Global Forestry Data for the Economic Modeling of Land Use*

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1. INTRODUCTION

In recent years, considerable concern has been raised about the sustainability of the world's forested ecosystems (FAO, 2003). With deforestation rates in tropical regions estimated to be as high as 12 million hectares per year (FAO, 2003; Houghton, 2003), much of the concern has centered around tropical deforestation. In contrast to these developments in tropical areas, there is evidence that the area of forests in temperate regions is expanding. Given the large potential storage of carbon in both temperate and tropical forests, these changes in land use can potentially lead to large fluxes of carbon both into and out of forests (Houghton, 2003; Plattner et al. 2002; Dixon et al., 1994). In addition to the potential carbon fluxes, forest management and land use change influences a host of other local and global environmental impacts.

Developing a better understanding of the relationship between forest management, competition between agriculture and forestry for land, and environmental outcomes is an important task. This book examines economic methods that help researchers and policy makers explore how demand, technology change, and policy choices influence land use outcomes. While there is a large literature exploring economic interactions among different sectors including the agriculture and forestry sectors (see for example, Hertel et al., 1997), little attention has thus far been paid to the effects on land competition. Furthermore, policy makers and researchers are increasingly advocating policies that focus on increasing the stock of carbon in forestlands (i.e., carbon sequestration) or on mitigating greenhouse gas emissions from the agricultural sector. To better understand how global drivers like population, economic growth, technology change, and climate policy influence the demand for different types of land and carbon stocks on the landscape, it is important to develop computable general equilibrium models (CGE) that capture important interactions between stocks and flows on the landscape and the resulting production of outputs intended for markets.

One important step in developing CGE models that account for land competition is to develop globally consistent databases of land use and management. This chapter describes the development of such a database of forest stocks and management. While the UN Food and Agricultural Organization (FAO) routinely publishes reports on forest area and total biomass in countries, the data they provide are highly aggregated (UN FAO, 2005). In particular, while information is available on the total growing stock and biomass, age class information, and yield functions– fundamental arguments in the ecological production function for land– are not provided in FAO data sources. Aside from estimates of production and value of production (FAOSTAT), little data are available on the costs and benefits of managing forestland. This chapter presents the results of an effort to compile data from regional and other sources on forestry inventories in age classes, on forest yield functions, and on other economic data relevant for forest production.

There are several reasons for undertaking this data step. First, industrial forestry is now largely conducted by managing the age class structure of the forest. When forests are planted, it takes many years before they can be harvested, and when forests are harvested, it takes many years to regenerate the carbon. If, for example, landowners are given incentives to manage carbon, they must weigh the influence of their management decisions (e.g., age of harvesting and planting intensity) against the benefits derived from carbon outputs and traditional timber outputs. This is a fundamentally dynamic decision, dependent on current and future price forecasts (both for carbon and timber prices as well as competing land use prices), technology, and other factors. These decisions must be carefully modeled in order to determine the influence of policies on the carbon balance of the landscape.

Second, there are broad productivity differences across the landscape. Forest production functions vary from location to location. While it is exceedingly difficult with today's modeling technology to be spatially explicit within the context of global, or even national models, it is useful to account for differences among species and their relevant production (yield) functions. We accomplish this task in the database by providing data for timber species within national-level agro-ecological zones.

Third, different economic processes are influencing land use in different regions. In tropical regions, there is currently substantial loss of forestland in favor of conversion to agricultural uses, whereas in temperate regions land is being converted from agricultural to forest uses. These trends are likely related to demand and technology, as well as the value of the forests. It is important to account for cross-country and within-country differences in the costs and technologies of production in order to capture the effects of economic influences on these trends.

This chapter begins by describing the global forest sector, and the storage of carbon in forests. A brief discussion of current efforts aimed at incorporating forestry management into CGE models is provided. It then describes the development of a global forestry database containing forest inventories and economic variables at the country level. The database is intended for use by individuals interested in developing general equilibrium models of forestry and agricultural markets. The database has been developed in conjunction with the Global Trade Analysis Project at Purdue University (GTAP), and thus has been constructed to provide data that can be used within the framework of the GTAP system. Authors interested in other applications, however, may also find the data useful and may be able to apply the data to their own research in the context of a wide variety of global economic models of forestry and land use.

This chapter also presents descriptive information about the dataset. Two types of information are offered. First, data on forest inventories, merchantable timber yield functions, and biomass expansion factors are provided. The data are available at the country level for most countries that have forests. The forest inventory data are further disaggregated into agro-ecological zones. Second, data on important economic variables are provided so analysts may incorporate this data into economic models. Data on economic variables are provided for timber types and is not disaggregated to the agro-ecological zones.

The data are derived from numerous sources of information, as described below. While it is tempting to view this as a complete effort, it is important to recognize that many vital pieces of data are missing for certain regions of the world. Thus, the dataset is not entirely complete, although we continue to modify it and provide updates. We hope that as a first effort to integrate global forestry inventory and economic information, the data may be useful for economic modelers interested in the economics of forestry.

2. THE GLOBAL FOREST SECTOR AND CARBON SEQUESTRATION

Global estimates of the total land base in forests vary greatly from source to source. Differences arise from different definitions used for forests, and from different years in which the inventories were collected. As an example, Table 1 presents two sets of data for the total area of forests. One set of data is from FAO (2005), which utilizes a broad definition of forestland, and a second source is the compilation used by Sohngen and Mendelsohn (2007), who use a more restrictive definition for timberland. Timberland is generally more productive than forestland. Current estimates from FAO (2005) indicate that there are around 3.9 billion hectares of forestland globally (Table 1). Sohngen and Mendelsohn (2007) have collected data directly from some countries, and their estimates suggest less total area devoted to forests – estimating a global total of 3.6 billion hectares. Yet in some regions their estimates are higher than FAO estimates.

The largest stocks of forests are found in South America and Russia, both with more than 800 million hectares of forests. The U.S., Canada, Southeast Asia, Africa, and Oceania have the next largest forest areas, in the 200 – 400 million hectare range. Other regions have less than 200 million hectares. Total carbon in forests (aboveground and soil carbon, combined) roughly follows the distribution of forest area, although some differences arise. Canada and Russia, for instance, contain a larger proportion of total carbon than forest or timberland because they have large stocks of carbon stored in soils. FAO data suggest that there have been around 12 million hectares per year of forestland lost during the period 2000-2005, with these losses largely occurring in developing country, tropical regions. Strong afforestation efforts in China and elsewhere have offset these losses to some extent, so the net loss of forests is only around 7.4 million hectares per year. Using an average regional aboveground carbon storage rate (see below) and assuming all of the stock was emitted as a result of conversion to crop or grazing land, deforestation of 12 million hectares per year caused an emission of around 1.3 Pg C (1 Pg C = 10^{15} g C) per year during the period 2000-2005.

World industrial roundwood production has risen around 1.2% per year since the 1960s, with the strongest gains occurring from 1961 to the late 1980's (Figure 1). Industrial roundwood is the primary material extracted from forests for industrial purposes (pulp and paper, sawnwood, etc.). The large reduction in production in the late 1980's and early 1990's is mainly attributed to the dissolution of the Former Soviet Union. Industrial roundwood production was relatively stable throughout the 1990's, but recently has grown again, due to rising production in Russia, South America, Europe, and Oceania (Table 2). The U.S. and Europe lead world production, providing 49% of the world's total timber, however, timber harvests have grown relatively slowly in the U.S. in the last decade (column 2 of Table 2).

Consumption of industrial roundwood (column 3 of Table 2) is highly correlated with regional production, indicating that trade in industrial roundwood is limited compared to the robust trade in end-products (e.g., sawnwood, paper, and other manufactured wood products). As an example, sawnwood production, consumption, and net imports averaged for the period 2001 – 2005 for the same regions are shown in table 3. The major wood products importing regions are illustrated in the final two columns. For example, the U.S. is the largest importer of sawnwood, importing 28% (primarily from Canada). Japan and China are the next biggest net importers, importing 38.6% and 27.7% of their sawnwood respectively. The trends in tables 2 and 3 illustrate the implications of world economic trends in timber markets. The U.S. Canada, Central America, and South America are largely self-sufficient in industrial wood, although end products move from region-to-region. On the other hand, Europe and China import industrial roundwood, while Russia is an exporter. Industrial roundwood exports from western Russia largely go to Europe. Europe subsequently makes products and is a net exporter of sawnwood material. Exports from the Russian Far East, as well as Southeast Asia and Oceania move towards China and Japan, both of whom import industrial roundwood as well as sawnwood and other value-added wood products. These results show that strong growth in China, combined with limited resource availability in Japan, are having strong effects on industrial wood markets throughout Asia. Further, while production in Russia has picked up in recent years, it appears that substantial quantities of the industrial roundwood harvested are leaving the country before value is added through the production process.

An important trend in forest production in recent years has been the emergence of production through non-indigenous plantation forests. According to FAO (2005), there are around 140 million hectares of plantations established globally (Table 4, column 2 total), and the area of plantations was expanding by around 2.8 million hectares per year in the early 2000's (Table 4, column 3, total). More than half of this expansion has come in China. Forest plantations are used for a variety of purposes, including sawtimber, pulpwood, and fuelwood uses. A different report suggests a smaller area of industrial wood plantations of around 96 million hectares (ABARE – Jaako Poyry, 1999). A large proportion of the plantations established worldwide according to ABARE – Jaako Poyry (1999) are non-indigenous species imported from other regions. Sedjo (2004) estimated that these non-indigenous plantations comprised around 10% of worldwide timber harvest in the mid-1990's. Daigneault et al. (2007) suggests that supply from these plantations is around 13% of world timber supply currently, and that supply from these plantations will increase to over 41% of worldwide timber supply by 2050.

Average prices for industrial roundwood imports and exports have fallen in real terms by 0.7-1.0% per year over the past 40 years (Figure 2). The strongest reductions in prices have occurred in Latin America and Europe. Prices rose over the time period in Asia by 0.3% per year. A price series for delivered logs in the Pacific Northwestern U.S. is also shown, although this price series is available only through the 2002 (R. Haynes, personal communication). The data suggests that prices in that region rose by around 0.6% per year over the last 40 years, although prices have fallen since the highs of the early 1990's. Interestingly, the trends of the past 10-15 years shown in Figure 2 depart from long-term historical price changes, which imply rising resource scarcity for renewable wood resources (Sohngen and Haynes, 1994). This shift results from a change in the global resource base from primarily an old-growth resource to a truly renewable plantation resource (see Sedjo and Lyon, 1990 and Sohngen et al., 1999).

3. GLOBAL FORESTRY DATA DESCRIPTION

Several important pieces of information are useful for modeling forestry within a general equilibrium context:

- Data on the area of forests
- Data on age class distribution of forests
- Data on biomass at different age classes.
- Data on the accessibility of forests
- Data on costs of managing timber
- Data on the value or price of timber.

For some countries, data were derived directly from sources within the country, as noted in Table 5. For other countries, data were derived from the United Nations Food and Agricultural Organization. For each country, the data in this dataset are provided for different forest types (hardwoods, softwoods, and mixed forest types) within agro-ecological zones. The agro-ecological zones are based on temperature, so that ecological conditions within AEZs are roughly consistent. Modelers who wish to account for competition between forests and other land uses, such as agriculture, can model that competition within regions that have consistent ecological attributes by utilizing the AEZ dimension of this data base.

The data pieces identified in table 6 have been made available for each country. Some additional description of each of the variables provided, and the sources for the data, are described below. Table 6 also presents the data for two representative timber types in the United States, Pacific Northwestern Softwood Plantations and Southern Pine Softwood Plantations.

(1) Total hectares (Million hectares):

The total area in hectares for each forest type is derived from various sources for each country. Total hectares for each country are consistent with FAO (2005) Data for individual management types is not based on FAO (2005) data, and thus may differ with that document.

(2) Land Rent ($ per hectare per year):

Land rental is given in year 2000 US $ per hectare per year. Land rental values are derived from the land rental functions used in Sohngen et al. (1999), and Sohngen and Mendelsohn, (2003, 2007). These represent estimates of the value of the land in the next best alternative to forestry (typically agriculture) for the region in question. An alternative measure of rent can be obtained using the net present value calculation discussed below, where annual land rent is approximately r*(net present value), where r is the interest rate. For these data, net present values are provided. Rents can be obtained by multiplying the net present value by the interest rate, which we have assumed is 5%. These are shown for several species in the U.S., China, and Brazil in Table 7. In general, estimates of the rental value based on the rental function will be higher than the rental value derived from the NPV formula because the rental value from the rental function is calculated for the marginal hectare in forests, whereas the net present value is calculated for an average hectare.

(3) Timber Production (Million m^3 per year):

With the exception of a few countries, such as the United States, timber production data by timber type is difficult to obtain. As a consequence, timber production is estimated for each timber type in each country in the dataset with the following methods. First, aggregate national timber production for each country is obtained from the United Nations Food and Agricultural Organization FAOSTATS database (FAOSTATS, 2006). The data are distributed to the specific timber types in each country using results from the baseline simulations in Sohngen and Mendelsohn (2003, 2007). Because these proportions are generated for larger aggregated regions in the analysis by Sohngen and Mendelsohn (2003, 2007), for the country-level estimates provided here, they should only be considered estimates of actual production of those types within a country.

(4) QA Timber Log Price (\$ per m^3):

Quality adjustment factors for log prices have been developed for each region. The numeraire price is US southern softwood timber. Prices for all other types are adjusted so that they are relative to this type. Quality adjustment factors take into account price differentials (using average price data from FAOSTATS), and other factors, such as whether the type typically provides raw material mainly for sawtimber or pulpwood markets. These estimates were developed in the mid-1990's based on data from the 1960's – early 1990's.

(5) QA Net Stumpage Price (\$ per m^3):

Stumpage prices are the quality adjusted timber log price less the costs of accessing the timber (maintaining and building roads), logging, and hauling to mills. The original data for this was derived from Sedjo and Lyon (1990) and adjusted in

Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2007) to reflect changes in general price levels.

(6 - 8) Merchantable Yield function parameters (m^3 per hectare):

Merchantable yield functions represent estimates of the merchantable yield for the timber type in m^3 per hectare of roundwood. There are three parameters used in the merchantable yield functions. The form of the merchantable yield function is:

$$V_a^M \text{ (m}^3\text{ per hectare)} = \exp(m - n/(a - c)) \qquad \text{if age} > c$$

$$V_a^M \text{ (m}^3\text{ per hectare)} = 0 \qquad \text{if age} < c$$

Parameters "m" and "n" are typical growth parameters. Parameter "a" is the age of the forest, and "c" represents a minimum age for merchantable timber. It is assumed that little merchantable timber volume exists on the site before this age. Representative yield functions for upland hardwoods in the U.S. South are shown in Figure 3. For this forest type, $m = 6.46$, $n = 25$, and $c = 30$. While biomass expands relatively rapidly on the site, the merchantable component of biomass takes some years to develop.

Users of these data must be careful when using these yield functions because merchantable timber and carbon are not directly proportional. At young ages, stands may have substantial carbon, but little merchantable timber. An approach to accounting for carbon in younger stands is described below in the discussion for the data item "Forest Carbon Stock". A different issue occurs at the older ages. Many of the merchantable yield functions should only be applied to stands at or below typical rotation ages. These typical rotation ages vary widely for different species, from 10 years old for very productive plantation species, to more than 100 years for northern hardwoods and softwoods. Users need to be careful when using the yield functions beyond economically optimal rotation ages, for example, by imposing maximum ages on their forests (30 years for very productive plantations or 100 years for other species) in their analysis.

(9) *Regeneration Cost ($ per hectare):*

Average regeneration costs are given in year 2000 US $ per hectare. These averages represent average intensity of regeneration effort in the timber type for the country in question. The regeneration estimates are obtained from the model described in Sohngen et al. (1999) for larger aggregated regions than the countries contained in this dataset, and thus can be considered only average estimates of the regeneration costs for a particular timber type in the country in question.

Note that timber modelers should carefully consider how they use these regeneration costs in that regeneration costs are likely to increase on average if timber prices are rising. Further, increases in timber regeneration costs will increase future timber volumes. It is suggested that users of this data who are interested in developing dynamic models potentially follow the methods outlined in Sedjo and Lyon (1990) and Sohngen et al. (1999), where regeneration costs are sensitive to future timber price predictions, and regeneration costs affect the yield of timber.

(10) Net Present Value ($ per hectare):

Average net present value for each timber type is given in year 2000 US $ per hectare. It is estimated as the value of the site in timber production for the timber type using the following formula,

$$\text{(4)} \qquad \text{NPV} = \frac{(P^{QA}) * (V_a^M)(1+r)^a - C}{(1-(1+r)^{-a})}$$

In equation (4), P^{QA} is the quality adjusted net stumpage price, "a" is the rotation age, V_a^M is the merchantable yield of the timber type at age "a", "r" is the discount rate (5% used here), and C is the regeneration cost.

(11) Annual Forest Area Harvested (Million hectares per year):

Annual forest areas harvested are estimated for each timber type using information on the optimal rotation of the timber type from Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2007), the area of the timber type, and total timber harvest in the country. For the purposes of this data, these numbers are approximations for the initial period of the data (circa 2000). Future annual areas harvested will vary prices and harvested quantities change, and these variables will depend on the economic models that independent modelers are developing and the scenarios they are running.

(12) Forest Carbon Stock Total (Million tons C; 1 ton = 1000 Kg = 1 Mg):

The stock of carbon in million metric tons (1 metric ton = 1 Mg = 1000 kg) for each forest type is estimated by using information on the area of forests, the age class distribution, the merchantable yield functions, and the carbon conversion factor to convert merchantable forest stock to metric tons of carbon. Forest carbon stock (FCS) for each timber type is:

(5) $$FCS = \sum_{a=1}^{T} (Area_a) * (V_a^C)\alpha$$

where $Area_a$ is the area of land in each age class, "a", in the timber type, V_a^C is the yield for timber at a specific age, and α is the carbon conversion factor for forest stock described below. Note that in the case of calculating carbon, we use a modified version of the yield function described above in order to account for carbon in young forests. In particular, the following yield function should be used:

(6) $$V_a^C \text{ (m}^3\text{ per hectare)} = \exp(m - n/a)$$

Where the parameters m and n are the same as used in the merchantable yield function described above, however, the parameter c is not used for estimating forest carbon.

(13) Forest Carbon Sequestration 10 yr (Million metric tons C per year):

Forest carbon sequestration in million metric tons (10^6 Mg) per year for each timber type is estimated from Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2007). The estimates are first generated for the broad regional types described in that model. Since that model looks forward, estimates are derived for the period 2000 – 2010, as projected by that model. The results for broad regions are disaggregated to specific countries and timber types based on the proportion of forestland areas of each type in each country. Note that these estimates rely only on disaggregating by proportions of forestland and not upon the actual disaggregated age cohorts by country.

(14) Forest Carbon Sequestration 50 yr (Million metric tons C per year):

Forest carbon sequestration in million metric tons per year for each timber type is estimated from Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2007). The estimates are first generated for the broad regional types described in that model. Since that model looks forward, estimates are derived for the period 2000 – 2050, as projected by that model. The results for broad regions are disaggregated to specific countries and timber types based on the proportion of forestland areas of each type, in each country. Note that these estimates rely only on disaggregating by proportions of forestland and not upon the actual disaggregated age cohorts by country.

(15) Carbon associated with forest stock (Mg C per m^3):

This is the metric tons (Mg) of carbon per m^3 of merchantable wood. The units of this measure are Mg/m^3. In equation (5), this parameter was shown as α. Note that this is a single parameter used to account for the density of specific timber types (typically around 0.5), whole tree factors (typically 1.4 – 1.6), and forest floor carbon. It includes only above-ground storage, and does not include forest soil carbon. These parameters have been calibrated from numerous data sources, and are described in more detail in Sohngen and Sedjo (2000).

(16) Carbon associated with products (Mg C per m^3):

This is the metric tons (Mg) of carbon per m^3 of roundwood, given in Mg/m^3. This parameter should be applied to the removed wood volume that is converted to wood products. It is an average value for both sawnwood and pulpwood products and thus can be used for both.

(17) Long term storage percent:

This estimates the proportion of wood that enters into long term wood products. For this study, a 30% average has been assumed for the world, based on studies by Winjum et al., 1998. This proportion of total volume removed is assumed to be permanently stored in wood products and landfills. Individual modelers may choose to make different assumptions about this variable, depending their own data sources and the particular timber types in which they are interested. For example, estimates of product usage in different market segments, and decay rates for carbon in these different products have been made by numerous authors, including for example, Karjalainen et al. (1994), Heath et al. (1996), Skog and Nicholson (1998). Results from these or other studies could be used by modelers to augment the market storage component.

(18) Net forest area change (FAO data; 1000 hectares per year):

This estimates the net forest area change for each timber type in each country in the dataset. The sum across the regions equals the estimated forest area change based on the recent *State of the World's Forests 2003* report from FAO (2003). Country level estimates have been disaggregated to specific timber types using proportions projected by the model described in Sohngen et al. (1999).

(19) Net forest area change 10 yr (Million hectares per year):

An alternative projection of net change in forest area is estimated using the model described in Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2007). The estimates are first generated for the broad regional types described in that model. Since that model looks forward, estimates are derived for the period 2000 – 2010, as projected by that model. The results for broad regions are disaggregated to specific countries and timber types based on the proportion of forestland areas of each type, in each country.

(20) Net forest area change 50 yr (Million hectares per year):

An alternative projection of net change in forest area is estimated using the model described in Sohngen et al. (1999) and Sohngen and Mendelsohn (2003). The estimates are first generated for the broad regional types described in that model.

Since that model looks forward, estimates are derived for the period 2000 – 2050, as projected by that model. The results for broad regions are disaggregated to specific countries and timber types based on the proportion of forestland areas of each type in each country.

(21) Marginal Access Cost for inaccessible timber types ($ per hectare):

Marginal access costs are applied only for certain inaccessible types occurring in temperate and boreal regions. These marginal access costs represent the cost of building additional access roads and infrastructure to access forests in these regions. They are equivalent to the marginal value of the stumpage on that site (the value of harvesting current old growth forests plus the net present value of the future forest on the site). Note that the net stumpage value for these sites will thus be $0 per hectare when subtracting marginal access costs from the value of current and future harvests.

Forest Area by Age Class:

Inventory data on the area of forests in 10 year age classes is provided. This data has been obtained from original sources within countries where available (Table 1). For other countries, we have utilized data from FAO (2005) on total forest area, and allocated forests to age classes. For countries in the following regions, Southeast Asia, Central and South America, Africa, and Central Asia, the first two forest types (M1 and M2 in the dataset) are high-value timber plantation. These forests have been assigned to specific age classes using the data from Sohngen et al. (1999). For all other types in these same regions where age class information is not available from FAO (2005), forests are assigned to age class 5, or 50 years.

Forest areas are broken into accessible and inaccessible areas. The definition of inaccessible is taken from FAO (2001). The data used comes from Appendix 3 table 15 using the "forest available for wood supply with different distances to infrastructure." For the purposes of our analysis, we have assumed that forests within 10 kilometers of infrastructure (including rivers) is accessible. The rest is inaccessible. We made some adjustments to this: For example, for the US, we used 30 kilometers. For a number of countries, the data were cross referenced with data on accessible forestland provided with the information in UN (2000).

Forest Growing Stock by Age Class:

Growing stock for each age class and accessible and inaccessible forests has been calculated as:

$$(7) \qquad GrowingStock_a = (Area_a) * (V_a^C)$$

Forest Carbon Stock By Age Class:

The stock of carbon in million metric tons (1 metric ton = 1 Mg = 1000 kg) for each forest type is estimated by using information on the area of forests, the age class distribution, the merchantable yield functions, and the carbon conversion factor to convert merchantable forest stock to metric tons of carbon. Forest carbon stock (FCS) for each timber type is:

$$FCS = \sum_{a=1}^{T} (GrowingStock_a)\alpha \tag{8}$$

4. ADJUSTING DATA TO AGRO-ECOLOGICAL ZONES

The data on timber types in each country can be allocated into agro-ecological zones. To do this, three steps were taken. First, predictions of the distribution of different ecosystem types from Haxeltine and Prentice (1996) were overlain with a global forest area dataset from Ramankutty and Foley (1999) to estimate the proportion of forestland residing in each ecosystem type in each country. Second, this estimate of the proportion of forestland in each ecosystem type was used in combination with total forestland estimates from FAO (2005) to determine the area of forestland in each ecosystem type in each country. Third, age class distributions from Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2006) were used to develop country level estimates of the area of forests in each age class and timber type within the country. As described above, for countries where age class data is not available, forests were assigned to the age class 50, or in the case of plantations, age class distributions were inferred from Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2007).

These three steps provided information on the area of land in different types of forests and age classes within each country. To distribute these forest types to AEZs, we use the AEZ definition from Ramankutty and Foley (1999) in combination with the ecosystem type map from Haxeltine and Prentice (1996) to generate an estimate of the proportion of land in each ecosystem type that resides in each AEZ. These proportions were used to allocate the timber types in each country to AEZs. Because we do not have specific age class information on AEZs, each age class is proportionally allocated by total area to the respective AEZs for a timber type.

Although estimates of the area of forestland and the age class distribution of forests by AEZ have been generated, it is not feasible to generate corresponding estimates of all the economic parameters in the dataset by AEZ. These economic parameters include prices, costs, parameters for yield functions, factors for carbon sequestration, etc. Data at the country or regional level from Sohngen et al. (1999) and Sohngen and Mendelsohn (2003, 2007) are provided for each of the timber types within AEZs.

5. DATA LIMITATIONS

Several caveats with the data should be considered. First, one would typically expects more timber price variation across countries than reflected in these data. The prices and quality adjustment factors for prices were originally developed for a global model that aggregates the world into 9 regions: North America, South and Central America, Europe, the Former Soviet Union, China, Asia-Pacific, India, Oceania (Australia and New Zealand), and Africa. Within each of these regions, there are likely to be price differentials reflected in other data sources that are not reflected here. For modelers interested in global analyses, the price differentials contained in this data are adequate for general comparisons across broad global regions. However, modelers seeking to use the data for more selected local analyses involving countries within a particular region may consider adjusting the prices used for timber with more recent data from the FAOSTATS database (FAOSTATS, 2006).

Second, an analogous issue is that there will be larger differences in forest productivity in particular countries than reflected in these data. The reasons are similar to those described above for prices: The productivity of land in specific timber types was originally estimated so that it could be applied to large areas of timber in the nine regions of the model in Sohngen et al. (1999). The same parameters have been applied to all timber types in each country located in a particular region. Thus, the productivity estimates may fail to reflect important differences in specific countries. Unlike price data, however, there are no global databases with country specific timber yield function parameters, hence it is not possible at this point to make further corrections to the data for specific countries.

Third, in addition to providing country specific data, the data on forestland areas has been further disaggregated to specific AEZs. Thus, the dataset provides an estimate of the quantity of timber in a timber type in each agro-ecological zone. While the overall estimates of forestland areas in specific AEZs conform to the aggregate estimates from Ramankutty and Foley (1999), the dataset only provides economic information on the general timber type, not a specific set of parameters for each timber type and AEZ combination. There are reasons to believe that the same timber type might have different productivity in different AEZs (e.g., oaks grow at different rates in different ecological zones), but it was not possible with this data to estimate those differences.

Clearly, there are uncertainties associated with the data and parameters provided in this dataset. For instance, the inventory data for many countries, like the U.S., Canada, Europe, and Russia are collected by sampling plots within the country and sometimes combining this data with satellite observations. Extrapolating plot level data to entire regions or countries has inherent uncertainties. While in some cases, the sampling distributions can be determined from the underlying data, this information has not as of yet been included in the data set. Alternatively, satellite data is often used to estimate forest areas and deforestation rates in developing tropical countries. The satellite observations, however, are often taken for specific regions and then extrapolated to larger areas (i.e. Houghton, 2003). At this time, information on the distribution of key data and parameters in this dataset has not been compiled and is not presented.

6. CONCLUSION

This chapter describes the development of a global forestry database that can be used in the context of partial and general equilibrium modeling. The data provides country-level information on the initial area of forests by timber or ecological type, the age class distribution (where available), and economic parameters useful for modeling forestry. Forest areas, age class distributions, and carbon stocks are broken into AEZs for modelers interested in modeling land comp etition between forestry and agriculture within regions that are fairly homogeneous. The data are available at the Global Timber Market and Forestry Data Project website: http://aede.osu.edu/people/sohngen.1/forests/GTM/index.htm.

Chapter 11[1] in this volume describes how this data can be used in modeling. Specifically, that chapter examines the importance of modeling age classes in forestry when considering carbon sequestration policy, and different methods that can be used to capture components of this dynamic picture within the context of static CGE modeling. Readers interested in obtaining additional information should consult with that chapter and with the models referenced in that chapter.

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[1] GTAP Working Paper No. 49

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Table 1. Forestland and timberland statistics for regions of the world, with comparison between data compiled for Sohngen and Mendelsohn (2005) and FAO (2005). Data in parentheses is proportion of world total.

	Sohngen & Mendelsohn (2005)			FAO (2005)		
	Total Timberland	Carbon		Total Forestland	Δ ha yr^{-1}	Total Land Area
		Aboveground	Total	Hectares	Hectares	Hectares
	10^6 hectares	Pg C	Pg C	10^6 ha	10^6 ha	10^6 ha
US	201.7 (0.06)[1]	11.9	49.9 (0.06)	303.1	159	962.9
Canada	412.8 (0.11)[2]	12.8	132.3 (0.15)	310.1	0	997.1
South America	868.7 (0.24)[3]	103.7	210.1 (0.23)	831.5	-4,253	1,783.8
Central America	56.4 (0.02)[3]	5.2	12.3 (0.01)	86.7	-545	248.0
Europe	186.7 (0.05)[4]	5.9	27.8 (0.03)	192.6	757	590.2
Russia	838.1 (0.23)[5]	35.9	255.6 (0.29)	808.8	-96	1,707.5
China	154 (0.04)[6]	7.3	27.3 (0.03)	220.0	3,841	1,138.4
India	49.9 (0.01)[3]	3.3	9.9 (0.01)	67.7	29	328.7
Oceania	199.2 (0.06)[3,7]	5.2	25.2 (0.03)	206.3	-355	856.4
Southeast Asia	209.1 (0.06)[3]	27.6	54.7 (0.06)	215.4	-2,879	569.5
Central Asia	38 (0.01)[3]	1.3	6.3 (0.01)	43.6	13	1,102.7
Japan	23.7 (0.01)[3]	0.9	4 (0.00)	24.9	-2	37.8
Africa	356.1 (0.10)[3]	35.6	81 (0.09)	635.4	-4,039	3,031.0
Total	3,594.4	256.6	896.2	3,946.1	-7,370	13,354.0

[1] USFS FIA, Various Years; [2] Lowe et al (1994); [3] FAO (2000, 2005) and regional sources; [4] Kuusela (1993); [5] Forest Account (2003); [6] Ministry of Forestry, Center for Forest Inventory; [7] Bureau of Rural Sciences (2003), ABARE (1999), New Zealand Ministry of Agriculture and Forestry (MAF).

Table 2. Average Industrial Wood Production 2001 – 2005, and Annual % Change 1995 – 2005. Data from FAOSTATS-Forestry (http://faostat.fao.org/)

	Production		Consumption
	Million m^3/yr (Proportion of Total)	% Chg/yr (1995 - 2005)	Million m^3/yr (Proportion of Total)
US	412.0 (0.26)	0.45%	404.1 (0.25)
Canada	193.2 (0.12)	0.70%	195.4 (0.12)
South America	155.1 (0.10)	2.70%	152.6 (0.1)
Central America	10.3 (0.01)	0.14%	10.3 (0.01)
Europe	364 (0.23)	2.07%	383.1 (0.24)
Russia	126.6 (0.08)	5.22%	88.2 (0.06)
China	98.3 (0.06)	-0.45%	127.6 (0.08)
India	20.6 (0.01)	-0.70%	23.4 (0.01)
Oceania	48.7 (0.03)	1.89%	38.4 (0.02)
Southeast Asia	77.8 (0.05)	-1.40%	71.9 (0.04)
Central Asia	13.8 (0.01)	0.24%	15.5 (0.01)
Japan	15.6 (0.01)	-3.48%	28.1 (0.02)
Africa	69 (0.04)	0.43%	64.8 (0.04)
Total	1604.9	1.19%	1603.3

Table 3. Average Sawnwood Production, Consumption, and Net Imports (2001 – 2005), Data from FAOSTATS-Forestry (http://faostat.fao.org/)

	Production	Consumption	Net Imports	Net Imports/Consumption
	Million m^3/yr	Million m^3/yr	Million m^3/yr	(Proportion if positive)
US	89.9	125.0	35.1	28.1%
Canada	58.0	21.2	-36.8	--
South America	35.3	29.7	-5.6	--
Central America	4.4	6.8	2.4	35.3%
Europe	111.7	105.2	-6.5	--
Russia	20.5	9.5	-11.0	--
China	14.9	20.6	5.7	27.7%
India	11.8	11.8	0.0	--
Oceania	8.3	7.3	-1.0	--
Southeast Asia	17.2	13.9	-3.3	--
Central Asia	6.6	11.2	4.6	41.1%
Japan	14.0	22.8	8.8	38.6%
Africa	8.5	11.6	3.1	26.7%
Total	401.7	397.3	-4.3	28.1%

Table 4. World forest plantations.

	FAO (2005)			ABARE (1999)
	2000	2005	Δ Hectares 2000 - 2005	~ 1998
	Million ha	Million ha	1000 ha yr^{-1}	Million ha
US	16.3	17.1	157.4	16.3
Canada	0.0	0.0	0.0	2.5
South America	10.6	11.4	156.6	6.6[1]
Central America	1.3	1.3	12.6	0.1
Europe	11.2	10.7	100.6	16.9
Russia	15.4	17.0	320.4	8.9
China	25.2	32.8	1,531.6	11.3[1]
India	2.8	3.2	84.2	4.9
Oceania	3.5	3.9	74.8	2.8[1]
Southeast Asia	12.4	13.4	202.5	5.8[1]
Central Asia	4.9	5.1	28.4	0.0
Japan	10.3	10.3	-2.0	10.5
Africa	12.7	13.2	110.6	3.7[1]
Total	126.5	139.3	2,777.7	95.9

[1] Largely non-indigenous plantations.

Table 5. Countries/Regions for which data was derived from primary sources within the countries or regions, and the sources of the data.

Region and Data Source	Area	Distinguishes forest types & subregions	Distinguishes Forest Age Class	Timber Production Estimated
US: USDA, Forest Service Forest Inventory and Analysis (USFS FIA, Various Years)	Yes	Yes	Yes	Yes
European countries: Kuusela (1993)	Yes	Yes	Yes	Yes
Russia: Forest Account (2003); Backman and Waggener (1991)	Yes	Yes	Yes	Yes
Canada: Lowe et al. (1994)	Yes	Yes	Yes	Yes
Australia: Bureau of Rural Sciences (2003) ABARE (1999)	Yes	Yes	No	No – except plantations
New Zealand: New Zealand Ministry of Agriculture and Forestry (MAF).	Yes	Yes	No	No – except plantations
China (Ministry of Forestry, Center for Forest Inventory)	Yes	Yes	Yes	Yes
All Other Countries: UN FAO (2005)	Yes	Yes	No	No

Table 6. Data for two U.S. Management Types. Numbers in the left-most column refer to the numbers in the descriptions of the data in the text.

#	Data Name	Description	M1 US PNW Plant.	M2 US South Pine Plant.
1	Total hectares (Million hectares)	million hectares circa 1990 – 2000	3.97	10.02
2	Land Rent ($$/ha; from rental function)	Marginal land rent ($$ per hectare for last hectare in forests)	$50.46	$262.59
3	Timber Production (Million m3/yr)	Annual timber roundwood production	18.63	46.35
4	QA Timber Log Price ($$ per m3)	Quality adjusted gross log price	$80	$80
5	QA Net Stumpage Price ($$ per m3)	Quality adjusted net log price (gross price - marginal access, harvesting and hauling costs)	$49	$49
6	Yield function parameter "a"	Merchantable yields are given in m^3/hectare	6.15	5.4
7	Yield function parameter "b"	Merchantable yields are given in m^3/hectare	30	25
8	Yield function parameter "c"	Merchantable yields are given in m^3/hectare	30	10
9	Regneration Cost ($$ per ha)	Average regeneration costs per hectare	$200	$250
10	NPV ($$ per ha)	Net present value of bare land in the forest type	$638	$1479
11	Annual Forest Area Harvested (Million ha/yr)	Estimate of annual area of forestland currently harvested.	0.07	0.31

Table 6, Continued

#	Data Name	Description	M1 pnw plt	M2 s.p. plt
12	Forest Carbon Stock (Million Tons Carbon)	Total Stock of carbon in forests in million Mg carbon (1Mg = 1000 Kg)	177.15	149.88
13	Forest Carbon Sequestration (Million Tons/yr) 10 yr	Projected carbon changes in stock over the period 2000 – 2010, derived from timber model described in Sohngen et al. (1999)	-2.16	3.00
14	Forest Carbon Sequestration (Million Tons/yr) 50 yr	Projected carbon changes in stock over the period 2000 – 2050, derived from timber model described in Sohngen et al. (1999)	2.27	12.00
15	Carbon associated with forest stock (Mg/m3, or Tons/m3)	Conversion factor to take merchantable forest stock and convert to carbon; accounts for whole tree factor and other carbon on the site, but which is not merchantable.	0.24	0.28
16	Carbon associated with products (Mg/m3, or metric tons/m3)	Conversion factor to take harvested timber logs and convert to carbon.	0.22	0.25
17	Long term storage percent (percent in long term wood products)	Percent of harvested timber assumed to be stored in long term timber products	0.30	0.30
18	Net forest area change (FAO data; thous ha/yr)	Regional estimate of net forest area change predicted by FAO for 1990 - 2000	11.863	18.807
19	Net forest area change (Million ha/yr) 10 yr	Projected forest area change over the period 2000 – 2010, derived from timber model described in Sohngen et al. (1999)	0.09	-0.21
20	Net forest area change (Million ha/yr) 50 yr	Projected forest area change over the period 2000 – 2010, derived from timber model described in Sohngen et al. (1999)	0.03	0.04
21	Marginal Access Costs for inac. ($$ per ha)	Marginal access cost for marginal hectare accessed.	NA	NA

Table 7. Comparsion of rental values calculated from the set of rental functions in Sohngen and Mendelsohn (2007) and from the net present value (NPV) formula.

	Rental Function	Rent Derived from NPV Formula
	$/ha/yr	$/ha/yr
United States		
US PNW Conifer Plantation	$50.46	$14.40
US Southern Pine Plantation	$262.59	$132.71
US Southern Natural Pine	$15.79	$15.13
China		
China Plantation - South	$77.17	$13.26
China Temperate Mixed	$16.21	$3.59
China Northern Softwoods	$13.66	$3.47
Brazil		
Brazil Softwood Plantation	$262.52	$350.03
Brazil Hardwood Plantation	$266.17	$354.89
Brazil Tropical Forest	$7.74	$1.55

Figure 1. World Industrial Roundwood Production, 1961 – 2005.

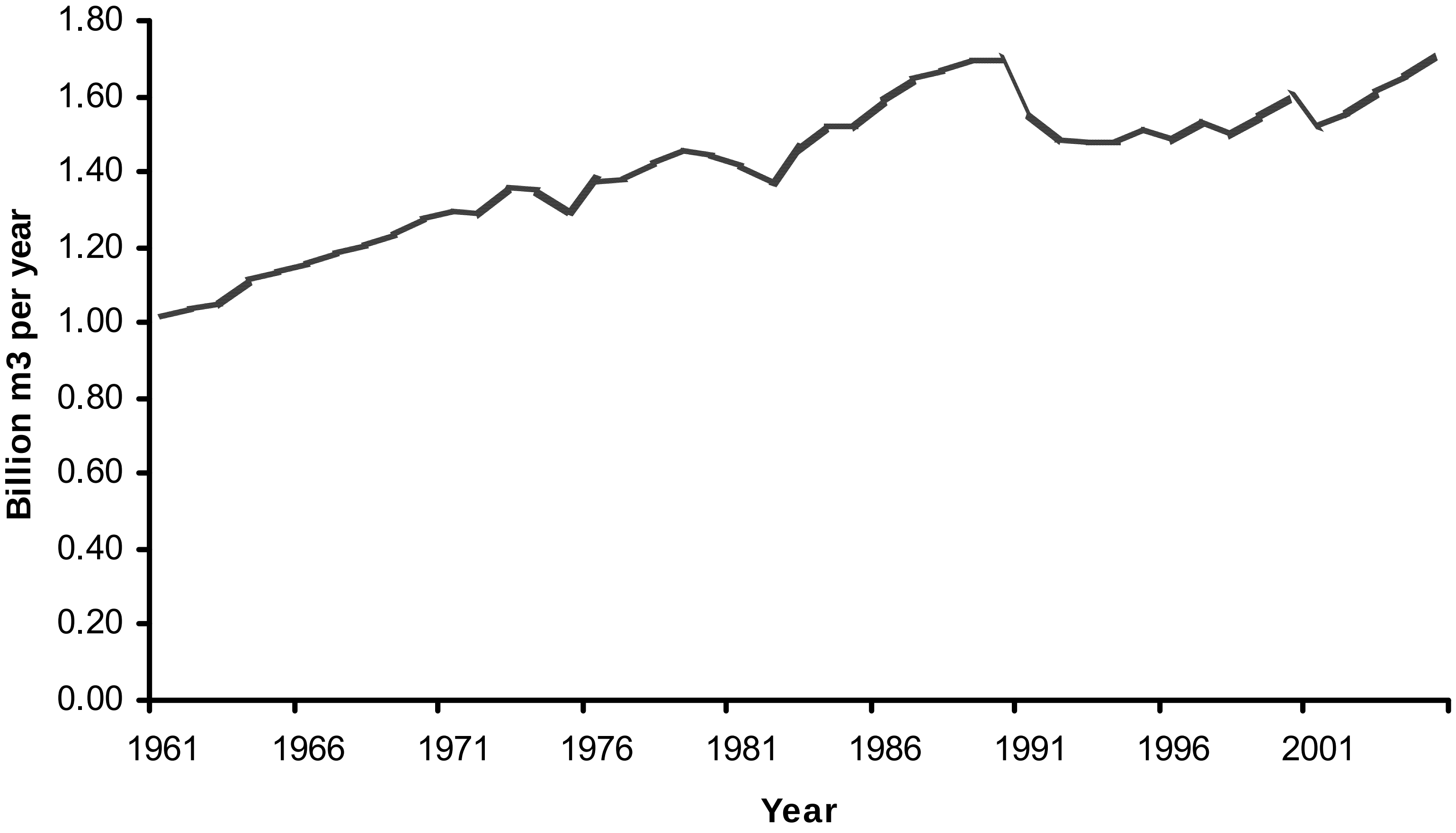

Figure 2. World industrial roundwood prices for imports and exports (FAOSTATS) , and U.S. Pacific Northwest (PNW) delivered log prices (R. Haynes, personal communication). World average import and export prices are F.O.B. prices at the point of important or export (FAOSTATS). U.S. PNW Delivered Log Prices are the price of delivered logs to the point of milling.

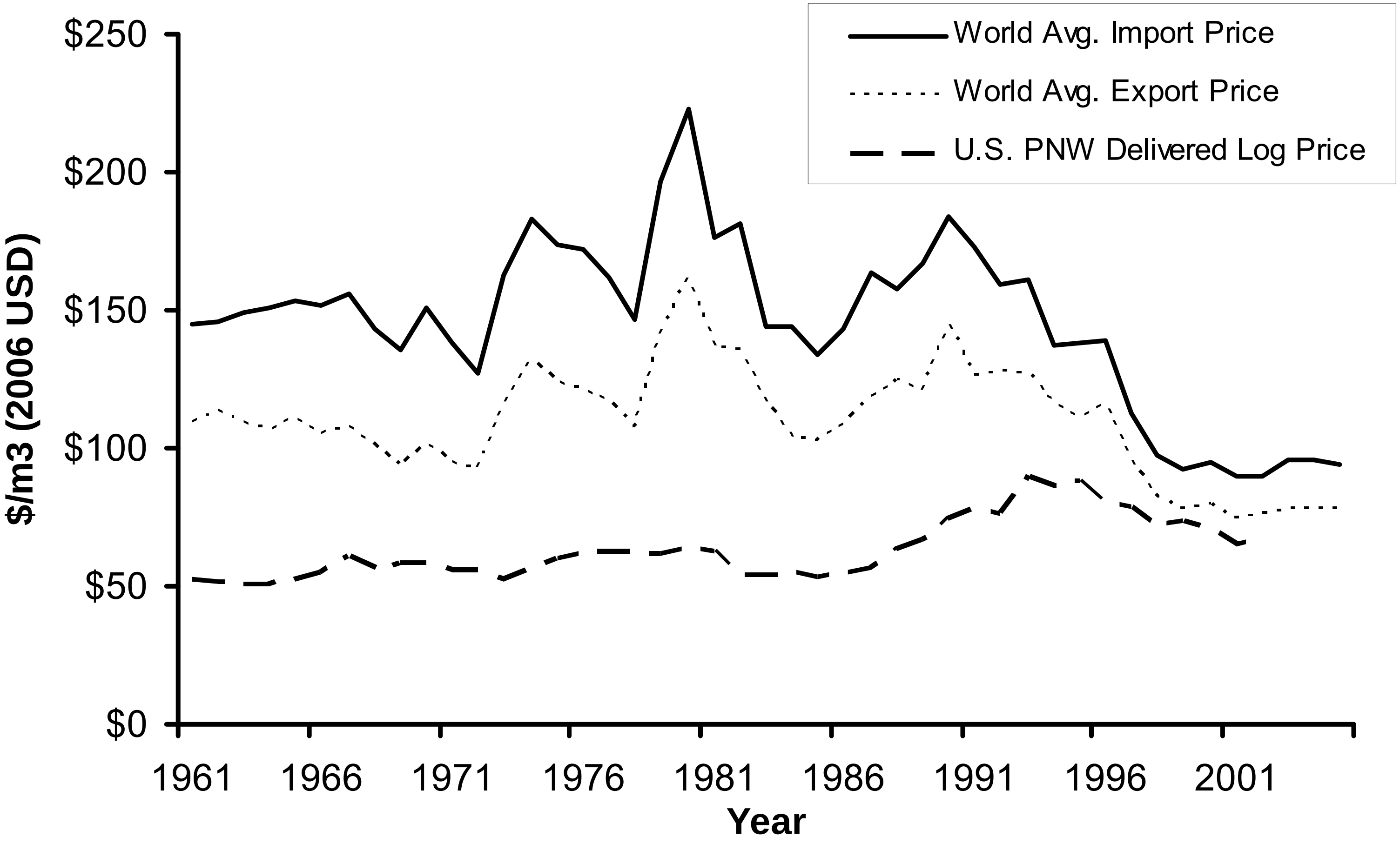

Figure 3. Biomass yield and merchantable timber yield functions for upland hardwoods in the U.S. south.