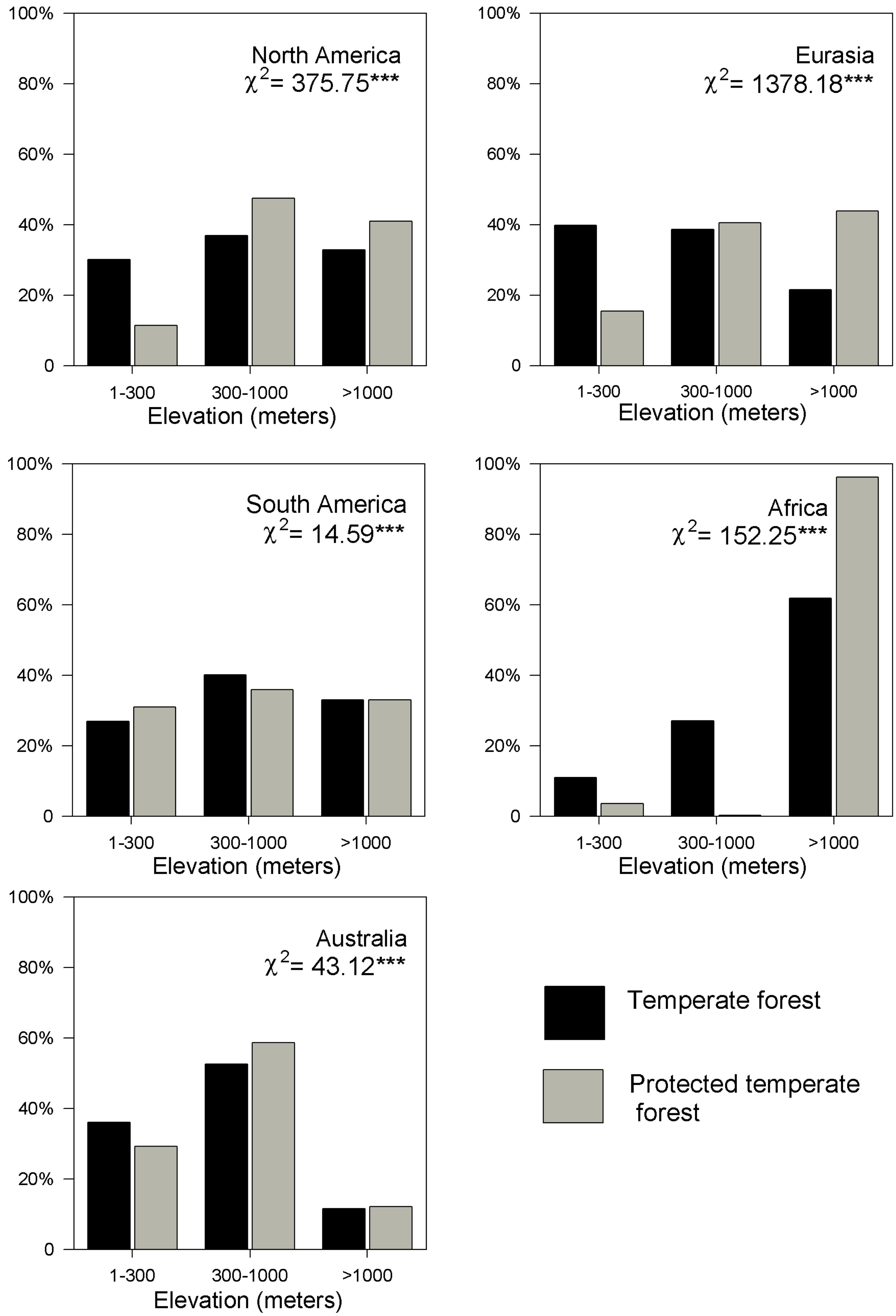


Figure 5. Percent temperate and protected temperate forest at different elevations.
*** $p < 0.001$

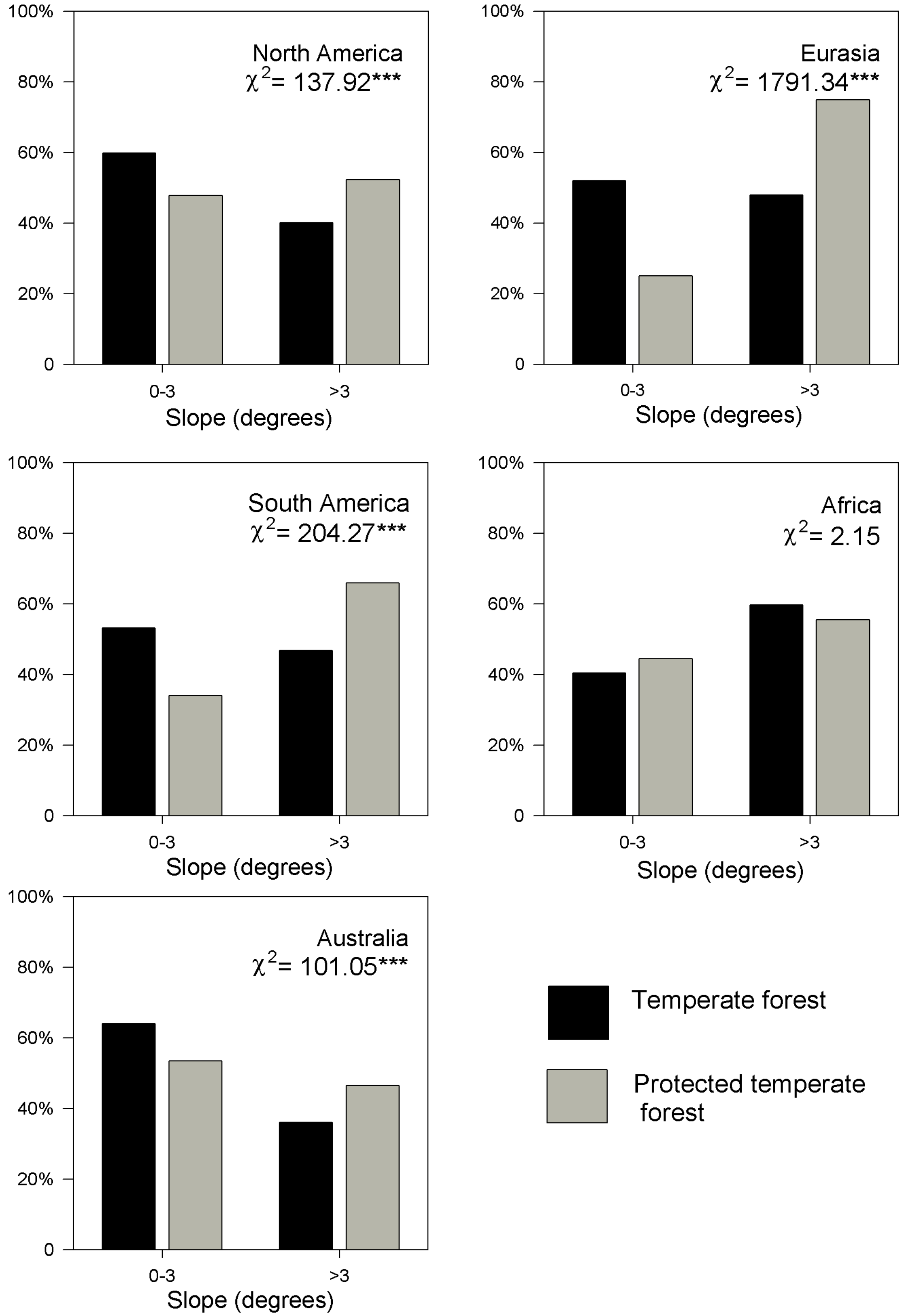


Figure 6. Percent temperate and protected temperate forest at different slopes.
*** p< 0.001

Geographic Range

Temperate forest protection demonstrates a geographic bias when compared to the geographic distribution of all temperate forest areas. Based on Mann-Whitney U tests, I detected the most significant differences in geographic distribution in Eurasia (Ux =1918720.0, n = 12591, p = <0.001; Uy=5176450.0, n = 12591, p = <0.001) where protection is heavily biased toward the south and the east (Figure7, Table3). Protection in South America is also unevenly distributed along latitudinal and longitudinal axes (Ux=36511.0, n = 893, p = <0.001; Uy=22644.0, n = 893, p = <0.001); heavily concentrated in the south and to the west (figure 8, table3). Significant longitudinal bias occurs in North America (Ux=127296.5, n = 3452, p = .001; Uy=146124.5, n = 3452, p = 0.219), where protection is focused in the west (figure9, table3). In Africa (Ux=16174.5, n = 633, p = <0.001; Uy=9256.0, n = 633, p = 0.528) and Australia (Ux=77940.0, n = 965, p = 0.008; Uy=66204.0 n = 965, p = 0.381) protection is focused east of the overall temperate forest coverage respectively (Figure10, Table 3).

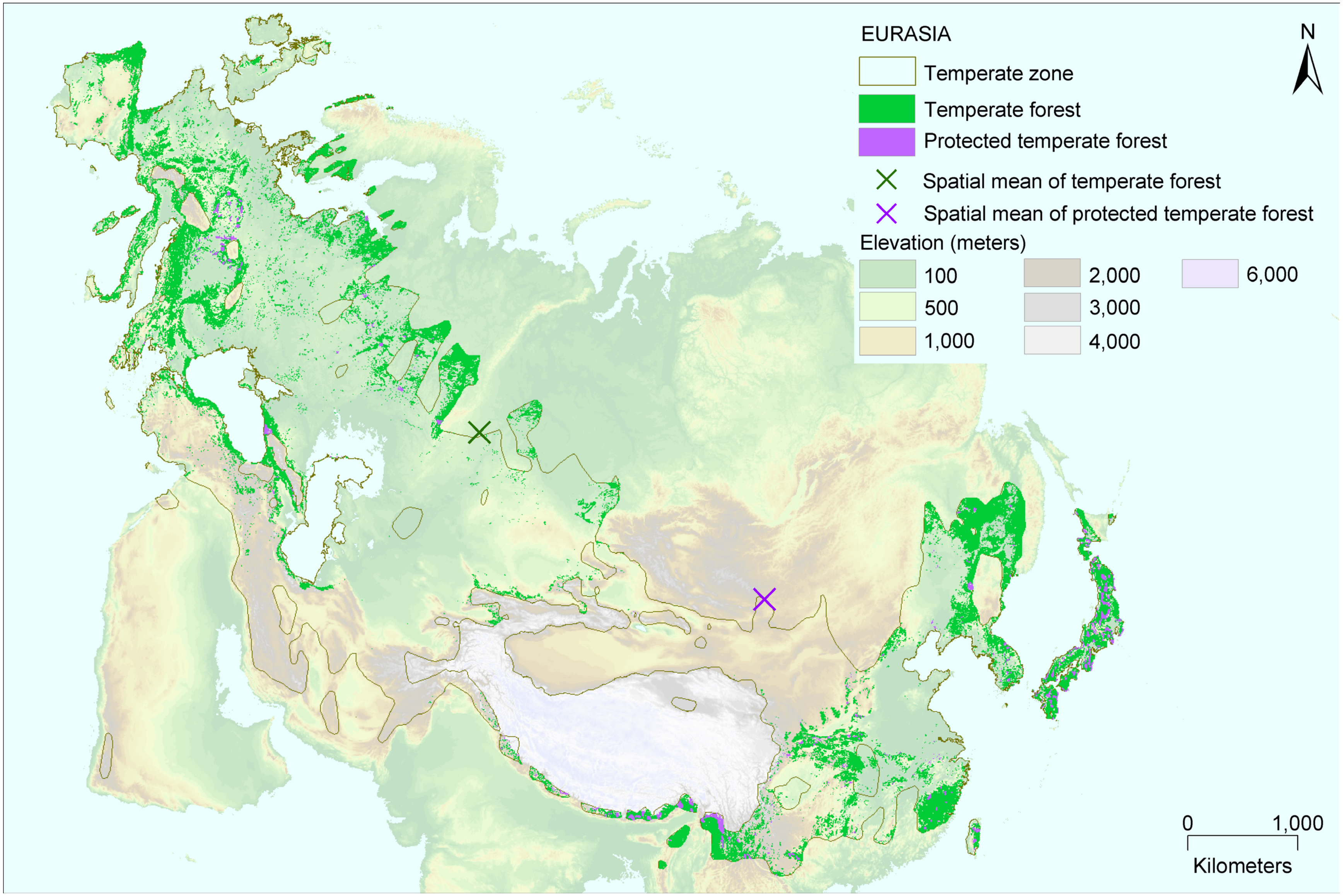

EURASIA
Temperate zone
Temperate forest
Protected temperate forest
Spatial mean of temperate forest
Spatial mean of protected temperate forest
Elevation (meters)
100
500
1,000
2,000
3,000
4,000
6,000
N
0
1,000
Kilometers

Figure 7.

Table 3. Mean centroid location of temperate and protected temperate forest patches

	Temperate forest		Protected temperate forest		U-values	
	Mean		Mean			
	x	y	x	y	Ux	Uy
Africa	-537965.9	680688.3	1396710.0	584358.1	16174.5***	9256.0
Australia	1248530.0	-2064540.0	1327400.0	-2304140.0	77940.0**	66204.0
Eurasia	-2328760.0	1580870.0	261319.7	62050.8	1918720.0***	5176450.0***
North America	196722.8	-537004.2	-184257.8	-837381.7	127296.5**	146124.5
South America	-543510.1	-942819.1	-1057303.0	-2270419.3	36511.0***	22644.0***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$


SOUTH AMERICA
Temperate zone
Temperate forest
Protected temperate forest
Spatial mean of temperate forest
Spatial mean of protected temperate forest
Elevation (meters)
100
500
1,000
2,000
3,000
4,000
6,000
0
590
Kilometers

Figure 8.

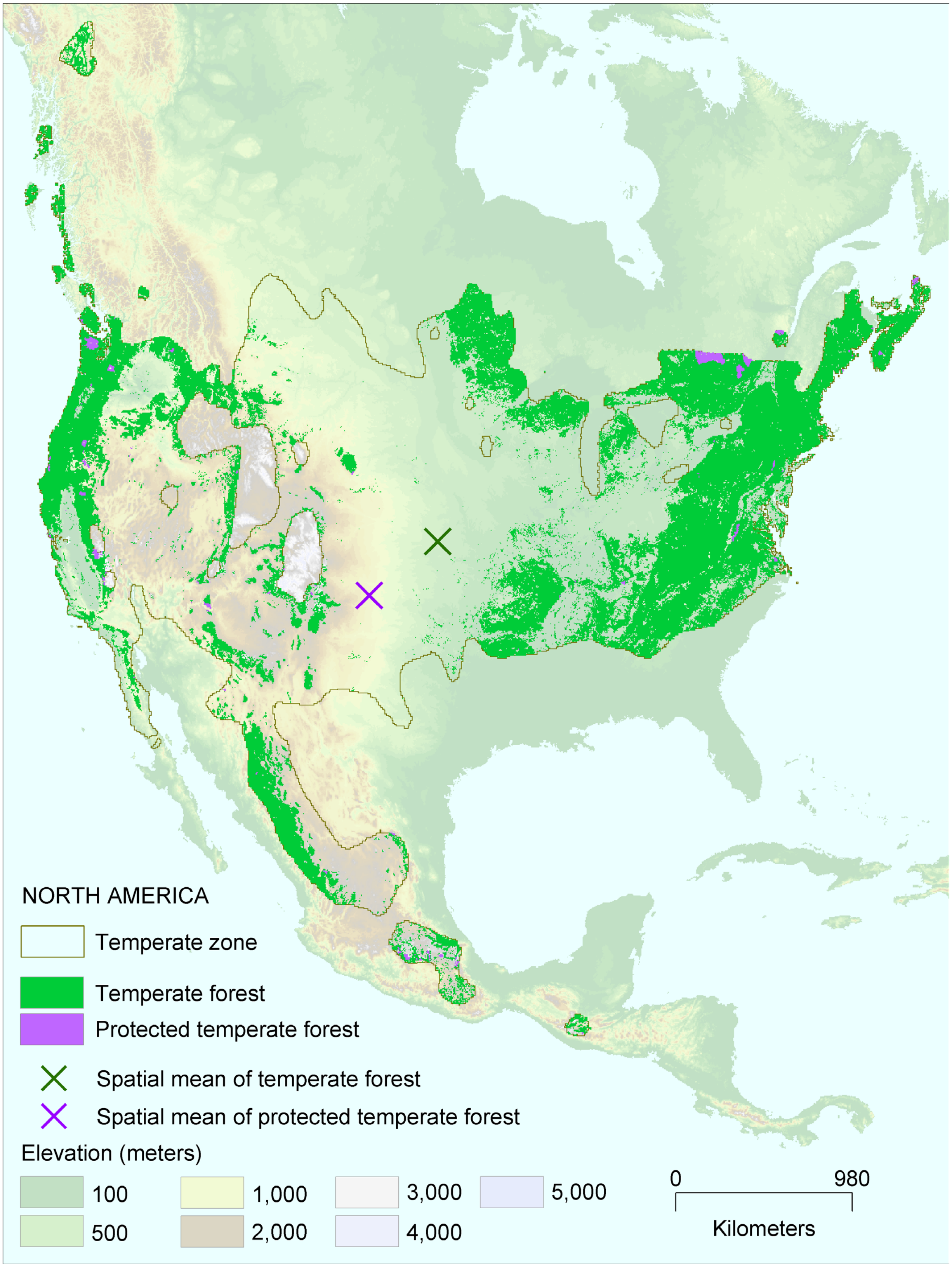

NORTH AMERICA
Temperate zone
Temperate forest
Protected temperate forest
Spatial mean of temperate forest
Spatial mean of protected temperate forest
Elevation (meters)
100
500
1,000
2,000
3,000
4,000
5,000
0
980
Kilometers

Figure 9.

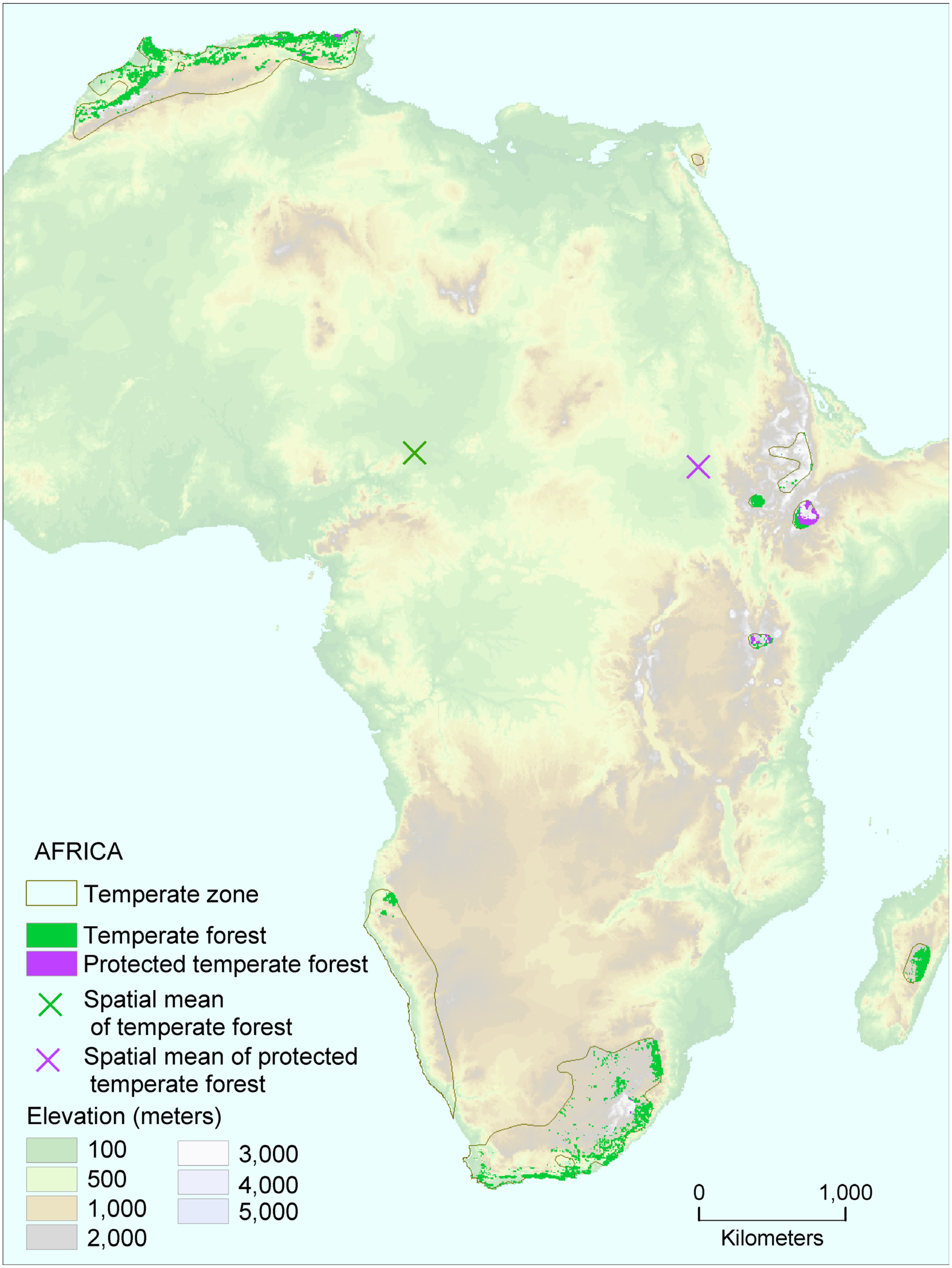

AFRICA
Temperate zone
Temperate forest
Protected temperate forest
Spatial mean
of temperate forest
Spatial mean of protected
temperate forest
Elevation (meters)
100
500
1,000
2,000
3,000
4,000
5,000
0
1,000
Kilometers

Figure 10.

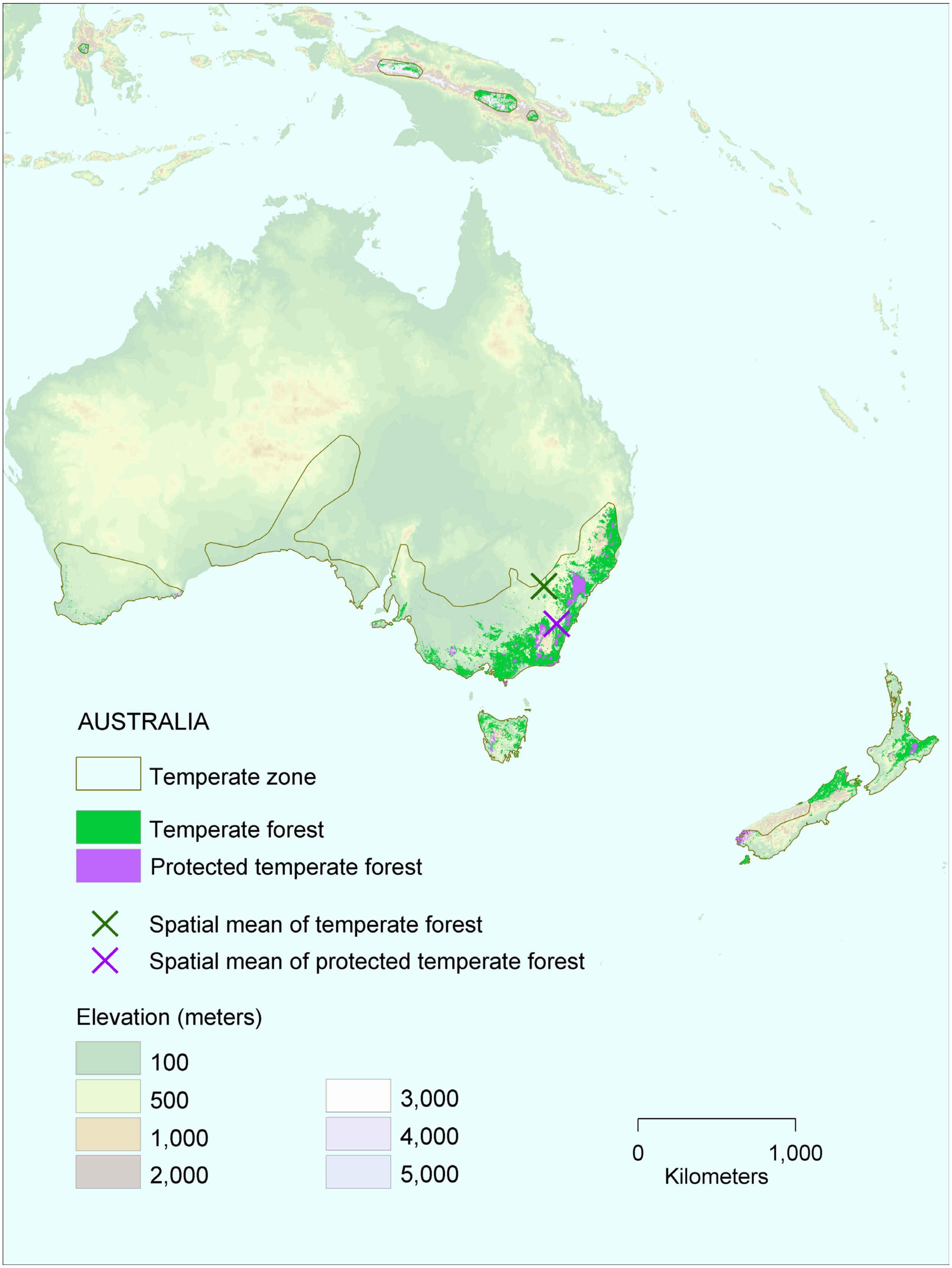

AUSTRALIA
Temperate zone
Temperate forest
Protected temperate forest
Spatial mean of temperate forest
Spatial mean of protected temperate forest
Elevation (meters)
100
500
1,000
2,000
3,000
4,000
5,000
0
1,000
Kilometers

Figure 11.

DISCUSSION

Global Forest Decline

Forests in all biomes have severely declined during the past 8,000 years. However, results from my studies demonstrate that forests across boreal, temperate and tropical biomes have declined differently. The increase in deforestation, in the tropical biome specifically, has been a major concern over the last few decades (Williams 2003). However, in contrast to general public perception, boreal deforestation has also increased over the last decades (Williams 2003, Dudley 1992) but is only slowly gaining attention. To date, there have been no coarse scale global studies that measure long-term change across biomes. My analysis clearly reveals that overall forest losses have been much higher in the temperate biome (65%) than in the tropical biome (45%) or the boreal biome (13%).

Temperate Forest Decline

Temperate forests, once the second most abundant forest type, have been dramatically reduced and now are the least common forest type. Of the worlds remaining forests 39% are boreal, 18% are temperate forests and 43% are tropical. Temperate forests now are the most rare and endangered of these three major forest types. It is these forests that have suffered the most extensive loss due to human activities (Rosen and Roberts 2000).

Temperate forests are rare today as a result of historic deforestation, most replaced by agriculture and settlements, and remaining forests are heavily used (Bryant, et al. 1997). In addition, proximity to population centers and associated transportation networks may have increased the rapid exploitation of temperate forests by making them more accessible to human activities and use.

Proximity to well-developed industrial centers may also have had indirect negative effects on temperate forests by increasing acid rain and invasion of introduced exotic species and diseases. Declines in Europe's temperate forests due to acid rain have been well documented, as have been the detrimental impacts of exotic diseases and pests on temperate forests, such as gypsy moth, chestnut blight and Dutch elm disease in Europe and North America (Brasier and Buck 2001, Peterken and Mountford 1998, Buskie 2001, Krasny and DiGregorio 2001, Wermelinger 1995, Diamond et al. 2000, Robin and Heiniger 2001).

Tropical Forest Decline

Tropical forests have declined 45% in the last 8,000 years (Table 2). Despite dramatic forest losses in the tropics during the last few decades (Williams 2003), my findings indicate that tropical forests have been and continue to be the most abundant forest cover, globally. Originally comprising 45% and currently 43% of the total forested area on earth (Table 1). However, because of the high levels of biodiversity and endemism found in tropical forests, even relatively small losses represent a significant loss in global biodiversity with many unique species going extinct (Wilson 1992).

Boreal Forest Decline

Boreal forests have declined the least, 13%, perhaps because these forests are less productive and were logistically difficult to harvest until recently. Developments of modern forestry technology and the increased demand for pulpwood have made large-scale commercial exploitation, and landscape-size clear cuts of these forests a reality (Yaroshenko et al. 2001). Boreal forests in Canada and Russia have experienced increased use and there are serious concerns about the long-term sustainability of current timber extraction levels in a biome that has limited regeneration potential (Dudley 1992).

Bias in Global Forest Protection

The 5% of temperate and 3% of boreal forest that is protected is far less than the 15% of tropical forest that is currently protected. This finding is consistent with previous reports regarding the protection level of these forest biomes (Greene and Paine 1997, Bryant et al. 1997, Rosen and Roberts 2000). Considering that that there is very little temperate forest left on the earth, such a small percentage represents a dangerously low level of protection.

Boreal, like tropical forests, are relatively abundant, but have recently become a target of large-scale commercial logging (Dudley 1992, Yaroshenko et al. 2001). Deforestation in some temperate and boreal forests is occurring as rapidly as in tropical forests (Dudley 1992, Pinder et al. 1999). While tropical forest protection is very important, it is unacceptable to ignore the importance of other ecosystems including temperate and boreal forest ecosystems (Given 1990).

Although tropical forests are already the most protected, they continue to be the focus of the majority of conservation efforts made by international conservation organizations. Other possible reasons for the tropical bias in protected area systems include:

1. There is comparatively little public focus on forest ecosystem functions, such as carbon storage, nutrient cycling, and watershed protection. While these functions are essential to maintaining biodiversity, they do not get the level of attention that the biodiversity crisis is currently demanding. This may partly be due to the difficulties in quantifying and defining ecosystem functions.
2. There is little forest left in the temperate zone; it is hard to find intact forest that is not in demand, or being used for other purposes.
3. Temperate forest is highly valuable for many competing interests including agriculture and development. It is therefore expensive and politically difficult to protect (Bryant et al. 1997, Dudley 1992, Williams 2003).
4. Lower levels of biodiversity in the boreal and temperate forests than in the tropical forests, have been a major factor in setting conservation priorities lower for boreal and temperate forests than for tropical forests (Dudley et al. 1992).
5. Twentieth century population explosion, subsequent agricultural expansion and commercial exploitation have taken a dramatic toll on tropical forests in the last few decades (Williams 2003, WRI 2000). The greater demand has resulted in greater attention.
6. Some of the tropical bias in the development of international protected area systems may also be explained by political and economic differences between the so-called

developed and developing worlds (Williams 2003). Most large conservation organizations involved in protected area development are based in and financed by developed countries. These organizations also can have strong influence on the international donor community, requiring biodiversity protection in exchange for bilateral funding and development (Ramirez 2000).

7. Northern hemisphere donors seem to be more likely to support the conservation of charismatic species in a far away place than to invest into the protection of land and species in their own country (Dudley 1992, Williams 2003).

Ecosystem Services

Lack of protection in the temperate and boreal forests may result in the loss of important ecosystem services. Important forest ecosystem services include carbon storage, water filtration, soil stabilization, and microclimate stabilization.

Carbon Storage

Forests contain approximately 60% of the terrestrial carbon pool (Barker 1995). Although there is some debate, numerous reports indicate that temperate and boreal forests are more important for C storage than are tropical forests (Woodwell 2001, Dore and Guevara 2000). Atmospheric carbon has increased dramatically in the 21st century primarily due to increased use of fossil fuels (Woodwell 2001). Scientific studies demonstrate that these carbon increases are likely to cause global warming via the greenhouse effect (Ramirez 2000). Major carbon sinks are important to keep the global carbon cycle in balance (Dore and Guevara 2000). Losing carbon storing ecosystems through deforestation releases additional carbon and significantly contributes to existing problems of global warming (Ramirez 2000).

Water Filtration

Forests purify and moderate water flow. In the US alone, more than 60 million people rely on (temperate) National Forests for drinking water (WRI 2000). Deforestation raises the water table and increases surface flow, making flooding more likely, increasing turbidity and decreasing water quality in streams and rivers (Hocker 1979).

Soil Stabilization

Root structures remove water from soil and hold soil together, reducing landslips. Forests also reduce erosion by moderating runoff (WRI 2000, Dudley 1992, Hocker 1979).

Microclimate Stabilization

Forests have an insulating, moderating effect on local temperatures. In cold climates, forests provide a dark absorptive surface for heat from the sun, while forests provide shade and water transpiration that has a cooling effect in warmer climate zones (Dudley 1992, Hocker 1979). Forests also serve as a buffer against severe weather, creating more habitable conditions for all organisms.

Biases in Temperate Forest Protection

Elevation and Slope

My thesis demonstrates that temperate forest protection is biased toward high elevations and steep slopes. Lower elevation forests in temperate biome are protected far less than higher elevation areas (Figure 5), especially in North America, Eurasia and Africa. These findings are consistent with those of other researchers (Pressey 1995, Pressey et al. 2000, Rebelo 1992, Pressey and Tully 1994, Scott 2001a, Dudley 1992).

Except for the protection of unusual geographic features such as in Yellowstone National Park, protected areas were largely established on land that was unsuitable for other uses. Protection was provided for areas with steep slopes and high elevation, where agricultural or silvicutural use of the land was too expensive (Shands and Healy 1977, Soule and Terborgh 1999, Pressey 1994, Pressey et al. 1994). Higher soil quality, productivity, and biodiversity are generally found at lower elevations where soils and nutrients had greater accumulation patterns (Scott 2001a, Allen et al. 1991).

To date there have been no global analyses of temperate forest protection across the geographic and elevational ranges occupied by these forests. While my findings may seem obvious from a cultural or economic standpoint, it is important to quantify and document the magnitude of these biases in protection. My research measured the extent of existing bias in protection and demonstrates the potential consequences of these biases for global biodiversity protection.

Disproportionate protection of high elevations may leave important components of temperate forest ecosystems unprotected, especially highly productive forest types. Pressey (1994) warns that protection only in high elevations, may diminish the long term viability of populations occurring within the protected areas. Limited resources at higher elevations could leave many species with only marginal habitat. As unprotected forest surrounding protected areas is lost, populations are forced into the smaller habitat “islands” of protected areas. If these islands are high elevation, less productive habitat, populations may not have the necessary resources to maintain viable populations, even if individuals can survive. If protected areas are mainly population sinks, then even species occurring in widespread protected areas could decline (Pressey 1994).

Compositions of plants and animals change across elevational gradients (Allen et al. 1991). Representing the elevational range of temperate forests in protected areas may be important to the long term protection of the variety of communities found in the temperate forest biome. Protecting the range of habitat variation, may also provide a means for species to survive global change by accommodating adjustments to distributions (Hunter et al. 1988).

Geographic Bias

My analyses show that current protection does not represent the full geographic range of temperate forests. Geographic ranges of species are rarely considered in conservation strategies, however, genetic diversity and ecological variation are associated with geographic range (Scott et al. 2001b, Rehfeldt et al. 1984). Temperate forests are not species rich compared to tropical forests; much of the biodiversity in the temperate biome lies in genetic diversity within species (Dudley 1992). Protecting biodiversity of temperate forests may be a matter not only of protecting the species found there, but protecting the genetic diversity within the species. One way of accomplishing this would be to protect species throughout their geographic range (Scott et al. 2001b). Genetic diversity is what enables species to survive environmental changes, therefore protection at this level is crucial to the long-term survival and adaptability of species (Lesica and Allendorf 1995). Genetic variation associated with the geographic range of species may be lost, if the geographic range is not adequately represented in protected areas. Temperate forest protection is geographically biased on every continent included in the study.

Eurasia

The southeast bias in protected temperate forests in Eurasia may be the result of political and socio-economic factors. In Eurasia, temperate forests occur in two fairly distinct areas, northwestern Europe and East Asia. These areas are culturally and political very different. Governments in East Asia established protected areas in part to exert their influence across their territory, into the most remote areas (McNeely et al. 1994). In addition to reserves established for hunting, many reserves were established as religious sanctuaries (McNeely et al. 1994).

While there seems to be more temperate forest protection in the southern and eastern Asia in general, the extensive network of protected temperate areas in Japan, the eastern most country, has likely accentuated the existing bias in temperate forest protection (Figure 7).

North America

In North America, western bias in protection is likely the result of human population, and settlement patterns. By the time protected areas were being established much of the forest in the more heavily populated east was privately owned, cleared for agriculture, or harvested for timber (Williams 2003, Shands and Healy 1997). Today forests cleared over a hundred years ago are slowly regenerating. Protected areas established now, could contribute to the recovery and long-term survival of temperate forests in the eastern North America.

Australia

According to data used for this analysis, thirteen percent of the temperate forests in this region are protected. This is much higher than the global temperate forest

protection rate of 4.6% (Table 3). There is a slight southeastern bias in protection, however, it can probably be explained by the extensive protected area system in New Zealand, and relatively less protection on the southern tip of Western Australia.

Africa

As in Eurasia the majority of temperate forest occurs in two distinct areas on opposite ends of the continent. Protection is equally scarce in both the northern and the southern areas. Several large protected areas on the Mendebo Mountains and Mount Kenya are likely the cause of Eastern Bias in protection in Africa (Figure 10). Aside from these mountains, and a few small areas in the north, there is very little temperate forest protection in Africa.

South America

In South America protection is biased toward the southeast. There is very little temperate forest protection in South America, with the exception of southern Chile, the western most country in South America. Eighteen percent of Chile's land is under protection (Pauchard and Villarroel 2002). Several large protected areas in southern Chile account for 79% of the total protected temperate forest in South America (Figure 8).

In Conclusion

Temperate forests have declined more than the other major forest types. There is far less temperate forest than tropical or boreal forest. Of the forests in the major biomes, temperate forests are the least protected.

Although tropical forests have higher biodiversity than temperate and boreal forests, temperate and boreal forests provide important ecosystem services.

The goal of preserving biodiversity requires representation at all spatial and organizational levels including protection of forests in all of the major biomes and the diversity found throughout their ranges.

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APPENDIX

Grid legend for *Holdridge Life Zones of the World* (Leemans, 1989)

Life Zone Title	Biome
Polar desert	
Subpolar dry tundra	
Subpolar moist tundra	
Subpolar wet tundra	
Subpolar rain tundra	
Boreal desert	Boreal
Boreal dry scrub	Boreal
Boreal moist forest	Boreal
Boreal wet forest	Boreal
Boreal rain forest	Boreal
Cool temperate desert	Temperate
Cool temperate desert scrub	Temperate
Cool temperate steppe	Temperate
Cool temperate moist forest	Temperate
Cool temperate wet forest	Temperate
Cool temperate rain forest	Temperate
Warm temperate desert	Temperate
Warm temperate desert scrub	Temperate
Warm temperate thorn scrub	Temperate
Warm temperate dry forest	Temperate
Warm temperate moist forest	Temperate
Warm temperate wet forest	Temperate
Warm temperate rain forest	Temperate
Subtropical desert	Tropical
Subtropical desert scrub	Tropical
Subtropical thorn woodland	Tropical
Subtropical dry forest	Tropical
Subtropical moist forest	Tropical
Subtropical wet forest	Tropical
Subtropical rain forest	Tropical
Tropical desert	Tropical
Tropical desert scrub	Tropical
Tropical thorn woodland	Tropical
Tropical very dry forest	Tropical
Tropical dry forest	Tropical
Tropical moist forest	Tropical
Tropical wet forest	Tropical
Tropical rain forest	Tropical

VITA

Jennifer Gagnon was born in New Orleans Louisiana. Through activities with her family, such as camping, canoeing, hunting and fishing, she developed a love and respect for wildlife and natural landscapes. After studying sculpture at the University of Louisiana in Lafayette, she transferred to the University of California, Davis, where she earned a Bachelor of Arts in 1991. After teaching and working as an artist she returned to school, to study the sources of her inspiration. Courses in biology, ecology and geography at the University of New Orleans, and her desire to apply GIS techniques to meet conservation goals, led her to the Smithsonian National Zoological Park's Conservation and Research Center where she developed her thesis. While researching her thesis, she also conducted a regional habitat assessment for Asian elephants, produced maps for publication and instructed portions of GIS and remote sensing courses for wildlife managers, researchers and conservation professionals.