WORLD RESOURCES INSTITUTE

TECHNICAL NOTE

SPATIAL DATABASE OF PLANTED TREES (SDPT VERSION 1.0)

NANCY HARRIS, ELIZABETH DOW GOLDMAN, AND SAMANTHA GIBBES

ABSTRACT

The online Global Forest Watch (GFW) platform has become essential to how the international community understands and interacts with forest information. While most international policy frameworks and private sector commitments refer to monitoring "forests" or "natural forests," GFW monitors global "tree cover" and "tree cover change." "Tree cover" on the GFW platform includes natural and planted forests, as well as oil palm, rubber, orchards, cocoa, coffee, and other tree crops that are not typically considered forest.

The objective of this work is to spatially differentiate plantation forests and tree crops from natural and seminatural forests on a global scale. For this purpose, "tree crops" are stands of perennial tree crops, such as rubber, oil palm, coffee, coconut, cocoa, and orchards, and "planted forests" are stands of planted trees—other than tree crops—grown for wood and wood fiber production or for ecosystem protection against wind and/or soil erosion. By identifying and eliminating these areas from GFW's global map of tree cover, "natural forest" areas can be more readily isolated, leading to more effective tracking of national and global progress toward major international commitments that relate to forests, climate, and biodiversity. We conducted extensive outreach to compile, synthesize, and harmonize national maps of the world's planted forests and tree crops into a global map (Figure 1), which we refer to as the Spatial Database of Planted Trees (SDPT). Results show that in 2015, there were approximately 173 million hectares of planted forests worldwide, or slightly

CONTENTS

Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

Suggested Citation: Harris, N.L., E.D. Goldman, and S. Gibbes. 2019. "Spatial Database of Planted Trees Version 1.0." Technical Note. Washington, DC: World Resources Institute. Available online at: https://www.wri.org/publication/spatial-database-planted-trees.

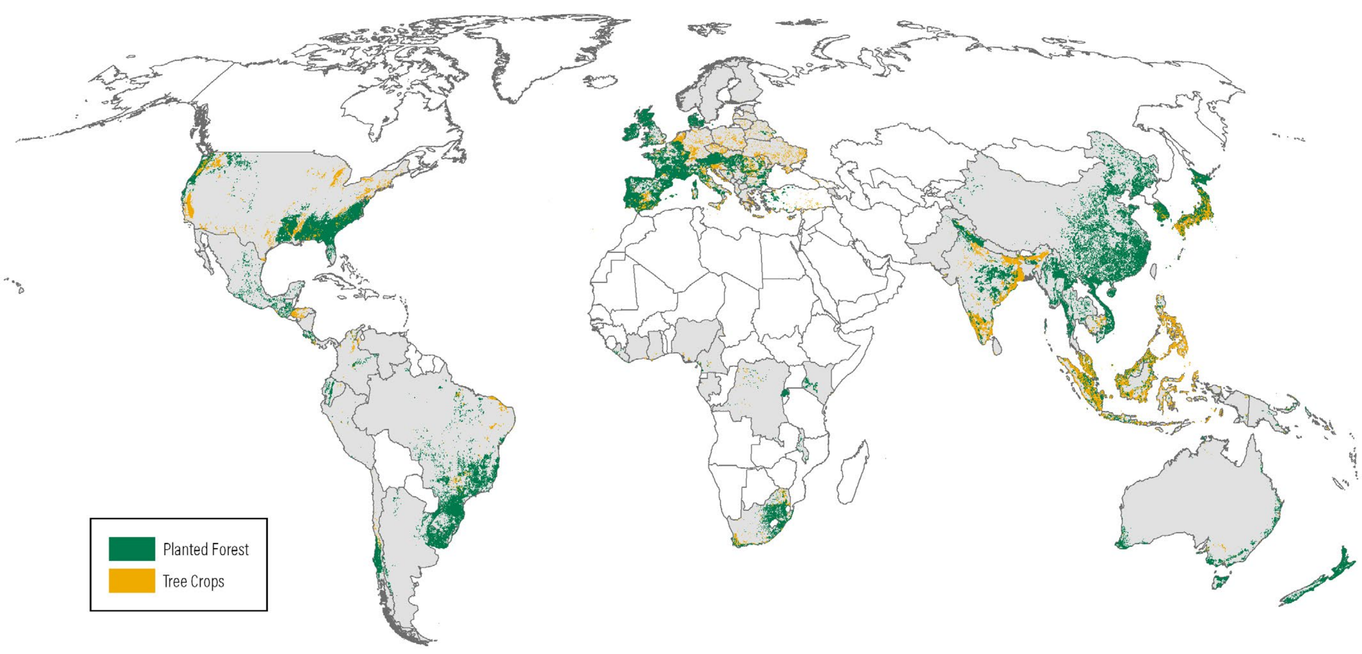
over 4 percent of total tree cover. An additional 50 million hectares were mapped as tree crops.

Ultimately, this first version of the SDPT is intended to incentivize the necessary efforts to improve information about where planted forests and tree crops are located throughout the world. The SDPT stands out as a living database that will continually evolve and improve as new data are produced by governments and independent researchers alike.

1. INTRODUCTION

Forests account for one-third of all land on Earth, or slightly over 4 billion hectares (ha) (Hansen et al. 2013; FAO 2015), and vary widely in terms of canopy cover, structure, and species composition. A continuum of forest states exists between primary natural forests and plantations, all of which can supply wood, fiber, fuelwood, and nonwood forest products, as well as provide important ecosystem services such as biodiversity conservation, climate regulation, carbon storage, and water supply. Plantations are able to efficiently produce high quantities of wood products that may alleviate pressure on natural forests, create jobs that support rural development, and/or provide a range of ecosystem services, especially when established on degraded lands. On the other hand,

Figure 1 | **Global Map of Planted Forests and Tree Crops**



Source: Various sources (summarized in Appendix A), compiled by World Resources Institute.

plantations and agricultural monocultures (e.g., oil palm) can have negative social and/or environmental impacts, such as conflicts relating to land tenure, loss of aesthetic values, declines in biodiversity and carbon stocks, and disruptions to hydrological cycling, compared to natural forests (Batra and Pirard 2015).

National statistics on global forest resources have been compiled by the Food and Agriculture Organization (FAO) of the United Nations since 1948. Changes in definitions, inconsistent data quality across countries, and lack of transparency about which areas within a country have moved into and out of different forest classes make evaluating global and national trends in forest quantity and quality difficult (Box 1). To provide an independent global record of how forests are changing around the world and in order to overcome gaps in spatially detailed forest information, Hansen et al. (2013) produced the first globally consistent and spatially detailed maps of annual tree cover change, using freely available Landsat satellite data from the U.S. Geological Survey. Gross tree cover loss data have been updated annually from 2001 to 2017, and gross tree cover gain data represent cumulative gains over the period 2000–12 (with annual updates to tree cover gain forthcoming).

The online Global Forest Watch (GFW) platform aims to increase public accessibility of these and other datasets derived from satellite imagery, enabling one to see how forests are changing around the world. On these maps, "tree cover" is defined as any woody vegetation greater than 5 meters in height; tree cover can be visualized at various canopy density thresholds (e.g., greater than 10 percent, 20 percent, 30 percent, etc.). On the GFW platform, tree cover is mapped as a single undifferentiated class. Therefore, tree cover includes primary, secondary, and planted forests, as well as tree cover within agricultural landscapes (oil palm and coffee plantations and orchards, among others) if these landscapes meet the biophysical height and cover criteria applied by Hansen et al. (2013) to define tree cover.

The objective of this work is to spatially differentiate plantation forests and tree crops from natural and seminatural forests on a global basis. This information can be used to disaggregate GFW's global tree cover change statistics, derived from spatially explicit data, into loss and gain occurring within natural and seminatural forests versus that occurring within plantations and agricultural systems containing tree crops. Since no method has been developed to delineate from satellite imagery all types of forest plantations and tree crops in a globally consistent and automated way, we compiled and synthesized national and regional spatial data into a global, harmonized Spatial Database of Planted Trees (SDPT). Until such a globally consistent dataset becomes available, we anticipate that this effort in data synthesis will increase public access to existing plantation and tree crop data. The SDPT is intended also to serve as an interim measure that enables GFW to report more confidently on areas of tree cover loss occurring within natural and seminatural forests. As such, we view the SDPT as a living database that will continually evolve and improve as new data are produced by governments and independent researchers alike.

Box 1 | What Is a Planted Forest?

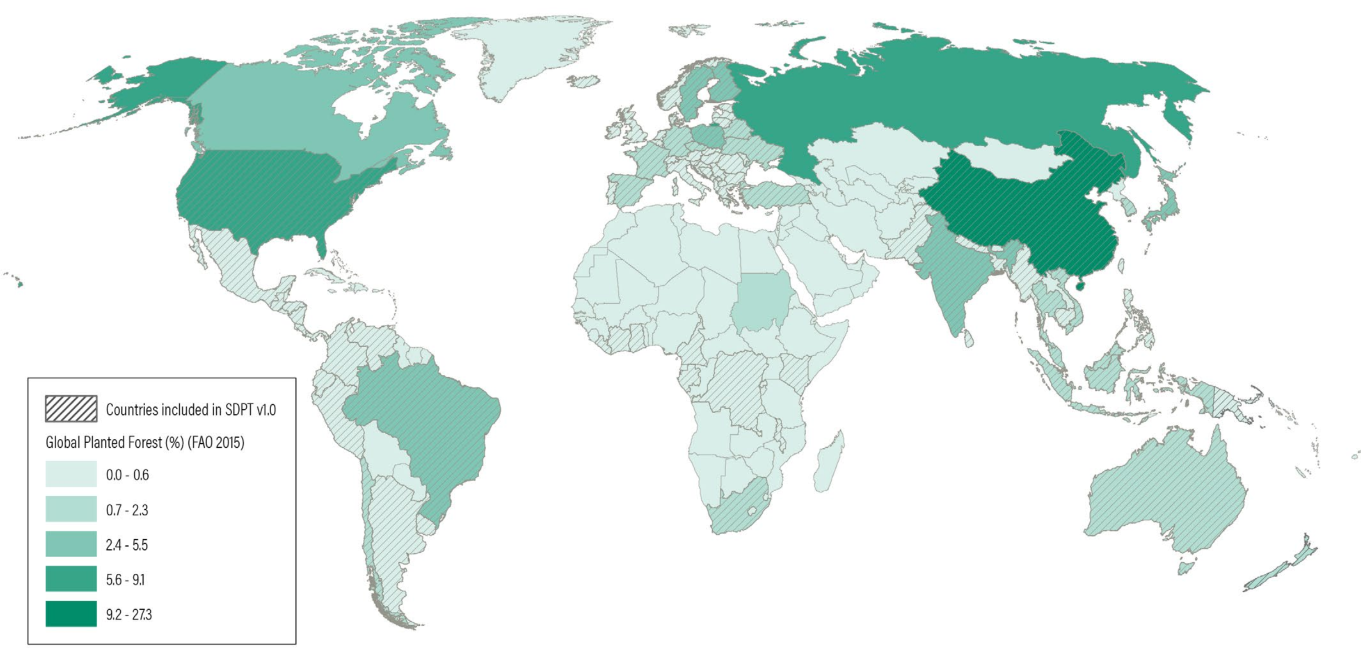
According to the most recent Forest Resources Assessment of the Food and Agriculture Organization (FAO) in 2015, there were approximately 293 million hectares of planted forest in the world, representing 7 percent of the world's estimated total forest area of 4 billion hectares (FAO 2015). Information about the distribution of global planted forests by country (Figure 2) reflects a compilation by FAO of national statistics reported by individual countries every five years. Countries included in Version 1.0 (v1.0) of the Spatial Database of Planted Trees (SDPT) are also shown in Figure 2; the overlay demonstrates that many countries with substantial areas of planted forest are included in the SDPT as well.

FAO's definition of planted forests has changed over time. Plantations were first defined by FAO as "trees established through planting and/or deliberate seeding of native or introduced species." (FAO 2000). Due to the specific case of plantations that were established long ago with low-intensity management—usually excluded from statistics about plantations, particularly in Europe—FAO (2004) further changed the scope to include "seminatural" forests; that is, forests established with native species or areas with intensive natural regeneration. In addition, FAO (2000) differentiated between plantation types a subset of planted forests, based on their productive or protective functions. To resolve issues of definition, FAO introduced in 2006 the term "planted forests" (Del Lungo et al. 2006), which covers a range of ecosystems from seminatural forests where trees were planted with subsequent light management, to strictly man-made tree plantations with short rotations. For the upcoming Forest Resources Assessment 2020, FAO has revised its definition of planted forest again to "forest predominantly composed of trees established through planting and/or deliberate seeding" and plantations as "planted forest that is intensively managed and meet ALL the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing."

Changing definitions and the lack of a universal typology applied by all countries have led to substantial confusion and debate about the usefulness of such a typology (Batra and Pirard 2015). Our effort to map planted forests was intended neither to resolve the definitional debate nor to generate primary data; it was simply an exercise in data synthesis. As such, planted forest areas have been included in the SDPT on a case-by-case basis, depending on the unique classification structure of each available dataset. We focus on including plantations that were likely to be intensively managed and excluded from our compilation areas of seminatural forests with intensive natural regeneration. These areas are common across Canada, Russia, and many European countries. The exclusion of seminatural forests from the SDPT has resulted in substantial differences for some countries between SDPT estimates of planted forest area versus those reported to FAO.

We also did not attempt to create a universal definition for a "tree crop" in the SDPT. Where available, we compiled maps of agroforestry systems and various perennial tree crops as an additional category to the SDPT, since these landscapes may also be included as tree cover, as defined by GFW, although they do not represent natural forest cover. The tree crop class in the SDPT does not include areas of trees that may be present within agricultural landscapes such as, windbreaks or shelter belts.

Figure 2 | Planted Forest Area, as a Percentage of Total Forest Area, Varies by Country



Source: FAO 2015. Countries included in Version 1.0 of the Spatial Database of Planted Trees are shown in hatched shading.

2. SPATIAL DATABASE OF PLANTED TREES

Data contained within the SDPT were created by various data providers, using different methodologies and definitions, and produced in varying output formats. These variations are summarized below. The complete list of maps and data descriptions included in this global synthesis is provided by country in Appendix A.

2.1 Source Datasets

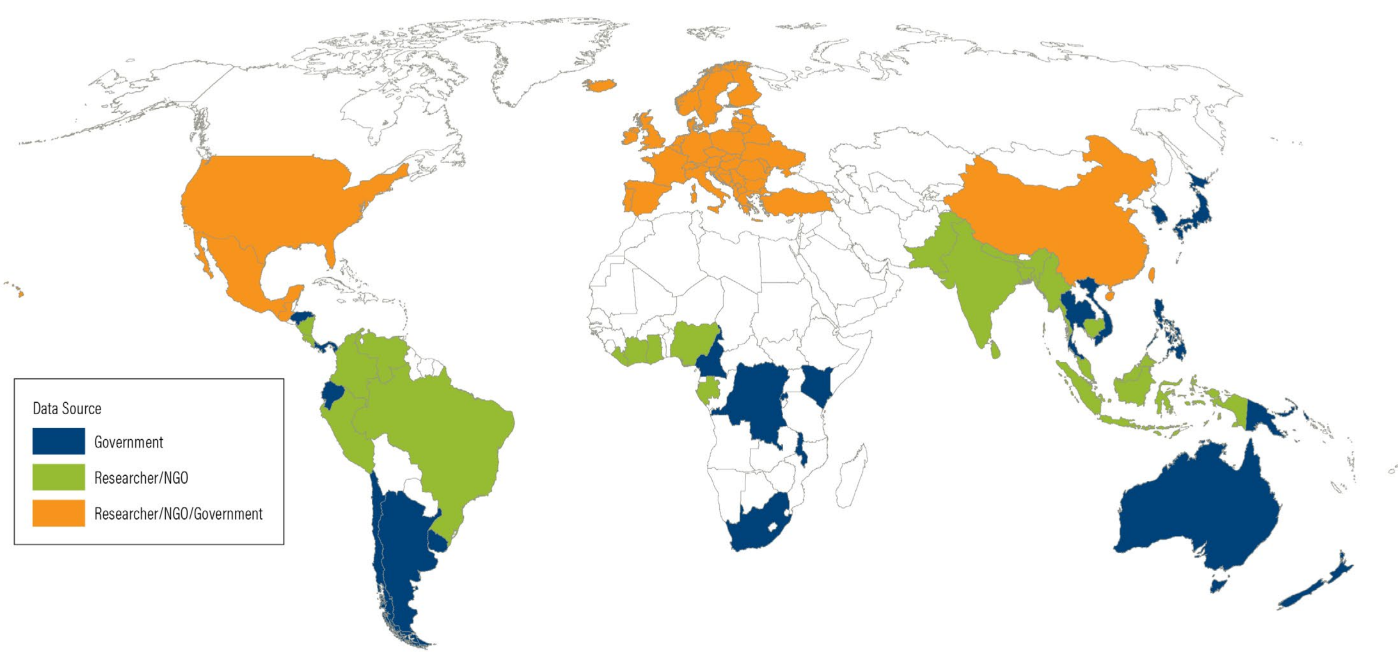
Relevant source data layers were compiled from national governments, nongovernmental organizations, independent researchers, or a combination of sources (Figure 3). Countries covered in v1.0 of the SDPT represent 82 percent of total global planted forest area, as reported in FAO (2015), or 93 percent of all global planted forest area outside of Canada and Russia. These two countries were excluded from the SDPT due to the high prevalence of seminatural forests rather than forest plantations.

2.2 Source Methodologies

Methods for mapping the extent and location of planted forests and tree crops vary by country (Figure 4). Land cover mapping has historically involved manual interpretation of aerial photography or satellite imagery, although many government agencies and researchers have shifted toward the generation of multiclass land cover maps, using automated classification methods. A single methodology would be preferable for mapping all planted forests and tree crops globally to ensure consistency; however, some methods may be more appropriate than others in different country contexts.

Almost all information included within the SDPT was derived from objective information, such as satellite-based observations and/or ground surveys, rather than from the boundaries of areas administratively designated for planting trees (e.g., concession boundaries). For some countries, a map was produced as the result of a

Figure 3 | **Sources of Data Used to Create the Spatial Database of Planted Trees**

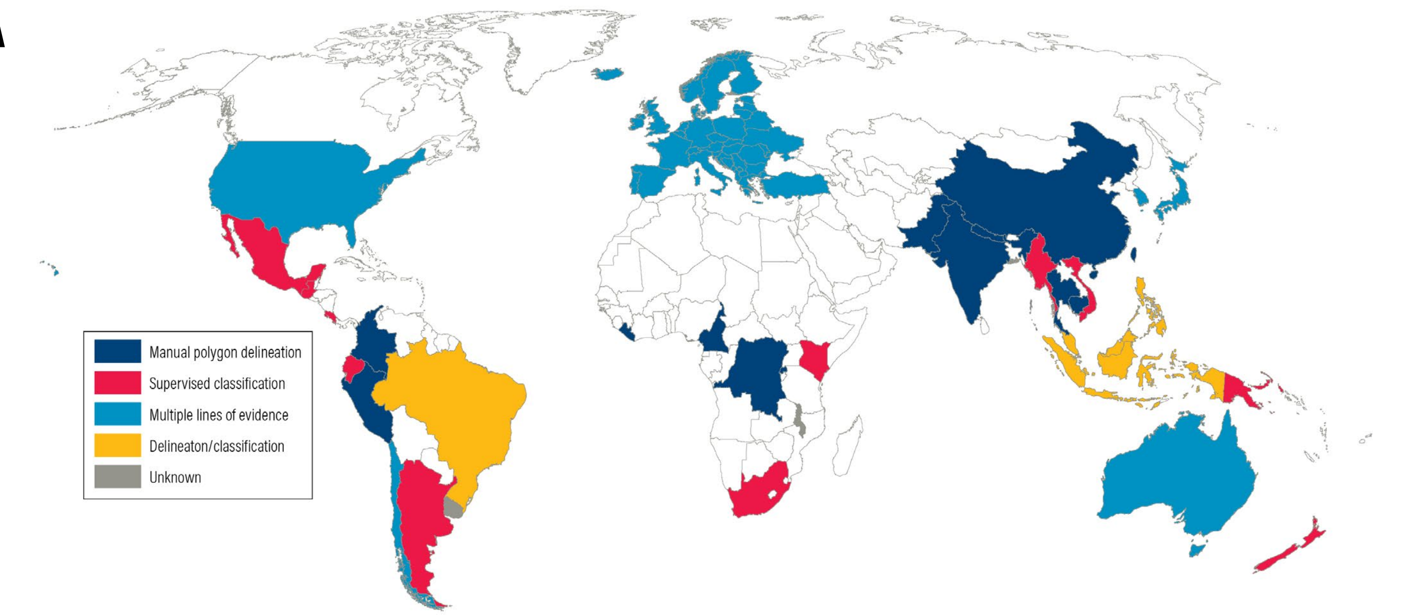


Source: WRI authors.

manual delineation of plantation or tree crop boundaries by expert interpreters using satellite imagery. For other countries, we extracted a forest plantations class or tree crops class from existing national land cover maps. For European countries and the United States, planted forest data were not available as stand-alone files or as a class within existing land cover maps. In these cases, we performed overlays of relevant spatial data layers to produce maps of likely planted forest locations, based on a Multiple Lines of Evidence approach. In Cameroon, concession boundaries were informed by satellite imagery interpretation, although they represent the single exception that reflects official concession boundaries for plantations and other types of planted trees, given that actual boundaries of planted trees were not delineated. For countries where no other tree crop information was available, we used a crowdsourced data layer from OpenStreetMap, which delineates locations of orchards worldwide. Methods are described in further detail in Appendix A.

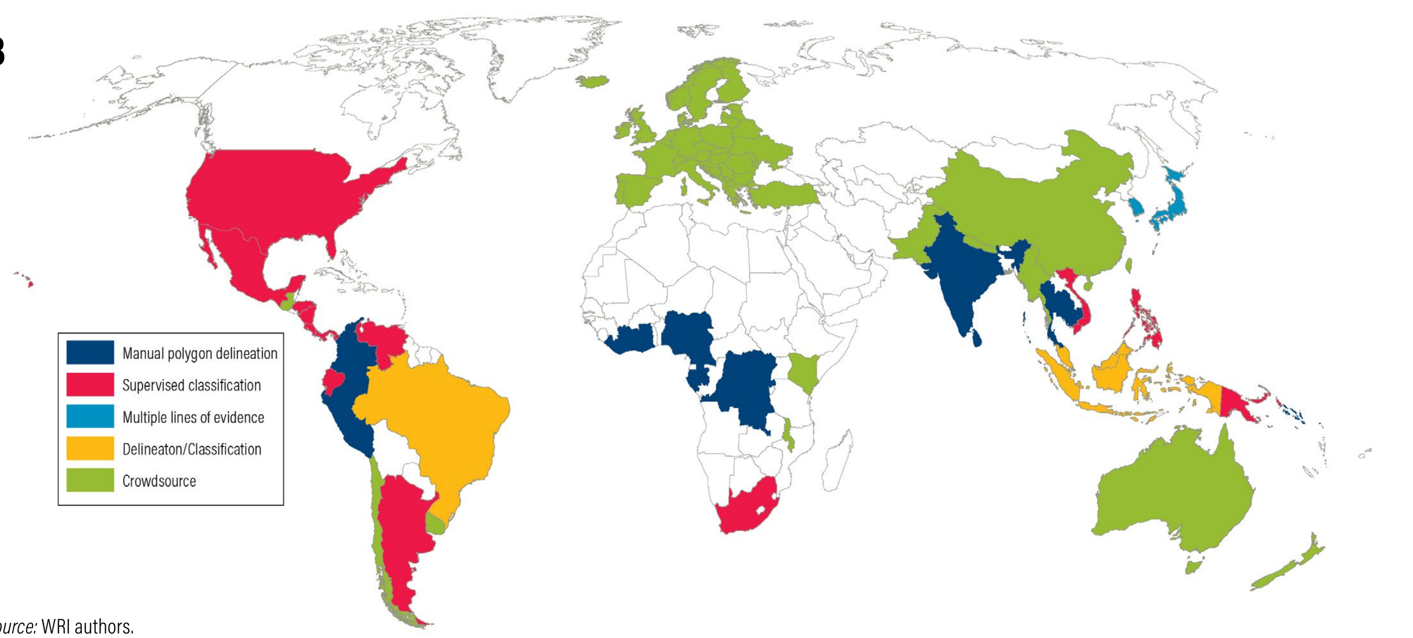
Figure 4 | **Methods Used to Delineate Boundaries of (A) Planted Forests and (B) Tree Crops**

A



Source: WRI authors.

B



Source: WRI authors.

2.3 Database Format

We created the SDPT as a Geographic Information System (GIS) vector file, linked to an attribute database. We also transformed the vector file into a raster (grid) file for the purpose of intersecting the SDPT with GFW's tree cover data. The attribute database provides information on the country, representative year, original data source, polygon area and, where available, species, ownership, and size information. The core field for identifying an individual polygon is ID_Global, the harmonized identifier of the SDPT providing the link to the spatial boundary.

2.4 Attribute Descriptions

Table 1 lists the full contents of the database and provides a description of each attribute. Within the database, missing fields in an attribute column indicate that no information was provided in the source data.

3. METHODS FOR HARMONIZATION OF DATA LAYERS

Several steps were involved to locate, download, clean, and process each individual dataset prior to being integrated into the harmonized global database. In the harmonization process, we preserved all attributes of original source datasets.

3.1 Data Download

Land cover, planted forest, and/or tree crop datasets were downloaded directly from the web, acquired by email or FTP sites directly from government or researcher points of contact, or obtained from public web maps where coordinates could be requested through Application Programming Interface queries. In these cases, we followed up with data providers to request permission to include these data into the SDPT.

Table 1 | **Spatial Database of Planted Trees: Attributes and Attribute Descriptions**

ATTRIBUTE	DESCRIPTION
ID_Global	Unique ID of polygon in the global database
Org_Code	Original ID from source data
Final_code	Species ID tied to rasterized version of the dataset
Country	Country where plantation polygon is located
Type	Classification as planted forest or agricultural trees
Deciduous_evergreen	Classification of tree species as either deciduous or evergreen
Broadleaf_conifer	Classification of tree species as either broadleaf or conifer
Common_name	Common name of planted species
Species	Latin name for planted species
Species_simple	Grouped categories for planted species
Size	Industrial-, medium-, and small-size designations for planted area (seven countries only)
Ownership	Plantation ownership classification (United States only)
Source	Reference for original data
Year	Year of source data (not year of source publication)
Area_ha	Size of polygon in hectares
Method_planted forest	Methodology used to map planted forest area
Method_ag_tree	Methodology used to map tree crop area

Note: ID = unique identifier.

3.2 Data Cleaning and Processing

We cleaned and processed datasets to produce vector data files. To process the source data, we merged any regional datasets to produce a country-scale shapefile. If necessary, we extracted polygons from land cover maps and corrected any existing geometry errors. We projected the data to the World Geodetic System 1984 (WGS84) datum and to World Eckert IV equal area projection, then dissolved by species, size, and any other relevant attributes. We cleaned the data to ensure there were no overlapping polygons. If overlaps were present in the data, we either removed the overlap if it related to a small area or created a separate mixed category for dissimilar overlapping attributes. This step ensures that tree cover loss or other variables are not double-counted within the polygons when generating summary statistics. We converted raster source data to polygon format and processed these files using the above steps.

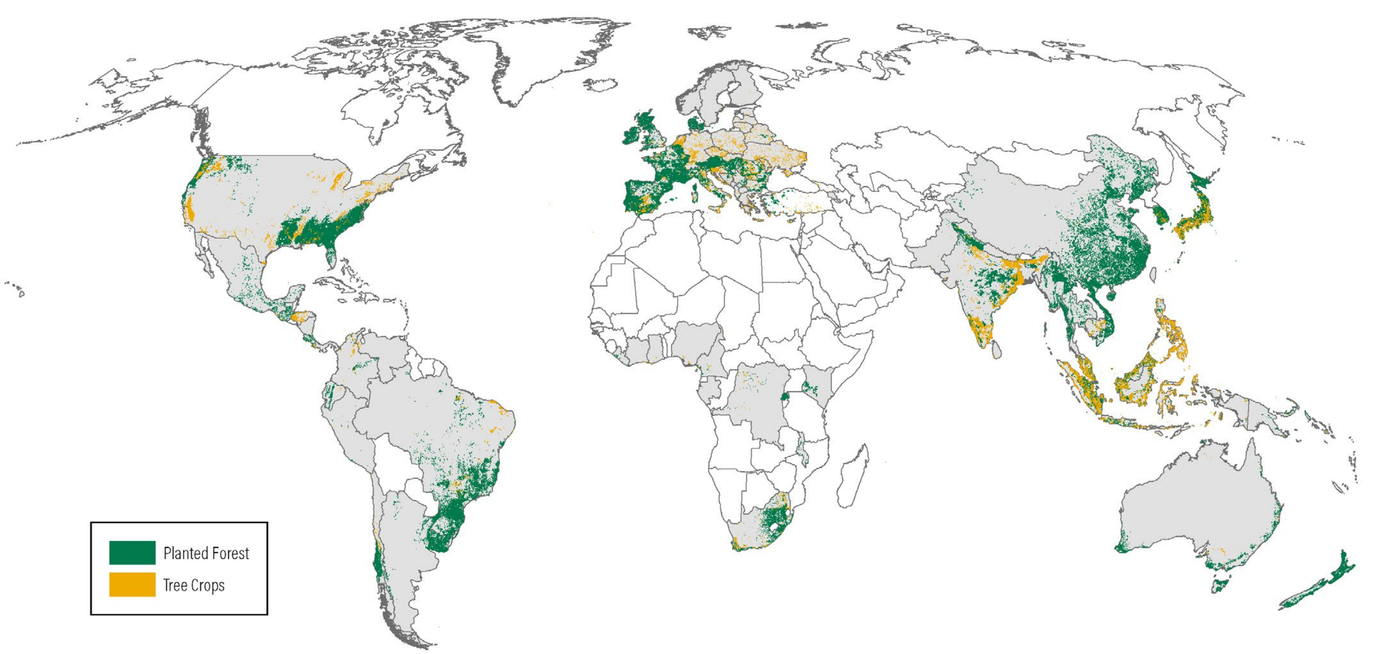
3.3 Attribute Harmonization

Once all individual source datasets were processed and cleaned, we created a global attribute table by exporting the original attribute data from each individual file. We assigned standardized common names, species names, ownership, and size information to allow for easier data selection across countries and assigned unique identifiers (ID) for each species. We added species information to the planted forest class, including whether the species (where provided) is evergreen or deciduous and broadleaf or conifer. We then assigned species to either planted forests or tree crops (Appendix C, Table C-1). We rejoined the final attribute tables using a common identifier.

4. RESULTS

Version 1.0 of the SDPT map is shown in Figure 5, and is nominally representative of 2015, although years for individual countries on the map vary. The SDPT contains 173 million ha of planted forests and an additional 50 million ha of tree crops (Table 2). Because spatial data are not available for some countries, the global total area in the SDPT should be considered an underestimate. Accuracy of the maps is generally high (>90 percent) for the minority of countries where accuracy has been assessed (Appendix B), although several countries in the SDPT do not have accuracy information due to the absence of, and/or cost of acquiring, appropriate and independent data to validate the map. In other cases, accuracy information may exist but has not been summarized in readily accessible metadata or other data documentation.

Figure 5 | **Global Map of Planted Forests and Agricultural Tree Crops**



Source: Various sources (summarized in Appendix A), compiled by World Resources Institute.

Table 2 | **Area of Planted Forest and Tree Crops by Country and Region**

REGION	COUNTRY	PLANTED FOREST (000 HA)		TREE CROPS (000 HA)
		SDPT V.1.0	FAO (2015)	SDPT V.1.0
AFRICA	Congo, Democratic Republic of the	85	60	97
	Kenya	194	220	4
	Liberia	137	8	8
	Malawi	138	419	1
	Rwanda	289	418	0
	South Africa	1,877	1,763	338
	Cameroon	33	26	95
	SDPT SUBTOTAL AFRICA	**2,753**	**2,914**	**543**
	Côte d'Ivoire	no data	427	20
	Gabon	no data	30	9
	Ghana	no data	325	33
	Ethiopia	no data	972	no data
	Morocco	no data	706	no data
	Nigeria	no data	420	40
	Others	no data	4,410	no data
	Remaining FAO SUBTOTAL AFRICA	**0**	**13,411**	**102**
	TOTAL AFRICA	**2,753**	**16,325**	**645**
ASIA	Cambodia	163	69	751
	China	45,121	78,982	18
	India	6,544	12,031	5,102
	Indonesia	5,654	4,946	21,093
	Japan	9,322	10,270	685
	Malaysia	1,667	1,966	9,031
	Myanmar	1,458	944	2
	Nepal	12	43	1
	Pakistan	7	362	4
	Philippines	321	1,245	6,595
	South Korea	918	1,866	109
	Thailand	150	3,986	198
	Vietnam	3,072	3,663	6
	SDPT SUBTOTAL ASIA	**74,409**	**120,373**	**43,595**
	Russia	no data	19,841	no data
	Others	no data	3	6
	Remaining FAO SUBTOTAL ASIA	**0**	**19,844**	**6**
	TOTAL ASIA	**74,409**	**145,008**	**43,601**

Table 2 | **Area of Planted Forest and Tree Crops by Country and Region (Cont'd)**

REGION	COUNTRY	PLANTED FOREST (000 HA)		TREE CROPS (000 HA)
		SDPT V.1.0	FAO (2015)	SDPT V.1.0
EUROPE	Belarus	145	1,910	23
	France	15,879	1,967	141
	Spain	12,383	2,909	1,468
	Turkey	432	3,386	37
	Austria	4,710	1,692	6
	Hungary	1,761	1,652	51
	Others	17,525	8,365	684
	SDPT SUBTOTAL EUROPE	**52,835**	**21,881**	**2,410**
	Finland	0	6,775	0
	Germany	0	5,295	86
	Czech Republic	0	2,643	23
	Poland	0	8,957	51
	Sweden	0	13,737	1
	Others	0	9,508	340
	Remaining FAO SUBTOTAL EUROPE	**0**	**46,915**	**501**
	TOTAL EUROPE	**52,835**	**68,796**	**2,911**
N. AND C. AMERICA	Costa Rica	73	18	31
	Guatemala	68	185	72
	Honduras	0	0	366
	Mexico	1,479	87	11
	United States	25,067	26,364	1,571
	SDPT SUBTOTAL NORTH AND CENTRAL AMERICA	**26,687**	**26,654**	**2,051**
	Canada	no data	15,784	no data
	Nicaragua	no data	48	7
	Panama	no data	80	7
	Others	no data	1137	no data
	Remaining FAO SUBTOTAL NORTH AND CENTRAL AMERICA	**0**	**17,049**	**14**
	TOTAL N. AND C. AMERICA	**26,687**	**43,703**	**2,065**
OCEANIA	Australia	2,025	2,017	75
	New Zealand	2,107	2,087	44
	Papua New Guinea	347	0	119
	SDPT SUBTOTAL OCEANIA	**4,479**	**4,104**	**238**
	Solomon Islands	no data	27	8
	Others	no data	0	no data
	Remaining FAO SUBTOTAL OCEANIA	**0**	**27**	**8**
	TOTAL OCEANIA	**4,479**	**4,131**	**246**

Table 2 | **Area of Planted Forest and Tree Crops by Country and Region (Cont'd)**

REGION	COUNTRY	PLANTED FOREST (000 HA)		TREE CROPS (000 HA)
		SDPT V.1.0	FAO (2015)	SDPT V.1.0
SOUTH AMERICA	Argentina	1,036	1,202	0
	Brazil	8,413	7,736	1,110
	Chile*	881	3,044	102
	Colombia	261	71	322
	Ecuador	131	55	16
	Peru	59	1,157	45
	Uruguay	1,391	1,062	63
	SDPT SUBTOTAL SOUTH AMERICA	**12,172**	**14,327**	**1,658**
	Venezuela	no data	557	22
	Others	no data	0	no data
	Remaining FAO SUBTOTAL SOUTH AMERICA	**0**	**557**	**22**
	TOTAL SOUTH AMERICA	**12,172**	**14,884**	**1,680**
WORLD	**WORLD SDPT SUBTOTAL**	**173,335**	**190,253**	**50,495**
	WORLD FAO TOTAL		**292,847**	

Sources: Spatial Database of Planted Trees and FAO (2015).
*Data include only ~40% of total plantation area.
Notes: SDPT = Spatial Database of Planted Trees; ha = hectares; v = version; FAO = Food and Agriculture Organization.

Countries included in the SDPT represent 82 percent of the world's total planted forest area in 2015, as reported by FAO (2015), or 93 percent of the world's total planted forest area reported outside of Canada and Russia (Table 2). Estimates of SDPT planted forest area (173 million ha) and FAO (190 million ha) are similar when excluding countries with no SDPT data, and area totals are similar for countries with substantial planted forest area as in the United States and Australia, most likely because both estimates are based on the same data for those countries. This small net difference in total area, however, masks substantial differences within countries (Figure 6). For European countries, large differences were expected, since the SDPT includes areas of non-native forests (Appendix A) and excludes areas of seminatural forests that may be reported by European countries as planted forests to FAO. For other countries, discrepancies are not as easily explained, and we anticipate that the SDPT will spark productive discussion among different data providers for a given country about how to achieve convergence among varying estimates.

5. CAVEATS AND LIMITATIONS

At least four major limitations exist with this first version of the SDPT: definitional inconsistency, temporal inconsistency, incomplete spatial coverage, and the absence of a uniform accuracy assessment. Despite these constraints, we expect that this first effort will incentivize additional and essential efforts to improve the planted forest and tree crop information produced by the forest monitoring community.

5.1 Definitional Inconsistency

Limitations in the SDPT around the lack of a consistent definition for planted forest and tree crops are highlighted in Box 1. The only way to remove this inconsistency in definitions would be to create uniform criteria on a global basis for all types of planted forests and tree crops across every country, in which case objective rules could be established about whether or not plantation infrastructure is included in the estimate, for example. This approach would be analogous to the creation of canopy density and height thresholds for defining “tree cover” in the original Hansen et al. (2013) data. Due to the variety of different ecosystems across the world that contain trees, this approach is more likely to be successful for delineating distinctive plantation types (e.g., oil palm or Eucalyptus monocultures) and more difficult for plantations that appear similar in satellite imagery to natural forests (e.g., Douglas fir plantations in the northwestern United States) and for mixed tree crop or plantation systems that contain a mosaic of different species and/or land uses.

5.2 Temporal Inconsistency

Maps of planted forests and tree crops are available for different representative years, ranging from 1995 to 1999 (Japan) to 2017 (U.S. tree crops) with a mode year (i.e., the most frequent year in the dataset) of 2015. On the basis of this information, we assigned the year 2015 to v1.0 of the SDPT, with the caveat that the map is likely to underestimate planted forest area and tree crops. This is because more recent plantings were excluded for some countries due to the absence of available data. Updates should be prioritized for countries that have outdated data, rapid plantation expansion, and/or large mismatches between SDPT and FAO statistics.

The SDPT can be used to exclude areas of global tree cover loss, after 2015, that has occurred within SDPT boundaries; these changes in tree cover can be considered as loss associated with plantation or agricultural activity and not as the loss of natural forest. The temporal inconsistency of the SDPT, however, means that it is *not* appropriate for inferring dynamics of conversion between natural forests and tree plantations prior to the year 2015.

5.3 Incomplete Spatial Coverage

According to FAO (2015), there are 15.8 million ha and 19.8 million ha of planted forests in Canada and Russia, respectively. Planted forest area reported by these two countries to FAO, however, most likely reflects a mix of seminatural planted and naturally regenerated forest. Therefore, these two countries are excluded from the SDPT. The Canadian Forest Service does not collect national data on the locations of nonforest tree crops, plantation forests, or other planted forests; the data reported by Canada to the FAO Global Forest Resources Assessment (FRA) are based on planting activity data collected in the country’s National Forestry Database.[1] Furthermore, the vast majority of managed forests in Canada are naturally regenerated or are assisted natural regeneration, which has been excluded from the database. In Russia, there is little to no observable difference between planted and naturally regenerated forests; the relevant difference is between old-growth stands, intensively managed commercial forests (planted and naturally regenerated), and secondary, nonactively managed stands (planted and naturally regenerated). It is therefore a challenge to separate the planted component of these forest types.[2]

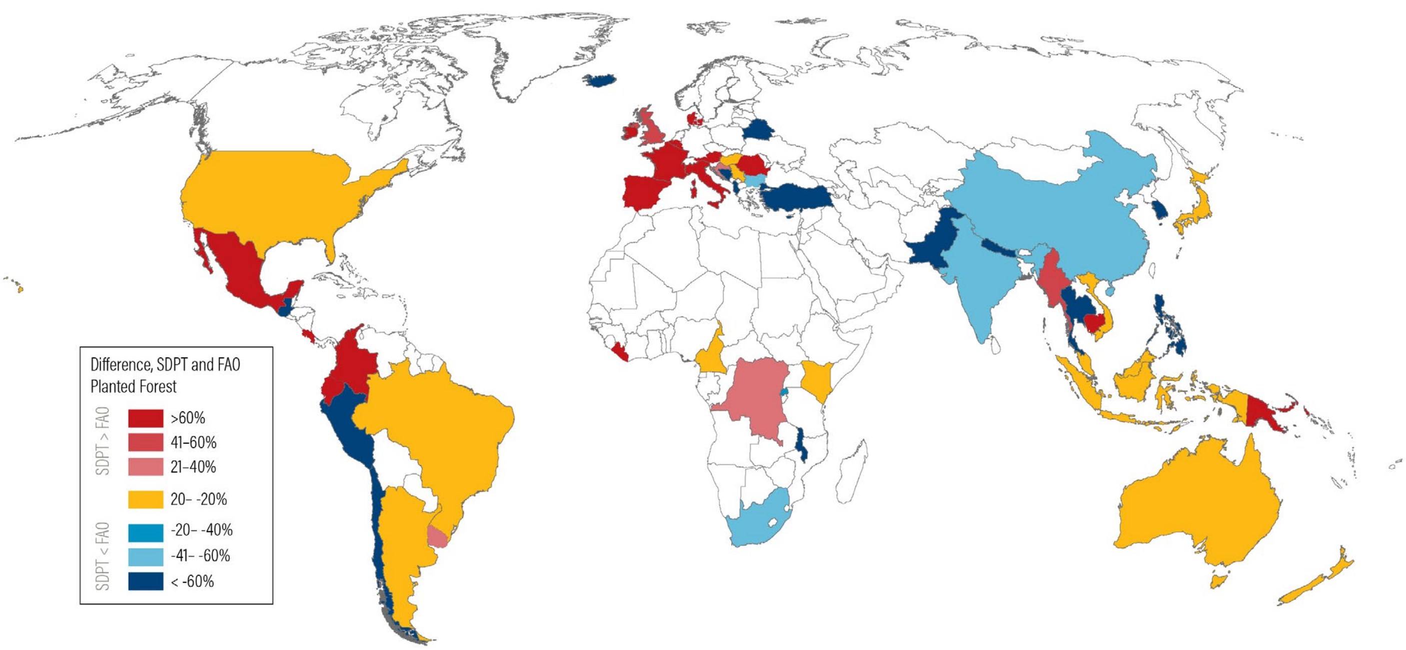
Beyond boreal forests, another substantial data gap in the SDPT is sub-Saharan Africa, where many countries reported large areas of planted forests to FAO (2015). For example, Sudan reported 6 million ha of planted forest in 2015 (Table 2), three times as much planted forest area as South Africa, a major supplier of global timber. In Ethiopia, planted area reported to FAO doubled from 0.5 million ha in 2010 to 1.0 million ha in 2015. Satellite-based land cover maps are being created for Ethiopia at present (with the inclusion of a forest plantation class), although they are not available as yet for public distribution.[3] FRA 2015 uses a tier system that provides an indication of data quality for each indicator. Tier 3 uses recent and robust data sources, Tier 2 relies on older and less complete data, and Tier 1 is an expert estimate (FAO 2015). In more than half of countries worldwide, reported statistics for planted forests in FAO (2015) are based on Tier 1 data (expert assessment). This is the case across all regions, particularly in the case of Africa, where 81 percent of countries report at the Tier 1 level. Through evaluation of FRA data, as well as this assessment presented in the SDPT, a clear priority for future research should be the creation and incorporation of accuracy-assessed planted forest information of a higher quality into international forest reporting systems.

5.4 Absence of a Uniform Accuracy Assessment

Although most maps compiled for the SDPT were derived from Landsat, SPOT, or RapidEye satellite imagery, with a spatial resolution of 30 meters or finer, the method for image interpretation varied from country to country. Some have used visual interpretation of images while others used automated per-pixel classification methods. The use of different source data and mapping methodologies is not necessarily an issue were the resulting map product assessed to be accurate, although accuracy information is not available for many countries of the SDPT.

The area of a given land cover class obtained directly from an automatically classified map may differ substantially from areas derived using a statistical sampling approach, because of map classification errors. One way to evaluate and correct for this potential bias is to calibrate the map

Figure 6 | **Comparison of Food and Agriculture Organization and Spatial Database of Planted Trees Regarding Planted Forest Area Estimates**



Source: WRI authors.

area with results from a sample-based assessment, where individual pixels on the map can be adjusted so that when totaled, they agree with regional and national statistics. In v1.0 of the SDPT, maps were compiled “as is” and may contain substantial biases that have not been evaluated as yet due to validation data not being readily available. Global validation of the SDPT in its current form would be challenging, due to the absence of uniform definitions, different dates of the datasets and, in some cases, mapping of mosaic plantation classes rather than actual locations of planted trees. An alternative approach could be to use existing maps for stratification, followed by a sampling analysis that focuses on the estimation of total plantation area rather than on map accuracy. This would be less useful to users, however, than a map supplemented with accuracy information. There are benefits and drawbacks to geospatially explicit maps and sample-based products alike; the aim here is to compile geospatially explicit information because it can be used by the GFW community at various spatial scales in a way that sample-based estimates cannot.

ABBREVIATIONS

FAO	Food and Agriculture Organization of the United Nations
FRA	Global Forest Resources Assessment 2015 of the Food and Agriculture Organization
GFW	Global Forest Watch
GIS	Geographic Information System
km	kilometer
m	meter
INFOR	Forest Institute (Instituto Forestal de Chile)
NFI	National Forest Inventory, Australia
REDD/CCAD-GIZ	Regional program of the German Agency for International Cooperation, Reducing Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic
SDPT	Spatial Database of Planted Trees
UML	Universal Mill List
v1.0	Version 1.0
WRI	World Resources Institute

APPENDIX A: CONTRIBUTING DATA LAYERS

If a country is missing from the list in Table A-1, the data have not been acquired yet because they were not readily available and/or because a very small (or zero) area of the country's forests are planted forests. Key features of each contributing data layer are summarized in Table A-1, and individual country data are summarized by region in the sections that follow.

Table A-1 | **Key Characteristics of Data Layers Included in the Spatial Database of Planted Trees**

COUNTRY	SOURCE YEAR	SPECIES AVAILABLE	METHODOLOGY	PLANTED FOREST (000 HECTARES)	AGRICULTURAL TREES (000 HECTARES)
Argentina	2013	Yes	Supervised classification	1,036	0
Australia	2013	No	Multiple lines of evidence (MLE): based on multiple forest, vegetation and land cover spatial datasets, combined with forest inventory data.	2,025	75
Brazil	2013/2014	Yes	Manual polygon delineation/supervised classification	8,413	1,110
Cambodia	2013/2014	Yes	Manual polygon delineation	163	751
Cameroon	Unknown	Yes	Manual polygon delineation	33	95
Chile*	2016	Yes	MLE: based on multiple forest, vegetation and land cover spatial datasets combined with forest inventory data	881	102
China	2004-2008	No	Manual polygon delineation	45,121	18
Colombia	2013/2014	Yes	Manual polygon delineation	261	322
Costa Rica	2012	Yes	Supervised classification	73	31
Congo, Dem. Rep. of	2013	Yes	Manual polygon delineation	85	97
Ecuador	2000, 2014	Yes	Supervised classification	131	16
Europe	2011, 2017	Yes	MLE: based on probability distribution maps of planted tree species	52,835	2,911
Gabon	2013-2015	Yes	Manual polygon delineation	no data	9
Ghana	2013-2015	Yes	Manual polygon delineation	no data	33
Guatemala	2012	No	Supervised classification	68	72
Honduras	2013	Yes	Supervised classification	0	366
India	2015	Yes	Manual polygon delineation	6,544	5,102
Indonesia	2013-2015	Yes	Manual polygon delineation/supervised classification	5,654	21,093
Ivory Coast	2013-2015	Yes	Manual polygon delineation	no data	20

Table A-1 | Key Characteristics of Data Layers Included in the Spatial Database of Planted Trees (Cont'd)

COUNTRY	SOURCE YEAR	SPECIES AVAILABLE	METHODOLOGY	PLANTED FOREST (000 HECTARES)	AGRICULTURAL TREES (000 HECTARES)
Japan	1995-1999	Yes	MLE: based on multiple forest, vegetation and land cover spatial datasets combined with forest inventory data	9,322	685
Kenya	2010	No	Supervised classification	194	4
Liberia	2014	Yes	Manual polygon delineation	137	8
Malawi	2012/2015	No	Unknown/Manual polygon delineation	138	1
Malaysia	2013-2015	Yes	Manual polygon delineation/supervised classification	1,669	9,031
Mexico	2011-2014	Yes	Supervised classification	1,479	11
Myanmar	2002 and 2014	No	Supervised classification	1,458	2
Nepal	2015	No	Manual polygon delineation	12	1
New Zealand	2012	No	Supervised classification	2,107	44
Nicaragua	2014	Yes	Supervised classification	no data	7
Nigeria	2013-2015	Yes	Manual polygon delineation	no data	40
Pakistan	2015	No	Manual polygon delineation	7	4
Panama	2014	Yes	Supervised classification	no data	7
Papua New Guinea	2012/2015	Yes	Supervised classification	347	119
Peru	2013/2014	Yes	Manual polygon delineation	59	45
Philippines	2003, 2017	Yes	Manual polygon delineation/supervised classification	321	6,595
Rwanda	2008	Yes	Manual polygon delineation	289	0
Solomon Islands	2013-2015	Yes	Manual polygon delineation	no data	8
South Africa	2013/2014	No	Supervised classification	1,877	338
South Korea	Unknown	Yes	MLE: based on multiple forest, vegetation and land cover spatial datasets combined with forest inventory data	918	109
Sri Lanka	2013-2015	Yes	Manual polygon delineation	no data	6
Thailand	2000	Yes	Manual polygon delineation	150	198
Uruguay	2015	No	Unknown	1,391	63
United States	2008/2011 2014/2016	Yes	MLE: based on multiple forest, vegetation and land cover spatial datasets combined with forest inventory data	25,067	1,571
Venezuela	2014	Yes	Supervised classification	no data	22
Vietnam	2016	Yes	Supervised classification	3,072	6

Source: Compiled by WRI authors.
Note: *Data includes only ~40% of total plantation area.

AFRICA

Cameroon

World Resources Institute (WRI) and Cameroon's Ministry of Forestry and Wildlife have created an interactive online forest atlas that contains a map of agro-industrial plantations, which delineates the boundaries of leases managed by national companies or international subsidiaries. The data correspond to the boundaries of the concessions. Most of the agro-industrial zones incorporated into this layer have been mapped from satellite images, in combination with field verification to determine the types of crop and the identity of logging companies. The dataset was produced by the Ministry of Forestry and Wildlife and WRI, with the support of the United States Agency for International Development, the Norwegian Ministry of Climate and Environment, and the UK Department for International Development, with ESRI and Erdas software contributions. Geographic boundaries should be considered as estimates. Data in the atlas are licensed under the Creative Commons Attribution 4.0 International License, indicating that anyone is free to copy and redistribute material in any format, and to transform and use the material for other purposes, including commercial.

Côte d'Ivoire, Ghana, Gabon, and Nigeria

WRI and FoodReg have been working to develop a Universal Mill List (UML) that contains the most comprehensive information available on the location of palm oil mills worldwide. We used this list to visually delineate oil palm plantation boundaries within a 50 kilometer (km) road network of existing mills, using high-resolution imagery, on the assumption that mills must source from palm plantations within a 24-hour drive time in order to preserve the quality of the oil. Thus, we estimated the sourcing area as land within a 50 km road network, and we mapped specific boundaries of oil palm plantations within this sourcing area using very high-resolution satellite imagery from DigitalGlobe. The representative year is 2013–15. These boundaries were added to the "tree crops" class.

Democratic Republic of the Congo

A map of planted areas in the Democratic Republic of the Congo was created by the Ministry of Environment, Nature Conservancy, and Sustainable Development (Ministère de L'Environnement, Conservation de la Nature, et Développement Durable; MECNDD) with the support of WRI. The layer represents areas occupied by any type of planted forests detected from satellite imagery, including industrial agriculture plantations, small-scale fields, and reforested sites. The data were produced by the Directorate of Forest Inventories and Management (Direction des Inventaires et Aménagement Forestiers), with the technical support of WRI, from the large-scale interpretation (1/50,000) of Landsat, ASTER, and ALOS satellite images, combined with other data from the Ministry of Agriculture, Livestock and Fisheries (Ministere de l'Agriculture, de l'Elevage et de la Pêches; MAEP). The extent of the dataset is national and represents planted areas since 2013. Data in the country's forest atlas are licensed under the Creative Commons Attribution 4.0 International License, indicating that anyone is free to copy and redistribute material in any format, and to transform and use the material for other purposes, including commercial.

Kenya

A forest type map of Kenya was created by the Kenya Forest Service, based on 2010 Landsat imagery, and includes four forest types from which we extracted the forest plantations class. Permission to include these data in the Spatial Database of Planted Trees (SPDT) was provided by Alfred Gichu of the Kenya Forest Service.

Liberia

Global Forest Watch (GFW) partner, Transparent World, delineated plantation boundaries from Landsat imagery for Liberia for 2013/14. The organization used visual delineation methods as an effective way to map heterogeneous plantation categories (different species and types) as a single class. Additional documentation on methods and results are found in Petersen et al. (2016). Results of an independent accuracy assessment indicate a combined omission error of 15 percent for Peru, Colombia, and Liberia (Appendix B).

Malawi

We merged two data sources for maps regarding planted forests. One set of shapefiles is from Malawi's Department of Forestry for 2012. The methodology for creating this dataset is unknown. We extracted the other set of shapefiles from a Land Use/Land Cover layer from the Food and Agriculture Organization (FAO) for 2015, obtained from FAO's GeoNetwork.[4] We merged files because the Department of Forestry data appeared incomplete.

Rwanda

The Government of Rwanda updated its 2007 forest inventory with 2008 high-resolution aerial photographs.[5] They applied manual polygon delineation, with the aid of visual interpretation algorithms and ground truthing, to digitize five natural forest classes and 13 planted forest classes. Digitized forests included trees greater than seven meters in height, forests with greater than 10 percent tree cover canopy density, and areas greater than 0.25 hectares (ha). We extracted the 13 planted forest classes and retained their species information in the attributes.

South Africa

A 2013/14 national land cover map of South Africa[6] was produced by GeoTerraImage for South Africa's Department of Environmental Affairs. From the map's 72 classes, we extracted the plantations/woodlots classes (mature, young, and clearfelled) as forest plantations, and a "cultivated orchards" class as tree crops. The land cover map is distributed with open access licensing and was created at 30 meters (m) resolution, using multiseasonal, multispectral Landsat 8 imagery and an object-based modeling approach. Accuracy statistics are provided in Appendix B.

ASIA

China

We obtained a map of China's planted forests at 1-km resolution from Shushi Peng, an independent researcher at the Sino-French Institute for Earth System Science at Peking University in Beijing. The planted forest map appears in *Atlas of Forest Resources of China (Seventh National Forest Resource Inventory)* (2010), released by China Forestry Press. Peng digitized the map in 2011 and originally used the planted forest boundaries in an analysis that applied satellite measurements to demonstrate how afforestation can affect land surface temperature (Peng et al. 2014). Although the data are visualized in the SDPT, WRI does not have permission to distribute the data beyond this project on the GFW map. Therefore, those interested in obtaining the spatial data should contact speng@pku.edu.cn.

India

A seamless vegetation map of India was created by Roy et al. (2015) and shared with WRI by lead author, P.S. Roy, an independent researcher at the University of Hyderabad in India. The map was prepared as a collaborative effort in which 21 institutes and 61 scientists participated. They used medium-resolution IRS LISS-III images (23.5-m resolution) from two seasons in 2005–06, using on-screen visual interpretation. The resulting vegetation map has a pixel-level accuracy of 90 percent, as assessed using 15,565 ground control points (Appendix B). The digital map is available through a web portal.[7] The vegetation type map has 12 classes of plantation forests, with each class corresponding to a different species. We extracted these 12 classes from the map and included them in the global planted forest layer. We also extracted the "orchard" class and categorized it within the "tree crop" class, along with other tree crop classes of areca nut, mango, tea, coffee, rubber, citrus, oil palm, almond, apple, and coconut. Accuracy statistics are provided in Appendix B.

Indonesia, Malaysia, and Cambodia

GFW partner Transparent World has delineated plantation boundaries from Landsat imagery for the three countries, Indonesia, Malaysia, and Cambodia, for 2013/14. They applied visual delineation methods as an effective way to map heterogeneous plantation categories (different species and types) as a single class. Additional documentation on methods and results are found in Petersen et al. (2016). Results of an independent accuracy assessment are provided in Appendix B.

The expansion of oil palm and wood fiber plantations across Southeast Asia since the early 1990s has been the topic of considerable academic research; thus, we compiled additional information from these other efforts in addition to those of Transparent World. For Indonesia, the expansion of oil palm and wood fiber plantations as mapped by Miettinen et al. (2016) for peat soils, and oil palm across all of Indonesia and across Borneo as mapped by Austin et al. (2015) and Gaveau et al. (2014), respectively. The three datasets delineate oil palm at different time periods; we created a 2000 oil palm map, using a combination of Austin et al. (2015), Miettinen et al. (2016) and Gaveau et al. (2014). We created an additional map for 2013–15 by combining the Transparent World data with the three oil palm datasets for 2015. In cases of overlapping plantation polygons among the datasets, the record was assigned the species from the Transparent World data. The plantation data source is retained in the attribute table and can be queried to use one or all data sources. Accuracy statistics and a comparison of different data sources for oil palm in Indonesia are provided in Appendix B.

For Malaysia, oil palm and wood fiber plantations were also delineated by Miettinen et al. (2016) for peat soils; Gaveau et al. (2014) for Sarawak and Sabah oil palm plantations; and Gunarso et al. (2013) for peninsular Malaysia. The three datasets delineate oil palm at different time periods; thus, we created a 2000 oil palm map using a combination of Miettinen et al. (2016), Gaveau et al. (2014), and Gunarso et al. (2013). We created an additional map for for 2013–15 by combining the Transparent World data with the three oil palm datasets for 2015. In cases of overlapping plantation polygons among the datasets, the record was assigned the species from Transparent World data. The plantation data source is retained in the attribute table and can be queried to use one or all data sources. Accuracy statistics are provided in Appendix B.

Japan

The Government of Japan's Ministry of the Environment conducts periodic vegetation surveys, and it disseminates the resulting vegetation distribution maps. Detailed shapefiles also are made publicly available. Assistance with locating such spatial data was provided by Brian Johnson of the Institute for Global Environmental Strategies in Japan. The most recent forest surveys are the sixth and seventh, although the website for downloading shapefiles for these survey data was continuously down. Therefore, we downloaded data from the fifth survey by prefecture and extracted all plantation classes therein. Data from Japan's fifth survey are not as detailed (1/50,000) as are those of the 6th and 7th (1/25,000) surveys; nevertheless, they are based on Landsat images (30-m resolution) in combination with ground survey data. We also extracted classes corresponding to orchards and gardens; these were classified as "tree crops." The representative year-range of the data is 1995–99.

Myanmar

Maps of Myanmar's forest cover for 2002 and 2014 were produced by a consortium of international organizations and environmental nongovernment groups and led by the Smithsonian Conservation Biology Institute and the Myanmar nongovernment organization Advancing Life and Regenerating Motherland. Landsat satellite imagery was used to assess the condition and spatial distribution of Myanmar's intact and degraded forests (Bhagwat et al. 2017). To determine forest categories—as well as canopy cover thresholds for these categories—and definitions, Bhagwat et al. (2017) conducted a two-day, premapping workshop in Yangon in 2015 with forest experts from government, universities, and nongovernmental conservation organizations. Forests were separated into those that are intact and degraded, including those as plantations. In the SDPT, we included all the forest and oil palm plantations mapped in 2002, as well as the forest and oil palm plantations that had been converted by 2014. Data were released with an open access license (Bhagwat et al. 2017). Accuracy statistics are provided in Appendix B.

Nepal

There are very small patches of plantation forests in Nepal, two—Ratuwamai Plantation and Sagarnath Plantation—of which are managed by the Forest Department and located in the Eastern Terai region. The boundaries of these plantation areas were mapped by Nepal's Forest Resources Assessment Project (GoN 2014), on the basis of ground reference data and high-resolution images.[8] The representative year of these plantation areas is 2012.

Pakistan

Pakistan has recently planted areas under the Billion Tree Tsunami project in northern Khyber Pakhtunkhwa Province, mapped by WWF-Pakistan. The representative year of these mapped plantation areas is 2015.

Philippines

A 2003 land use map for the Philippines was obtained from the country's National Mapping and Resource Information Authority (NAMRIA), which falls under the responsibility of the Department of Environment and Natural Resources. The map was produced using visual interpretation methods from Landsat imagery and contains three classes of forest plantations: broadleaved, coniferous, and mangrove forest plantations. A tree crop class was also included in the SDPT for 2015, based on the perennial crops category of a 2015 land cover map from NAMRIA. We did not include plantations from 2015, since the number of land cover categories as reduced after 2003; the forest plantation category of 2003 was aggregated into either Closed Forest or Open Forest in land cover maps for later years, depending on its physical status during the satellite image acquisition.

South Korea

We obtained GIS data on plantation forests from the Korean Forest Service.[9] These are produced using a combination of national inventory data and remote sensing imagery. Species information was provided in the original attribute file and was retained in the global attribute file.

Sri Lanka

WRI and FoodReg have been working to develop a UML that contains the most comprehensive information available on the location of palm oil mills worldwide. We used this list to delineate oil palm plantation boundaries within a 50 km road network of existing mills in Sri Lanka, using very high-resolution imagery from DigitalGlobe, on the assumption that mills must source from palm plantations within a 24-hour drive time in order to preserve the quality of the oil. The representative years are 2013–15. These boundaries were added to the "tree crops" class in the SDPT.

Thailand

Spatial data on forest cover in Thailand derives from the Thai Royal Forestry Department.[10] The map was created by manual image interpretation of Landsat images from about the year 2000. Original data were modified slightly to improve the georeferencing accuracy. Two plantation classes are included in the original data: "plantation" and "Eucalyptus plantation." We categorized the "Eucalyptus plantation" class into the planted forests class of the SDPT. The "plantation" class includes tree-covered areas that produce mainly nonwood products (e.g., oil palm, agroforestry, rubber) and, thus, we included this class in the SDPT under the "tree crops" category.

Vietnam

A 2016 national land cover/land use map was created by the Government of Vietnam using SPOT 5 imagery (2.5-m resolution). A "Data Sharing System" web mapping application is currently under construction as a tool for browsing Vietnam's forest resource data.[11] It will enable the visualization of maps of various forestry themes, a querying of forest plot information, overlays of forestry data with various background maps, and a querying of selected plot statistics. A 93-category forest type map of Vietnam for 2016 was obtained from the Vietnam Administration of Forestry and Vietnam's Forests and Deltas Program (funded by the United States Agency for International Development). We extracted the plantation classes and included them in the SDPT. These included wood and bamboo plantations, as well as palm and coconut tree plantations, among others. Wood and bamboo plantations, in addition to "new plantations," were included to the SDPT as "forest plantations," while other classes were categorized as "tree crops."

EUROPE

Plantations represent approximately 9 percent of Europe's total forest area (Forest Europe 2015), although no spatially explicit map delineates them. Due to the complications of spatially separating seminatural-planted forests from naturally regenerated forests, we focused our efforts in this study on mapping introduced (i.e., planted) species in Europe that typically fall under intensive forest management, and for which regional area statistics are available (Forest Europe 2015; see also Table A-2).

First, we used probability distribution maps for individual tree species from the *European Atlas of Forest Tree Species* (de Rigo et al. 2016, herein called the "JRC maps") and Brus et al. (2012) to map the most likely (i.e., highest probability) areas where each forest tree species group was present until the total reported area was reached of that species group for a given European region (Table A-2). We created species groups from individual tree species probability distribution maps as follows, with a "mixed" class created where individual introduced species distributions overlapped:

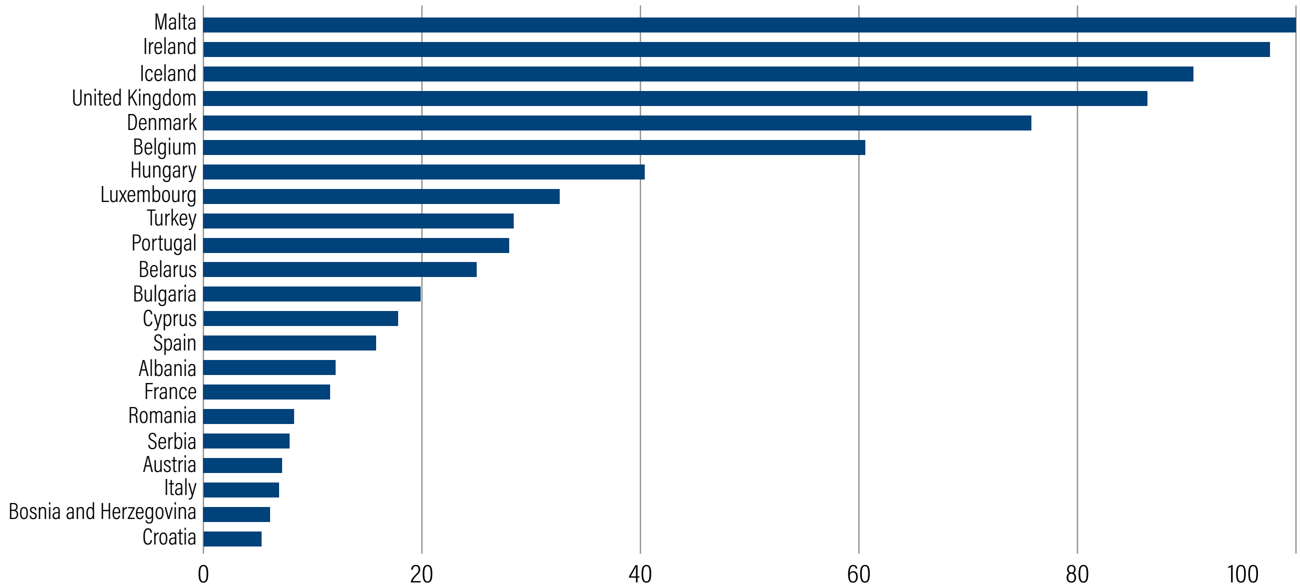
- *Pinus spp.*: Combination of *Pinus nigra*, *Pinus pinaster*, *Pinus halepensis* (from JRC maps) with the "other *Pinus*" class from Brus et al. (2012) to map areas of introduced pine.
- *Picea spp*: Combination of *Picea sitchensis* and *Picea abies*, which account for a substantial proportion of the forestry estate in Central-West and Northern Europe.
- *Pseudotsuga menziesii*: This is another important introduced tree species that has been widely planted in most parts of Europe due to its high production and high timber quality. We used the JRC map to estimate areas of *P. menziesii* until regional area totals were reached.
- *Eucalyptus spp*: The significance of Eucalyptus is particularly pronounced in Southeast Europe. In this case, we used the species probability map from Brus et al. (2012) to estimate areas of Eucalyptus until regional area totals were reached. No JRC map of Eucalyptus was available.
- *Populus spp*: This was estimated using a combination of the JRC map of *Populus nigra* and the Brus et al. map of *Populus spp.*
- *Larix spp*: This was estimated using a combination of *Larix spp.* maps from JRC and Brus et al. 2012.

Table A-2 | **Area Occupied by Individual Introduced Tree Species in Europe**

COUNTRY GROUP	AREA OF INTRODUCED TREE SPECIES (1,000 HECTARES)						
	PINUS SPP.	PICEA SPP.	PSEUDOTSUGA MENZIESII	EUCALYPTUS SPP.	POPULUS SPP.	LARIX SPP.	ABIES SPP.
North	565	179	0	0	1	54	33
Central-West	647	1362	731	0	280	276	18
Central-East	96	11	15	11	172	9	0
Southwest	312	0	40	770	97	9	0
Southeast	71	0	8	2	59	2	0
TOTAL AREA	**1,690**	**1,551**	**793**	**783**	**609**	**350**	**51**

Source: Forest Europe 2015.

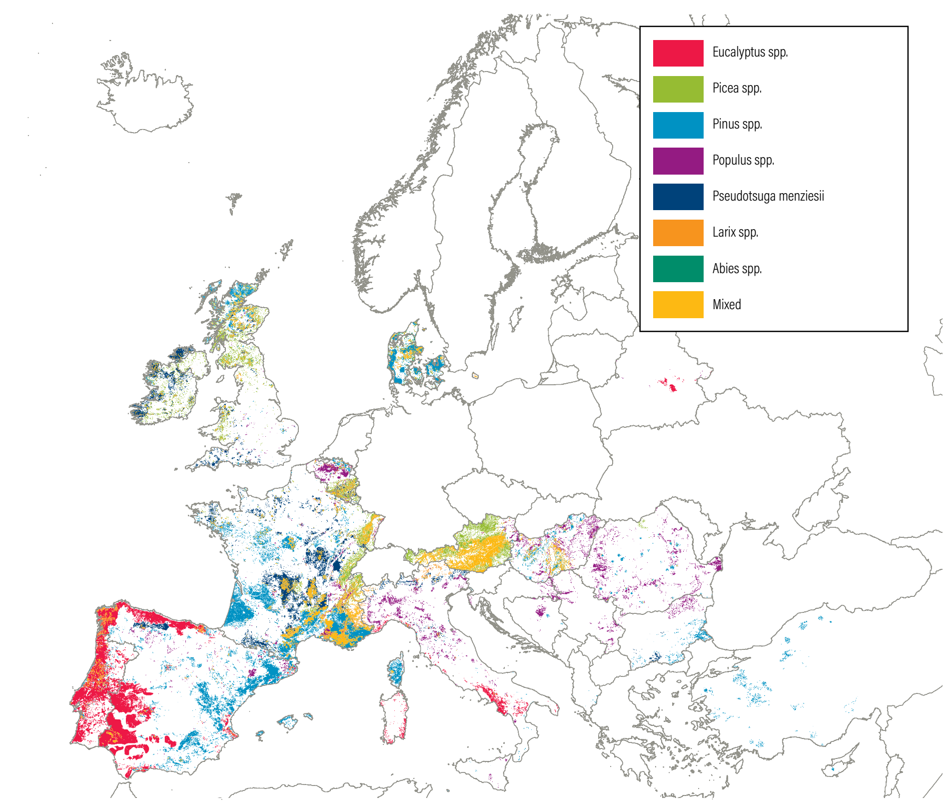
Figure A-1 | **European Countries with a Share of Plantations Greater than Five Percent of Total Forest Area, 2015**



Source: Forest Europe 2015.

Second, subsequent to creating tree species maps to match regional area totals for each introduced tree species, we included in the final map only those countries where plantations are reported to represent more than 5 percent of total forest area (Figure A-1). This excluded many countries (e.g., Poland, Germany) that contain large areas of managed forest that may be considered "planted" by FAO, but are considered seminatural forests and not plantations. The resulting plantation map for Europe is shown in Figure A-2.

Figure A-2 | **Final Plantations Map for European Countries**



Source: WRI authors, derived from Forest Europe (2015) introduced species statistics and species distribution maps from San-Miguel-Ayanz et al. (2016) and Brus et al. (2012).

NORTH AND CENTRAL AMERICA

Costa Rica

A land cover mapping project was developed by the National System of Conservation Areas (Sistema Nacional de Areas de Conservación; SINAC), National Forest Fund (Fondo Nacional de Financiamiento Forestal; FONAFIFO), and Ministry of Environment and Energy (Ministerio de Ambiente y Energia; MAE), with the technical and financial support of the regional program of the German Agency for International Cooperation, Reducing Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic (REDD/CCAD-GIZ).[12] High-resolution (5 m) RapidEye images were used to create a land cover map for 2012, from which we extracted the *plantaciones forestales* (forest plantations) class.

In addition, we acquired oil palm plantation boundaries for 2014, as mapped by Furumo and Aide (2017), based on MODIS imagery (250 m), and included these polygons in the "tree crops" category.

Guatemala

Guatemala's land cover map was created by the Inter-Institutional Group for Forest Monitoring and Land Use from the REDD/CCAD-GIZ regional program. Guatemala's National Institute of Forests (Instituto Nacional de Bosques; INAB) obtained 308 high-resolution (5 m) RapidEye images to cover the entire country and created a land cover map for 2012. These images, with a spatial resolution of 5 m, were used to detail 16 classes of forest, 21 subtypes of forest, and 16 subtypes of forest by density. For broadleaf, coniferous, and mixed forests, detailed densities (sparse and dense) were differentiated for the first time in Guatemala. For the SDPT, we extracted the *plantaciones forestales* (forest plantations) class. Accuracy statistics are provided in Appendix B.

In addition, we acquired oil palm plantation boundaries for 2014, as mapped by Furumo and Aide (2017), based on MODIS imagery (250 m), and included these polygons in the "tree crops" category.

Honduras

Honduras' first high-resolution forest and land cover map was produced by the Institute of Conservation and Forest Development, Protected Areas, and Wildlife (Instituto de Conservación y Desarrollo Forestal, Áreas Protegidas y Vida Silvestre; ICF), with the technical and financial support of the REDD/CCAD-GIZ regional program. RapidEye satellite imagery at 5 m spatial resolution from 2013 was acquired and analyzed to produce a map of the spatial distribution of forest types within the country. In contrast to earlier forest maps of Honduras, this version expands on other categories of wooded vegetation, including secondary vegetation, coffee and agroforestry areas, and information on trees outside of forests. The land cover map is currently visualized on the Global Forest Watch platform. While forest plantations in Honduras are often pine plantations, no forest plantation class was delineated in the land cover map. We extracted two classes of tree crops, *cafetales* (coffee plantations) and *palma africana* (oil palm plantations). Accuracy statistics are provided in Appendix B.

Mexico

Bosques Abiertos[13] was created by CartoCritica and Reforestamos Mexico as an interactive forest atlas for Mexico that features GFW's loss or gain of tree cover, as well as fire warnings and types of forest cover. The portal was developed with the support of the German Agency for International Cooperation within the framework of the Initiative to Strengthen Civil Society Organizations (Initiativa para el Fortalecimiento de la Sociedad Civil; IFOSC), a project financed by Germany's Federal Ministry of Economic Cooperation and Development and implemented in Mexico in collaboration with the Mexican Agency for International Development Cooperation (Agencia Mexicana de Cooperación Internacional para el Desarrollo; AMEXCID) and the General Directorate for Linkage with Civil Society Organizations (Dirección General de Vinculación con las Organizaciones de la Sociedad Civil; DGVOSC) of the Ministry of Foreign Affairs (Secretaría de Relaciones Exteriores). On the portal, a forest cover map for Mexico is available and was created for 2011/12 from RapidEye imagery at 5-m spatial resolution by the General Direction for Forest and Land Use (Dirección General de Gestión Forestal y de Suelos; DGGFS) of Mexico's Ministry of Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales; SEMARNAT). We extracted the *plantaciones forestales comerciales* (commercial forest plantations) class and incorporated it into the global plantations database. In addition, we acquired oil palm plantation boundaries for 2014, as mapped by Furumo and Aide (2017), based on MODIS imagery (250 m). We included these polygons in the "tree crops" category.

Nicaragua, Panama, and Venezuela

No maps were available for locations of forest plantations, but we acquired oil palm plantation boundaries for 2014, as mapped by Furumo and Aide (2017) and based on MODIS imagery (250 m). We included these polygons in the "tree crops" category.

For Panama, a 2012 land cover/land use map is visualized on a web map application, maintained by Panama's Ministry of the Environment (Ministerio de Ambiente).[14] The map, created from the interpretation of 5-m RapidEye imagery, includes two plantation classes, *bosque plantado coniferas* (coniferous planted forests) and *bosque plantado latifoliadas* (broadleaved planted forests), with additional classes of *café* (coffee), *citrico* (citrus), *platano/banano* (plantains/bananas), and *palma aceitera* (oil palm). This map was not available to include in Version 1.0 of the SDPT; it is hoped, however, that these data will be acquired to include into a future SDPT version.[15]

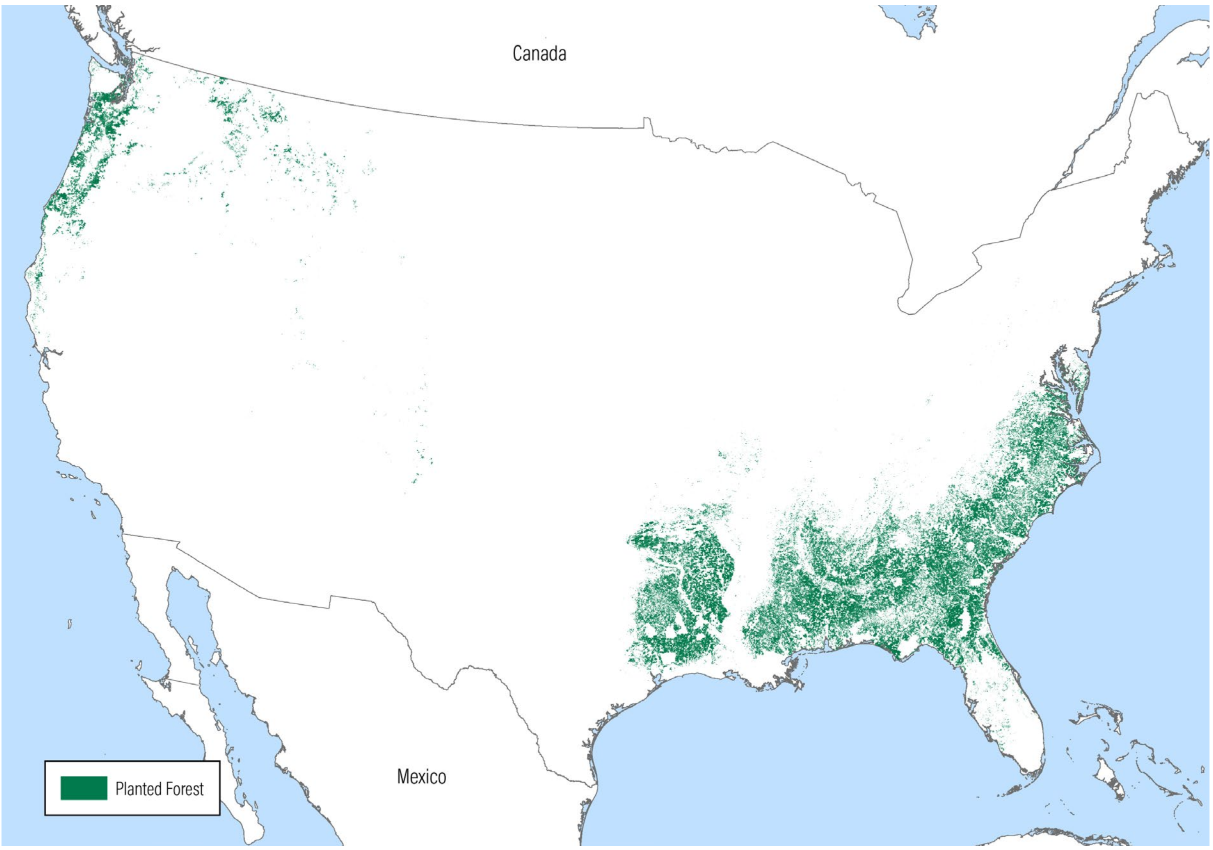
United States

The majority of U.S. planted forest area is concentrated in industrial pine forest plantations in the southeastern region of the United States (Stanturf and Zhang 2003), which are predominantly monocultures of three native pine species (loblolly pine [*P. taeda*], shortleaf pine [*P. echinata*], and slash pine [*P. elliottii*]). Additional areas of planted forests of Douglas fir are present in the U.S. Pacific Northwest. According to Stanturf and Zhang (2003), of every 100 ha of plantation in the U.S. southern region, 94 are privately owned (54 ha by industry, 40 ha by other private owners). Statistical estimates of planted forest area in the United States are derived from the Forest Inventory and Analysis program plots of the USDA Forest Service, which provide estimates at large scale (country or state administrative units); however, because the program plots sample only a small proportion of the landscape, these data are less useful for creating spatially explicit, fine-scale maps.

To map likely locations of forest plantations in the United States, we relied on overlaying a set of publicly available spatial layers, produced by the USDA Forest Service on forest type, timberland extent, forest age, forest ownership, and location of protected areas, produced by the United States Geological Survey (Table A-3). First, we selected seven forest types. These were associated with tree species that represent the dominant plantation species in the United States: Douglas Fir, Loblolly Pine, Loblolly Pine/Hardwood, Shortleaf Pine, Shortleaf Pine/Oak, Slash Pine, and Slash Pine/Hardwood. We combined these forest types with private ownership classes (corporate and family-owned) from the

Ownership Type data to map the seven forest types on privately owned land. Next, we used the Timberlands data layer to filter out any species of interest in privately owned land that were not considered timberland. We then removed protected areas inside the PADD (i.e., protected area downgrading, downsizing, and degazettement) easement class. Finally, we applied a Stand Age dataset to filter out forest stands outside the normal rotation age of the seven species. We selected only tree stands under 35 years for Loblolly[16] and Slash Pine,[17] 65 years for Douglas Fir,[18] and 70 years for Shortleaf Pine.[19] The resulting map is shown in Figure A-3.

Figure A-3 | **Map of US Plantation Extent**



Note: A methodology was used that integrates multiple publicly available spatial data layers, produced by the USDA Forest Service on forest type, timberland extent, forest age, forest ownership, and locations of protected areas produced by the United States Geological Survey.

Table A-3 | **Data Layers Used to Create a Map of Most Likely Forest Plantations in the United States**

DATA LAYER	SOURCE	INFORMATION USED TO DELINEATE PLANTATIONS CLASS
Timberlands	Nelson et al. 2009	Areas that fall within timberland extent
Forest type	Ruefenacht et al. 2008	Douglas Fir, Loblolly Pine, Loblolly Pine/Hardwood, Shortleaf Pine, Shortleaf Pine/Oak, Slash Pine, and Slash Pine/Hardwood
Ownership type	Hewes et al. 2017	Privately owned (corporate, family)
Stand age	Pan et al. 2011	Remove age classes above typical harvest age
Protected areas	USGS 2016	Outside of easements

Source: Compiled by WRI authors.

We used results from analyses by Chen et al. (2017) and Fagan et al. (2018) to cross-check the approach used in this study to map U.S. plantations. Chen et al. (2017) mapped plantations from 1928 to 2012 for the conterminous United States at a spatial resolution of 8 km. Through synthesis of multiple U.S. inventory data sources at plot, state, subregional, and regional scales, they generated spatially explicit plantation maps by including the planted area proportion range needed to reach the known area of each region, similar to the approach used for Europe, which is summarized on p. 18.

Comparing the 2012 plantation map to our approach in this study, there is a 25 percent difference in plantation area (Table A-4), with significantly more plantations mapped by our approach in the Carolinas, and less in Oregon and Washington. Besides temporal, resolution, and methodological differences between the two approaches, the larger area mapped with our approach in the Carolinas and Virginia could be explained by having included mixed hardwood and oak species in the pine classes.

Table A-4 | Area Comparison of Mapped Plantations and the Approach of This Study

STATE	PLANTED FOREST (HECTARES)		DIFFERENCE (%)
	CHEN ET AL. 2017	THIS STUDY	
Alabama	2,405,311	3,594,600	39.6
Arkansas	1,316,946	1,534,100	15.2
Florida	1,473,750	1,684,700	13.4
Georgia	2,886,421	4,154,500	36.0
Louisiana	1,770,183	2,204,700	21.9
Mississippi	2,011,407	2,096,900	4.2
Oklahoma	238,892	430,800	57.3
North Carolina	729,945	1,781,100	83.7
South Carolina	1,248,811	2,094,200	50.6
Texas	1,232,615	1,828,500	38.9
Virginia	488,391	818,600	50.5
Oregon	1,846,972	1,170,000	-44.9
Washington	1,215,282	1,004,600	-19.0
TOTAL	**18,864,926**	**24,397,300**	**25.6**

Note: Relates to states with greater than 100,000 hectares of planted forest.
Source: Chen et al. (2017) and WRI authors.

Fagan et al. (2018) distinguished pine plantations from natural forests of mixed pine and deciduous species in southeastern mixed forests and mid-Atlantic coastal forests of the United States, using structural, spectral, and temporal data from airborne and satellite remote sensing platforms. They report an overall map accuracy of 86–92 percent (depending on which "truth" data were used for the accuracy assessment, either Forest Inventory and Analysis data or Google Earth imagery), with user's accuracy of the plantation class of 75.8 percent or 85.7 percent, respectively.

We compared results from Fagan et al. (2018) to our results for areas of overlap within the southeastern and mid-Atlantic coast of the Fagan et al. (2018) study. A total of 3.2 million ha from Fagan et al. (2018) agreed with the results produced from our approach. Within the same extent, Fagan et al. (2018) classified an additional 4.5 million ha, while our study's method classified an additional 7.4 million ha (Table A-5; Figure A-4). In addition to the 10.6 million ha of planted forests mapped inside the extent mapped by Fagan et al. (2018), we mapped an additional area of 14.4 million ha of planted forest outside the Fagan et al. (2018) extent, for a total of 25 million ha (Figure A-4) across the conterminous United States. Planted forest area in 2015, reported by FAO (2015) for the United States, is 26 million ha.

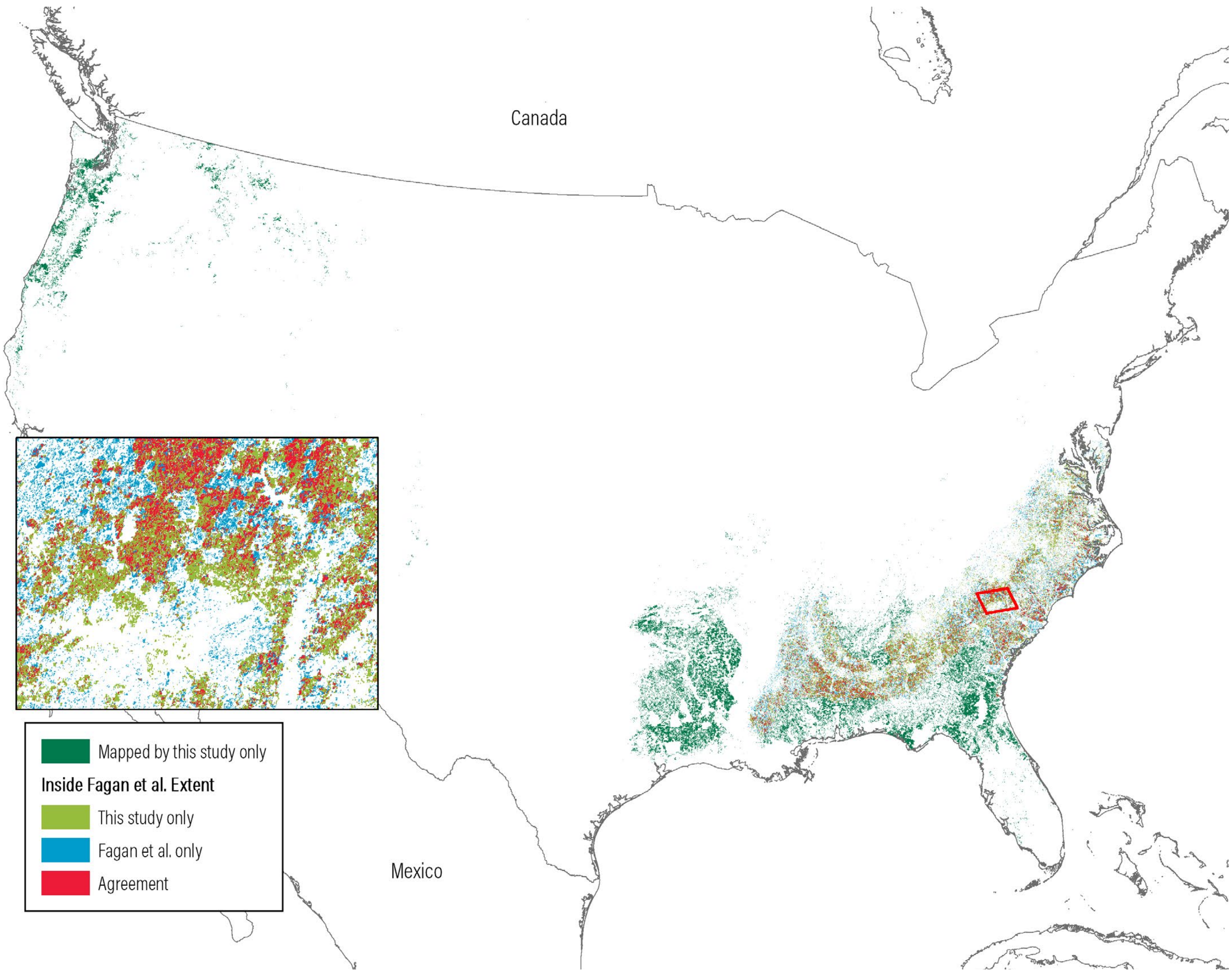
We included mixed hardwood species classes, which could explain the larger planted area captured by our approach in the Southeast compared to Fagan et al. (2018). The large discrepancy in spatial extent, shown in Table A-5, is likely due to differences in dataset resolution and methodologies. Fagan et al. (2018) mapped plantations at a spatial resolution of 30 m, while we relied on 250-m resolution datasets. To better understand this effect, we applied a 250-m buffer around our plantation dataset, resulting in 5 million ha of agreement within the Fagan et al. (2018) extent. Without a buffer, only 42 percent of Fagan et al. (2018) plantation area agreed with our dataset, although an additional 23 percent falls within one 250-m pixel of our mapped area, for a total of 65 percent agreement within one pixel of our dataset.

Table A-5 | Confusion Matrix of Mapped Plantation Areas for the Same Geographic Extent (Southeastern Mixed Forests and Mid- Atlantic Coastal Forests)

		FAGAN ET AL. (2018)	
		NOT PLANTATION	PLANTATION
THIS STUDY	Not plantation	33,153,719	4,480,037
	Plantation	7,383,880	3,231,464

Note: Confusion matrix shown is between this study (which uses an approach based on map overlays) and Fagan et al. (2018) (which uses a remote-sensing-based approach to map plantation areas directly).
Source: WRI authors.

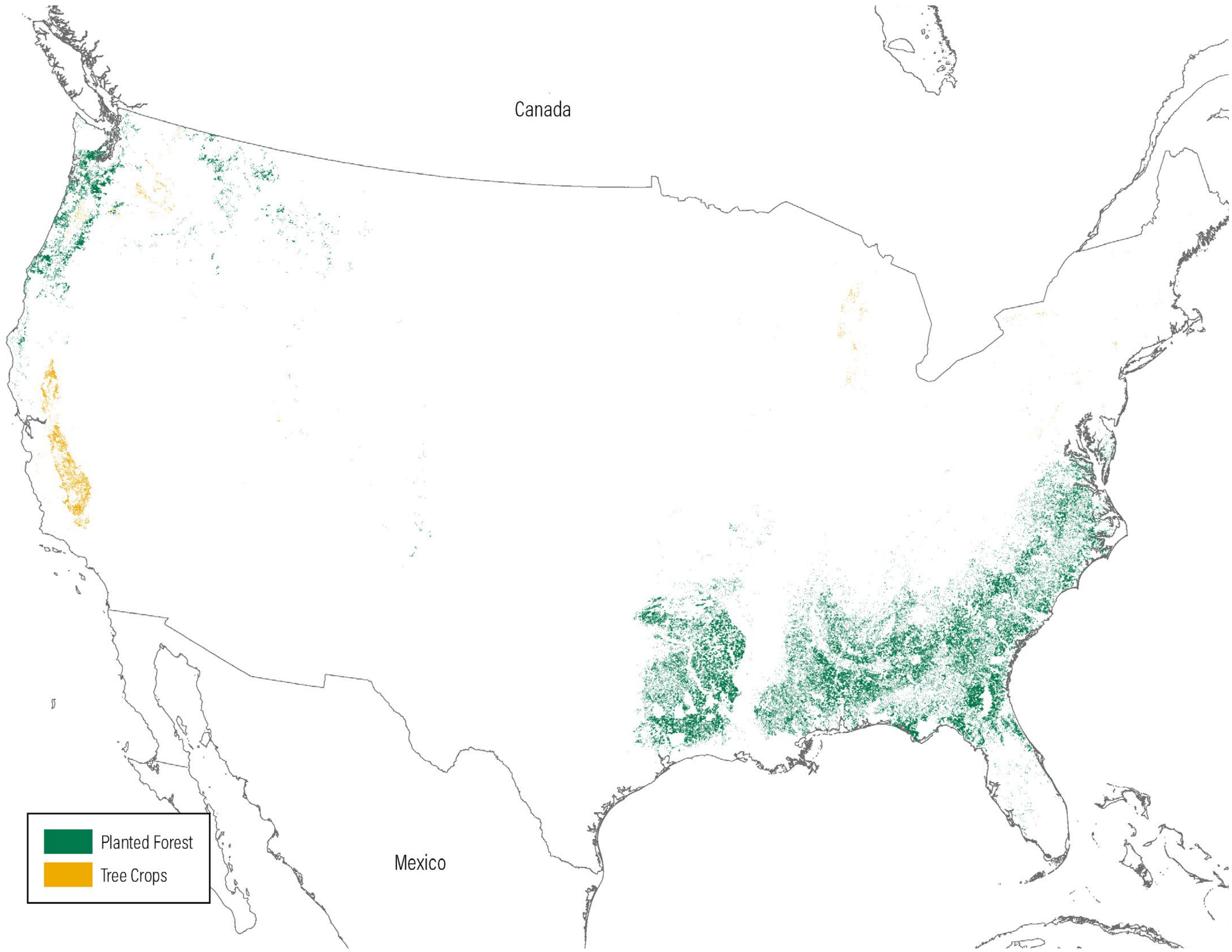
Figure A-4 | **Forest Plantation in the United States**



Note: Fagan et al. (2018) uses a remote-sensing-based approach to map plantation areas directly, while WRI authors mapped plantations using a GIS-based methodology involving the overlay of different spatial data layers.
Sources: Fagan et el. (2018) and WRI authors

In addition to mapping planted forests in the United States, we also included in this study agricultural tree crops as of 2017 by extracting classes from the Cropland Data Layer produced by the National Agricultural Statistics Service, as visualized on CropScape.[20] Classes included in the tree crops category are Christmas trees, fruit trees (cherries, peaches, apples, citrus, pears, oranges, plums, nectarines, apricots, pomegranates), tree nuts (pecans, almonds, walnuts, pistachios), olive trees, and a class of "other tree crops." The final map of planted forests and agricultural trees for the United States is shown in Figure A-5.

Figure A-5 | **Final Map of Planted Forests and Agricultural Trees in the United States**



Source: Various sources, compiled by WRI authors.

OCEANIA

Australia

We downloaded a 2013 Forests of Australia v2.0 raster layer for Australia from a web map application maintained by the Government of Australia's National Forest Inventory (NFI).[21] This map was created as the result of a collaborative partnership between federal, state, and territory governments, whose role is to collate, integrate, and disseminate information on Australia's forests. The data are derived and compiled by the NFI under the Australian Bureau of Agricultural and Resource Economics and Sciences. State and territorial agencies collect forest data using independent methods and at varying scales or resolutions. The NFI applies a national classification to state and territory data to allow seamless integration. Independent and multiple sources of external data are used to fill data gaps and improve the quality of the final dataset. A Multiple Lines of Evidence methodology is applied in which multiple forest, vegetation, and land cover spatial datasets are sourced from relevant state and territorial public agencies, and, where appropriate, data from these agencies—and external sources—are used to fill information gaps.

Forests of Australia v2.0 has three national forest categories: native forest, industrial plantations, and other forests. "Industrial plantations" and "other forests" are planted forest categories; "industrial plantations" are plantations managed commercially and reported through the National Plantation Inventory, and "other forests" are planted forests not managed commercially or otherwise not reported through the National Plantation Inventory. We extracted the two planted forest classes and incorporated them into the SDPT. The industrial plantation component of the dataset is at a coarser resolution (250-m cell size versus 100 m for other forest types), owing to confidentiality arrangements set by data suppliers. The data are licensed under a Creative Commons Attribution 3.0 Australia License.

New Zealand

We downloaded a 2012 land use map for New Zealand from a web map application maintained by the Government of New Zealand's Ministry for the Environment.[22] The land use map is composed of New Zealand–wide land use classification, nominally at January 1, 1990; January 1, 2008; and December 31, 2012 (known as 1990, 2008, and 2012). These date boundaries were dictated by the Kyoto 1st Commitment Period (2008–12) within the 1997 Protocol. The layer can therefore be used to create either a 1990, 2008, or 2012 land use map, depending on which field is symbolized (2012 in the case of this study).

The land use map distinguishes between natural forest and plantation forest. In the original data, LUC_ID 72 and LUC_ID 73 tag the exotic forest by period (pre-1990 and post-1989 forest). The 2012 land-use map was derived from SPOT 5 satellite imagery, as well as Landsat 7 imagery, to supplement change detection from 2008 up to the end of 2012. The data are made available under a Creative Commons Attribution 4.0 International license. Access to the data is provided on the understanding that the dataset, held by LUCAS and published on the Data Service website of the Ministry for the Environment, remains the authoritative master copy.

Papua New Guinea

Papua New Guinea reports no area of planted forest (FAO 2015). However, we downloaded a map of forest plantations, as well as a map of estate and smallholder oil palm plantations, from a web map application maintained as part of Papua New Guinea's National Forest Monitoring System.[23] The forest plantation data are from a 2012 forest base map, developed by the Papua New Guinea Forest Authority with support from the Japan International Cooperation Agency, using RapidEye and ALOS/PALSAR data.

The oil palm data is from New Britain Palm Oil Ltd., acquired in September 2015. This firm continues to update the information. We assigned forest plantations as planted forest and oil palm areas as tree crops in the SDPT.

Solomon Islands

WRI and FoodReg have been working to develop a UML that contains the most comprehensive information available on the location of palm oil mills worldwide. We used this list to delineate oil palm plantation boundaries within a 50 km road network of existing mills in the Solomon Islands, using very high-resolution imagery, on the assumption that mills must source from oil palm plantations within a 24-hour drive time in order to preserve the quality of the oil. Thus, the sourcing area has been estimated as land within a 50 km road network. The representative years of the data created are 2013–15. Approximately 27,000 ha of planted forest is reported in FAO (2015) for the Solomon Islands; the country, however, did not submit a report, and, therefore, this estimate is based only on a desk study completed by FAO.

SOUTH AMERICA

Argentina

We downloaded a map of 2013 forest plantations from a public web map application created and maintained by Argentina's Agroindustria, under the Ministry of Production and Work (Ministerio de Produccion y Trabajo).[24] The map was created from remote sensing imagery from multiple sensors, including Landsat 5 and 7, at 30-m spatial resolution; SPOT 4 and 5 satellite images; multispectral of 10 m of spatial resolution; and panchromatic of 5- and 2.5-m spatial resolution. Information is updated through the visualization of high-resolution images of the Google Earth server and Microsoft Corporation's Bing Maps. The purpose of the mapping exercise was to identify existing forest plantations in the country and to have an annual digital coverage of forest plantations that serve as a basis for executing forest inventories at the national and provincial levels alike. Attributes of the data include the type of plantation (genus) where known; these attributes were retained in the global attribute table. The data are generated and made available publicly, with free visualization and no restriction on its use.[25]

Brazil, Colombia, and Peru

GFW partner Transparent World delineated plantation boundaries from Landsat imagery for Brazil, Colombia, and Peru for 2013/14. They used visual delineation methods, since they are effective ways in which to map heterogeneous plantation categories (different species and types) as a single class. Some timber species in Brazil were captured using a semi-automated classification technique. Additional documentation on methods and results can be found in Petersen et al. (2016). Results of an independent accuracy assessment indicate an omission error of 35 percent for Brazil and 15 percent for Peru, Colombia, and Liberia (Appendix B).

Chile

We obtained a map of forest plantations produced for 2014 by Chile's Forest Institute (Instituto Forestal de Chile; INFOR). We downloaded INFOR's forest plantation data for 2014 from its public web map.[26] INFOR has oversight over the data they collect, which represents approximately 40 percent of total plantation area in Chile on small- and medium-size properties; INFOR's continuous inventory does not collect data from the regions located to the north of the Coquimbo region. The other 60 percent of spatially explicit data cannot be made available in the SDPT due to data restrictions.

Ecuador

Ecuador's Ministry of Environment (Ministerio del Ambiente) created a historical time series of land-use maps, which were used in Ecuador's REDD+ Forest Reference Emission Level submission to the United Nations Framework Convention on Climate Change. Land cover was mapped for 1990, 2000, 2008, and 2014. These maps reflect the country's first effort to produce spatial information on forest cover, developed not only as part of the country's ongoing processes for forest cover and forest loss monitoring, but also in the context of its national readiness process for the REDD+ program. Each land cover map was produced by analyzing Landsat and Aster images; these are publicly available for download.[27] We extracted the "forest plantations" category for 2000 and 2014. In addition, we acquired oil palm plantation boundaries for 2014, as mapped by Furumo and Aide (2017), based on MODIS imagery (250 m), and included these polygons in the category "tree crops" in the SDPT.

Uruguay

We downloaded a 2015 land cover map for Uruguay from a web map application, maintained by the System of Territorial Information (Dirección Nacional de Ordenamiento Territorial; DINOT) of Uruguay's Ministry of Housing, Territorial Planning and Environment (Ministerio de Vivienda, Ordenamiento Territorial y Medio Ambiente; MVOTMA).[28] Of the 17 detailed land cover classes mapped, we extracted the *plantación forestal* category and delineated these areas as the boundaries of Uruguay's planted forests. We also extracted the *frutales* class (citrus and other fruit plantations), which were categorized as tree crops. Use of the data is free and open to the public.[29]

APPENDIX B: ACCURACY ASSESSMENTS

Several country maps within the SDPT did not include accuracy information due to the absence of, and/or cost of acquiring, appropriate and independent data to verify them. In other cases, while accuracy information was available, it was not summarized in readily accessible documentation format. Users of the SDPT are encouraged to follow up with individual data providers, as needed, for further information. Below is a summary of accuracy information for each country, where available.

Australia

Because the Forests of Australia map was compiled from multiple datasets of varying original scales, a standard accuracy assessment was not conducted. Rather, confidence in the positional accuracy of a given class was assessed, according to how much overlap there is among different levels of evidence. According to the documentation provided with the data, while the accuracy of individual classes may be variable, in general, the accuracy of wood production forests is higher than that of the other forests, which are less intensively managed.

Ecuador

Forest Carbon carried out an independent accuracy assessment of the 2000 and 2008 land-use maps for Ecuador; the overall accuracy was estimated at 95.5 percent for the 2000 map and 94.0 percent for the 2008 map. While the individual class accuracy for the plantation class may be available, it was not provided in the documentation that was accessed when downloading the data.

Guatemala

The overall accuracy of the land cover map was measured at 88 percent. While the individual class accuracy for the plantation class may be available, it was not provided in the documentation that was accessed when downloading the data.

India

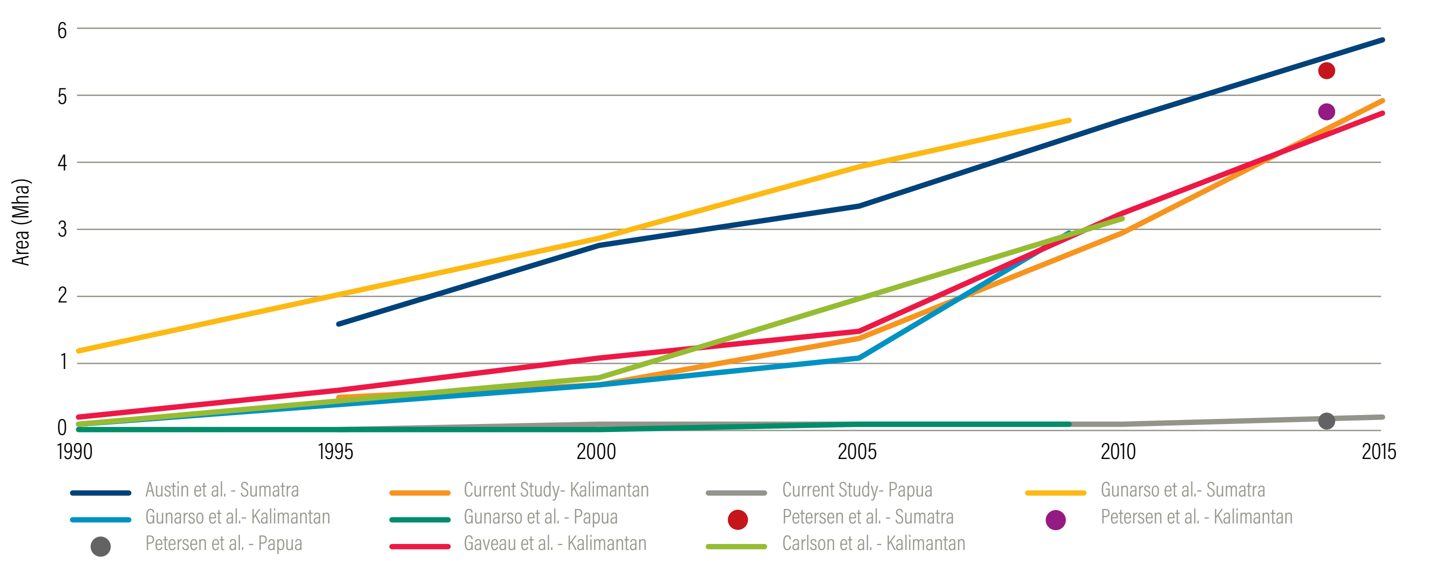
The vegetation map for India has a pixel-level accuracy of 90 percent, assessed using 15,565 ground control points. The forest plantation class had a user's accuracy of 86 percent and a producer's accuracy of 97 percent; the orchards class had a user's accuracy of 79 percent and a producer's accuracy of 99 percent. Each individual class within the vegetation map included accuracy statistics that were generally above 90 percent.

Indonesia and Malaysia

Several researchers have mapped industrial oil palm and wood fiber plantations across Southeast Asia, particularly including Indonesia. A comparison of results from different data sources for Indonesia is provided in Figure B-1 (Austin et al. 2017), and accuracy statistics for each individual map follow.

- **Austin et al. (2017):** Accuracies of oil palm maps for Indonesia range from 89 percent to 91.5 percent, with roughly equal errors of commission and omission. Error matrices for all years of the analysis are provided in the supplement to the paper and are not reproduced here.
- **Miettinen et al. (2016):** The industrial plantation species identification (oil palm and pulp plantations) across peat in Indonesia and Malaysia had a high overall accuracy of 95 percent. The oil palm class had user's and producer's accuracies of 95.6 percent and 99.4 percent, respectively, and the pulp plantation class had user's and producer's accuracies of 97.0 percent and 90.1 percent, respectively. Classification errors were due mainly to newly established plantations where the species could not be confirmed during an accuracy assessment and where plantation areas were formed of two or more different plantations with different species.
- **Gaveau et al. (2014):** Overall accuracy of the Borneo land cover maps was 93.1 percent, with user's and producer's accuracies for the industrial oil palm plantations of 83.0 percent and 94.7 percent, respectively. User's and producer's accuracies for industrial timber plantations were 97.2 percent and 75 percent, respectively.

Figure B-1 | **Comparison from Various Studies of Estimates of Oil Palm Plantation Area: Sumatra, Kalimantan, and Papua Province (Indonesia)**



Source: Austin et al. 2017.

- **Gunarso et al. (2013)**: No accuracy assessment was provided.
- **Petersen et al. (2016)**: See below for accuracy assessment information for countries mapped by Transparent World.

Myanmar

Producer's accuracy for the plantation class in Myanmar was relatively high (89 percent), indicating that if a plantation were detected in the images, it would be generally and correctly classified. User's accuracy for the plantation class, however, was lower (58.2 percent), indicating overprediction. Classification accuracy decreased with patch size, with nearly 80 percent accuracy for large patches in comparison to only a 50 percent accuracy for very small patches. Previous research has indicated similar results, indicating that high spatial heterogeneity and small patch size, a common occurrence across Southeast Asia, will result in much lower classification accuracies.

New Zealand

The planted pre-1990 and post-1989 classes in New Zealand's land cover maps had user's accuracies of 96.8 percent and 97.6 percent, respectively. Producer's accuracies were 97.5 percent and 94.4 percent, respectively.

South Africa

Overall map accuracy was assessed through an independent accuracy assessment of 6,415 sample points, using high-resolution imagery from Google Earth. Overall accuracy of the map was 82.53 percent and average class accuracy was 88.36 percent. Accuracy for the plantation class was 89.30 percent (user's accuracy) and 94.35 percent (producer's accuracy), corresponding to omission and commission errors of 6 percent and 11 percent, respectively.

Brazil, Cambodia, Colombia, Indonesia, Liberia, Malaysia, Peru

In 2016, Alexandra Tyukavina at the University of Maryland performed an independent accuracy assessment for plantations mapped by Transparent World for seven countries (Brazil, Cambodia, Colombia, Indonesia, Liberia, Malaysia, and Peru). Due to the manual delineation of plantation areas that included "mosaic" plantation classes in lieu of actual locations of planted trees in the final data, a customized sampling design was devised with the objectives of (1) estimating the proportion of area occupied by planted trees and plantation clearings within each type of mapped tree plantation (i.e., large industrial, mosaic of medium-sized, mosaic of small-sized, clearings and very young plantations); and (2) estimating map omission errors (i.e., area occupied by planted trees and plantation clearings that fall beyond plantation boundaries mapped by Transparent World).

Sampling design

To best address validation objectives, a stratified random sampling approach was selected, with sampling strata being mapped plantation types, a 5-km buffer around mapped plantations, and the remaining country area (Table B-1). A 5-km buffer stratum was created to target the area along the boundaries of mapped plantations, where errors of omission are most likely to occur. Countries were grouped for the validation purposes, based on a similarity of plantation management practices (Table B-1): Group 1: Brazil; Group 2: Southeast Asian countries (Cambodia, Indonesia, Malaysia); and Group 3: Peru, Colombia, and Liberia as countries with emerging plantations.

A total of 3,000 sampling units was allocated within the resulting 18 sampling strata (Table B-1). Sample allocation was intermediate between equal and proportional by the area of the stratum. Sampling unit was a point (no area). Each sampled point was visually interpreted, using very high-resolution imagery from Google Earth and a 2014 Landsat cloud-free composite. For each point, two independent interpreters identified whether it had plantation land use in 2013–14 (visible planted trees in 2013 or 2014 imagery, or 2013–14 clearing, with planted trees visible in the imagery prior to 2013 and during 2015–16).

Narrow roads within plantations (< 30m) were considered a part of plantation land use. For the fresh clearings, with natural vegetation cleared around 2013–14 and with no evidence that the trees were planted in 2015–16 (no very high-resolution imagery), a separate low confidence interpretation category, "fresh clearings," was created. A small number of points (51 out of 3,000, or 1.7 percent) with uncertain land use—due to their location on the boundary of plantation and nonplantation land uses—and a several-meter shift between the consecutive very high-resolution images were considered as 50/50 plantation/nonplantation in the area calculations. Sampled points with the initial disagreement between the two independent interpreters were additionally evaluated by the third analyst, who made a final decision in these cases. Such a two-stage validation system allows minimizing interpretation biases that may be inherent to any individual analyst.

The area occupied by planted trees and plantation clearings within and outside of mapped plantations within each country group and its standard error were calculated. To do this, equations 3 and 4 from Olofsson et al. (2013) were used.

Table B-1 | Sampling Strata and Allocation of Sampling Units (Points)

TYPE OF PLANTATIONS	BRAZIL	SOUTHEAST ASIA COUNTRIES	OTHER COUNTRIES
Large industrial plantations	120	130	110
Mosaic of medium-sized plantations	170	200	120
Mosaic of small-sized plantations	110	170	100
Clearing/very young plantations	100	150	100
5-km buffer around all plantation types	300	250	260
No plantations	240	210	160
TOTAL	**1040**	**1110**	**850**

Note: Southeast Asian countries include Cambodia, Indonesia, and Malaysia. Other countries (with emerging plantations) include Peru, Colombia, and Liberia.

Validation results

- The large industrial plantation map class has the highest percentage of area, in all country groups, covered by planted trees in 2013–14 (73–88 percent), compared to mosaic and young plantation classes (Table B-2, excluding fresh clearings).
- Ninety-two percent of low-certainty, fresh clearings are located within two validation strata: very young plantations and a 5-km buffer around them (Table B-2).
- The largest omission error is observed in Brazil and the smallest in the Southeast Asian countries. All omission errors come from the 5-km buffer around mapped plantations, implying that the current plantation map is a valid indicator of the distribution of plantations (Table B-3).

Table B-2 | **Sample-Based Estimates of Plantation Area per Stratum**

SAMPLING STRATUM EXCLUDING FRESH CLEARINGS		AREA OF PLANTATIONS ± STANDARD ERROR (MILLIONS OF HECTARES)		PERCENTAGE OF PLANTATIONS FROM STRATUM AREA	
		EXCLUDING FRESH CLEARINGS	INCLUDING FRESH CLEARINGS	EXCLUDING FRESH CLEARINGS	INCLUDING FRESH CLEARINGS
BRAZIL	Large industrial plantation	7.35 ± 0.27	7.42 ± 0.26	86	87
	Mosaic of medium-sized plantations	0.17 ± 0.01	0.17 ± 0.01	58	58
	Mosaic of small-sized plantations	0.01 ± 0.00	0.01 ± 0.00	47	47
	Clearing/very young plantation	0.42 ± 0.03	0.49 ± 0.03	65	76
	5-km buffer around all plantation types	4.35 ± 1.35	4.79 ± 1.42	3	4
	No plantations	0.00 ± 0.00	0.00 ± 0.00	0	0
	TOTAL	**12.30 ± 1.38**	**12.87 ± 1.44**	**-**	**-**
SOUTHEAST ASIAN COUNTRIES	Large industrial plantation	17.56 ± 0.57	17.56 ± 0.57	88	88
	Mosaic of medium-sized plantations	4.98 ± 0.26	5.09 ± 0.25	65	67
	Mosaic of small-sized plantations	2.79 ± 0.16	2.79 ± 0.16	64	64
	Clearing/very young plantation	2.18 ± 0.13	2.82 ± 0.10	65	85
	5-km buffer around all plantation types	2.53 ± 0.74	3.68 ± 0.89	4	6
	No plantations	0.00 ± 0.00	0.00 ± 0.00	0	0
	TOTAL	**30.03 ± 0.99**	**31.94 ± 1.10**	**-**	**-**
OTHER COUNTRIES	Large industrial plantation	0.46 ± 0.03	0.46 ± 0.03	73	74
	Mosaic of medium-sized plantations	0.01 ± 0.00	0.01 ± 0.00	69	70
	Mosaic of small-sized plantations	0.01 ± 0.00	0.01 ± 0.00	70	70
	Clearing/very young plantation	0.05 ± 0.00	0.06 ± 0.00	66	77
	5-km buffer around all plantation types	0.09 ± 0.04	0.11 ± 0.05	2	2
	No plantations	0.00 ± 0.00	0.00 ± 0.00	0	0
	TOTAL	**0.63 ± 0.05**	**0.66 ± 0.05**	**-**	**-**

Note: Southeast Asian countries include Cambodia, Indonesia, and Malaysia. Other countries (with emerging plantations) include Peru, Colombia, and Liberia. Values indicate sample-based estimates of the area occupied by planted trees and plantation clearings within each mapped type of tree plantations, and areas outside of the map ("5-km buffer around all plantation types" and "No plantations" sampling strata). Area of plantations "excluding fresh clearings" is based on the samples with the following 2013–14 conditions: (1) planted trees; (2) narrow roads (<30 m) surrounded by planted trees; (3) re-clearings of previously planted trees; (4) 2013–14 clearings of natural vegetation with evidence of planted trees in 2015–16 as very high-resolution imagery. "Fresh clearings" is a low-confidence category, used to refer to the areas where natural vegetation was cleared in approximately 2013–14, and no evidence of the following land use is available (may or may not be cleared for plantation land use).
Source: A. Tyukavina (University of Maryland) and D. Aksenov (Transparent World).

Table B-3 | Omission Errors per Region

COUNTRY	OMISSION ERROR ± STANDARD ERROR (PERCENTAGE OF SAMPLE-BASED AREA OF PLANTATIONS)	
	EXCLUDES FRESH CLEARINGS	INCLUDES FRESH CLEARINGS
Brazil	35 ± 11	37 ± 11
Southeast Asian countries	8 ± 2	12 ± 3
Other countries	15 ± 7	17 ± 7

Note: Southeast Asian countries include Cambodia, Indonesia, and Malaysia. Other countries (with emerging plantations) include Peru, Colombia, and Liberia.
Source: A. Tyukavina (University of Maryland) and D. Aksenov (Transparent World).

APPENDIX C: SPATIAL DATABASE OF PLANTED TREES: LIST OF SPECIES

Table C-1 | Spatial Database of Planted Trees: List of Species

COMMON NAME	SPECIES NAME	AGRICULTURAL TREE OR PLANTED FOREST
Acacia/Wattle	*Acacia sp.*	Planted forest
African Pear	*Dacryodes edulis*	Tree Crop
Alder	*Alnus sp.*	Planted forest
Almond	*Prunus dulcis*	Tree Crop
Apple	*Malus pumila*	Tree Crop
Apricot	*Prunus armeniaca*	Tree Crop
Areca Palm	*Areca sp.*	Tree Crop
Ash	*Fraxinus sp.*	Planted forest
Australian Blackwood	*Acacia melanoxylon*	Planted forest
Bamboo	Unknown	Planted forest
Banana	*Musa sp.*	Tree Crop
Black Locust	*Robinia pseudoacacia*	Planted forest
Black Pine	*Pinus thunbergii*	Planted forest
Black Spruce	*Picea mariana*	Planted forest
Black Wattle	*Acacia mearnsii*	Planted forest
Bocote	*Cordia sp.*	Planted forest
Cacao	*Theobroma cacao*	Tree Crop
Cashew	*Anacardium occidentale*	Tree Crop
Casuarina	*Casuarina sp.*	Planted forest
Cedar	*Cedrus sp.*	Planted forest
Cherry	*Prunus sp.*	Tree Crop

Table C-1 | **Spacial Database of Planted Trees: List of Species (Cont'd)**

COMMON NAME	SPECIES NAME	AGRICULTURAL TREE OR PLANTED FOREST
Chilean Cedar	*Austrocedrus chilensis*	Planted forest
Chinese Cork Oak	*Quercus variabilis*	Tree Crop
Christmas Tree	Unknown	Tree Crop
Citrus	*Citrus sp.*	Tree Crop
Clove	*Syzygium aromaticum*	Tree Crop
Coconut Palm	*Cocos nucifera*	Tree Crop
Coffee	*Coffea sp.*	Tree Crop
Cypress	Unknown	Planted forest
Douglas Fir	*Pseudotsuga sp.*	Planted forest
East Asian Ash	*Fraxinus rhynchophylla*	Planted forest
East Asian Eurya	*Eurya japonica*	Planted forest
East Asian White Birch	*Betula pendula*	Planted forest
Eucalyptus	*Eucalyptus sp.*	Planted forest
Fir	*Abies sp.*	Planted forest
Fruit	Unknown	Tree Crop
Ginkgo	*Ginkgo biloba*	Tree Crop
Gleditsia	*Gleditsia sp.*	Planted forest
Gliricidia	*Gliricidia sp.*	Tree Crop
Grevillea	*Grevillea sp.*	Planted forest
Jacaranda	*Jacaranda sp.*	Planted forest
Japanese Bay Tree	*Machilus thunbergii*	Planted forest
Japanese Black Pine	*Pinus thunbergii*	Planted forest
Japanese Flowering Cherry	*Prunus serrulata*	Tree Crop
Japanese Raisin	*Hovenia dulcis*	Planted forest
Japanese Red Cedar	*Cryptomeria japonica*	Planted forest
Japanese Red Pine	*Pinus densiflora*	Planted forest
Japanese Stone Oak	*Pasania edulis*	Tree Crop
Jezo Spruce	*Picea jezoensis*	Planted forest
Korean Chestnut	*Castanea crenata*	Tree Crop
Korean Dendropanax	*Dendropanax morbiferus*	Tree Crop
Korean Pine	*Pinus koraiensis*	Planted forest
Korean Red Pine	*Pinus densiflora*	Planted forest
Larch	*Larix sp.*	Planted forest

Table C-1 | **Spacial Database of Planted Trees: List of Species (Cont'd)**

COMMON NAME	SPECIES NAME	AGRICULTURAL TREE OR PLANTED FOREST
Loblolly Pine	*Pinus taeda*	Planted forest
Loose-Flower Hornbeam	*Carpinus laxiflora*	Planted forest
Mahogany	*Swietenia sp.*	Planted forest
Mango	*Mangifera sp.*	Agricultural tree
Mangrove	Unknown	Planted forest
Mesquite	*Prosopis sp.*	Planted forest
Monkey Puzzle	*Araucaria sp.*	Planted forest
Mono Maple	*Acer pictum*	Planted forest
Monterey Pine	*Pinus radiata*	Planted forest
Mulberry	*Morus sp.*	Tree Crop
Nectarine	*Prunus persica*	Tree Crop
Oak	*Quercus sp.*	Planted forest
Oil Palm	*Elaeis guineensis*	Tree Crop
Olive	*Olea europaea*	Tree Crop
Orange	*Citrus sp.*	Tree Crop
Padauk	*Pterocarpus sp.*	Planted forest
Palm	Unknown	Tree Crop
Peach	*Prunus persica*	Tree Crop
Pear	*Pyrus sp.*	Tree Crop
Pecan	*Carya illinoinensis*	Tree Crop
Peltophorum	*Peltophorum sp.*	Planted forest
Pine	*Pinus sp.*	Planted forest
Pistachio	*Pistacia vera*	Tree Crop
Pitch Pine	*Pinus rigida*	Planted forest
Plum	*Prunus sp.*	Tree Crop
Pomegranate	*Punica granatum*	Tree Crop
Poplar	*Populus sp.*	Planted forest
Princess	*Paulownia sp.*	Planted forest
Prune	*Prunus sp.*	Tree Crop
Red Cedar	*Toona sp.*	Planted forest
Roble	*Tabebuia sp.*	Planted forest
Rosewood	*Tipuana tipu*	Planted forest
Rubber	*Hevea brasiliensis*	Tree Crop

Table C-1 | **Spacial Database of Planted Trees: List of Species (Cont'd)**

COMMON NAME	SPECIES NAME	AGRICULTURAL TREE OR PLANTED FOREST
Sakhalin Fir	*Abies sachalinensis*	Planted forest
Sakhalin Spruce	*Picea glehnii*	Planted forest
Sal	*Shorea robusta*	Planted forest
Sawleaf Zelkova	*Zelkova serrata*	Planted forest
Sawtooth Oak	*Quercus acutissima*	Planted forest
Senna	*Senna sp.*	Planted forest
Shining Gum	*Eucalyptus nitens*	Planted forest
Shortleaf Pine	*Pinus echinata*	Planted forest
Slash Pine	*Pinus elliottii*	Planted forest
Southern Beech	*Nothofagus sp.*	Planted forest
Spanish Cedar	*Cedrela sp.*	Planted forest
Spruce	*Picea sp.*	Planted forest
Tasmanian Bluegum	*Eucalyptus globulus*	Planted forest
Taxodium	*Taxodium sp.*	Planted forest
Tea	*Camellia sinensis*	Tree Crop
Teak	*Tectona sp.*	Planted forest
Umbrella Tree	*Maesopsis sp.*	Planted forest
Walnut	*Juglans sp.*	Tree Crop
Wedding Cake	*Cornus controversa*	Tree Crop
White Cedar	*Melia azedarach*	Planted forest
Willow	*Salix sp.*	Planted forest

ENDNOTES

1. Graham Stinson, personal communication.
2. Dmitry Aksenov, personal communication.
3. F. Landsberg, personal communication.
4. For FAO's Geonetwork, see www.fao.org/geonetwork/srv/en/main.home.
5. For Rwanda's forest inventory, see www.researchgate.net/publication/301695298_RWANDA_FOREST_COVER_MAPPING_USING_HIGH_RESOLUTION_AERIAL_PHOTOGRAPHS_1.
6. See GIS Data Downloads at https://egis.environment.gov.za/data_egis/node/109.
7. See the Biodiversity Information System of the Indian Institute of Remote Sensing at http://bis.iirs.gov.in.
8. Anish Joshi of Arbonaut provided WRI with the GIS data of these areas.
9. Specifically from Nara Lee of the Korean Forest Service, who also provided the English translation of species names.
10. The data were received by the authors from Brian Johnson at IGES.
11. For a description of the datasets, see http://maps.vnforest.gov.vn/help/en/DataSets.htm.
12. For further information on REDD/CCAD-GIZ , see http://www.reddccadgiz.org.
13. See http://bosquesabiertos.org.mx/mapa for further information on this atlas.
14. To view the map, see http://www.miambiente.gob.pa/sinia.
15. Additional metadata can be found at http://consulweb.miambiente.gob.pa/arcgis/rest/services/Restauracion_Ecosistemas/CoberturaUsoTierra2012/MapServer/layers.
16. See "Managing Loblolly Pine Stands...from A to Z" at www.uaex.edu/publications/PDF/FSA-5023.pdf.
17. See *Slash Pine: Still Growing and Growing!* Proceedings of the Slash Pine Symposium on Jekyll Island, Georgia, April 23–25, 2002, at www.srs.fs.usda.gov/pubs/gtr/gtr_srs076.pdf.
18. See Zhou, Xiaoping, Richard W. Haynes, and R. James Barbour. 2005. "Projections of Timber Harvest in Western Oregon and Washington by County, Owner, Forest Type, and Age Class." General Technical Report PNW-GTR-633. United States Department of Agriculture & Forest Service Pacific Northwest Research Station. www.fs.fed.us/pnw/pubs/pnw_gtr633.pdf.
19. See U.S. Department of Agriculture. 1967. "Timber Management Guide for Shortleaf Pine and Oak-Pine Types in Missouri." Research Paper NC-19. www.nrs.fs.fed.us/pubs/rp/rp_nc019.pdf.
20. See https://nassgeodata.gmu.edu/CropScape of the U.S. Department of Agriculture, National Agricultural Statistics Service.
21. See "Forests of Australia (2013) v2.0" of the Australian Department of Agriculture and Water Resources at http://data.daff.gov.au/anrdl/metadata_files/pb_foa13g9abfs20160525_11a.xml.
22. See LUCAS NZ Land Use Map 1990, 2008, 2012 (v018) at https://data.mfe.govt.nz/layer/2375-lucas-nz-land-use-map-1990-2008-2012-v016.
23. See PNG REDD+ and Forest Monitoring Web-Portal by the Climate Change Development Authority and Forest Authority at http://png-nfms.org/portal.
24. See "Monitor Forestal," Subsecretariate of Industrial Forest Development (Subsecretaría de Desarrollo Foresto Industrial) at http://ide.agroindustria.gob.ar/visor/?v=forestal.
25. See Argentina's forest plantation map at GeoNetwork Open Source, http://ide.agroindustria.gob.ar/geonetwork/srv/spa/metadata.show?id=257&currTab=simple.
26. See http://mapaforestal.infor.cl/flexviewers/ifc_2016.
27. For more information, see http://suia.ambiente.gob.ec/en/anexos-nivel-referencia, Subsecretariate of Climate Change, Ministry of Environment, Ecuador.
28. See application in "Cobertura" at http://sit.mvotma.gub.uy/js/cobertura.
29. See terms and conditions at http://sit.mvotma.gub.uy/recursos/rm902-2011.pdf.

REFERENCES

Austin, K. G., A. Mosnier, J. Pirker, I. McCallum, S. Fritz, and P. S. Kasibhatla. 2017. "Shifting Patterns of Oil Palm Driven Deforestation in Indonesia and Implications for Zero-Deforestation Commitments." *Land Use Policy* 69: 41–48. https://www.sciencedirect.com/science/article/pii/S0264837717301552.

Batra, P., and R. Pirard. 2015. "Is a Typology for Planted Forests Feasible, or Even Relevant?" CIFOR *Infobrief*. No. 121. www.cifor.org/publications/pdf_files/infobrief/5608-infobrief.pdf.

Bhagwat, T. , A. Hess, N. Horning, T. Khaing, Z. M. Thein, K. M. Aung, K. H. Aung, P. Phyo, Y. L. Tun, A. H. Oo, A. Neil, W. M. Thu, M. Songer, K. LaJeunesse Connette, A. Bernd, Q. Huang, G. Connette, and P. Leimgruber. 2017. "Losing a Jewel—Rapid Declines in Myanmar's Intact Forests from 2002–2014. *PLoS ONE* 12(5): e0176364. https://doi.org/10.1371/journal.pone.0176364.

Brus, D. J. , G. M. Hengeveld, D. J. J. Walvoort, P. W. Goedhart, A. H. Heidema, G. J. Nabuurs, G. J., and K. Gunia. 2012. "Statistical Mapping of Tree Species over Europe." *European Journal of Forest Research* 131(1): 145–57. https://www.researchgate.net/publication/225482455_Statistical_mapping_of_tree_species_over_Europe.

Chen, G. 2017. "Spatial and Temporal Patterns of Plantation Forests in the United States Since the 1930s: An Annual and Gridden Dataset for Regional Earth System Modeling." *Earth System Science Data* 9(2): 545–56. https://doi.org/10.5194/essd-9-545-2017.

Del Lungo, A., J. Ball, and J. Carle. 2006. *Global Planted Forests Thematic Study: Results and Analysis*. Planted Forests and Trees Working Paper 35b, p. 38. Rome: Food and Agriculture Organization.

Fagan M. E. et al. 2018. "Mapping Pine Plantations in the Southeastern U.S. Using Structural, Spectral, and Temporal Remote Sensing Data." *Remote Sensing of Environment* 216: 415–26. https://app.dimensions.ai/details/publication/pub.1105712338?and_facet_journal=jour.1045931.

FAO (Food and Agriculture Organization). 2000. *Global Planted Forests Thematic Study: Results and Analysis*, by A. Del Lungo, J. Ball, and J. Carle. Planted Forests and Trees Working Paper 38. Rome: FAO. www.fao.org/forestry/12139-03441d093f070ea7d7c4e3ec3f306507.pdf.

FAO. 2004. "Planted Forests: Definitions." Online. www.fao.org/forestry/plantedforests/67504/en.

FAO. 2015. "Global Forest Resources Assessment." Online. www.fao.org/forest-resources-assessment/past-assessments/fra-2015/en/.

Forest Europe. 2015. *State of Europe's Forests 2015*. Madrid: Ministerial Conference on the Protection of FOREST EUROPE Liaison Unit Madrid. www.foresteurope.org/docs/fullsoef2015.pdf.

Furumo, P. R., and T. M. Aide. 2017. "Characterizing Commercial Oil Palm Expansion in Latin America: Land Use Change and Trade. *Environmental Research Letters* 12(2): 024008. https://www.illegal-logging.info/sites/files/chlogging/palmoillatinamericaIOP.pdf.

Gaveau, D. L., S. Sloan, E. Molidena, H. Yaen, D. Sheil, N. K. Abram, M. Ancrenaz, R. Nasi, M. Quinones, N. Wielaard, and E. Meijaard. 2014. "Four Decades of Forest Persistence, Clearance and Logging on Borneo." *PLOS ONE* 9(7): e101654. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0101654.

GoN (Government of Nepal). 2014. *Terai Forests of Nepal*. Publication No. 1. Forest Resource Assessment Nepal Project. Kathmandu: Department of Forest Research and Survey, Government of Nepal. www.dfrs.gov.np/downloadfile/The-TeraiForestsofNepal_Press-copy-%20final_1502865012.pdf.

Gunarso, P., M. E. Hartoyo, F. Agus, and T. Killeen. 2013. "Oil Palm and Land Use Change in Indonesia, Malaysia and Papua New Guinea." In *Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO)* Ed. by T.J. Killeen and J. Goon, pp. 29–63. Kuala Lumpur: Roundtable on Sustainable Palm Oil.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. A. Turubanova, A. Tyukavina, D. Thau et al.2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." S*cience 342*(6160): 850–53. http://science.sciencemag.org/content/342/6160/850.

Hewes, Jaketon H., Brett J. Butler, and Greg C. Liknes. 2017. "Forest Ownership in the Conterminous United States circa 2014: Distribution of Seven Ownership Types—Geospatial Dataset." Fort Collins, CO: Forest Service Research Data Archive. www.fs.usda.gov/rds/archive/Product/RDS-2017-0007.

Miettinen, J., C. Shi, and S. C. Liew. 2016. "Land Cover Distribution in the Peatlands of Peninsular Malaysia, Sumatra, and Borneo in 2015 with Changes Since 1990." *Global Ecology and Conservation* 6: 67–78.

Nelson, Mark, Greg Liknes, and Charles H. Perry. 2009. "Combining Forest Inventory, Satellite Remote Sensing, and Geospatial Data for Mapping Forest Attributes of the Conterminous United States." In McWilliams, Will, Gretchen Moisen, and Ray Czaplewski, comps. Forest Inventory and Analysis (FIA) Symposium 2008; October 21–23, 2008. Park City, UT. Proc. RMRS-P-56CD. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Olofsson, P., G. M. Foody, S. V. Stehman, and C. E. Woodcock. 2013. "Making Better Use of Accuracy Data in Land Change Studies: Estimating Accuracy and Area and Quantifying Uncertainty Using Stratified Estimation." *Remote Sensing of Environment* 129: 122–31.

Pan, Yude, Jing M. Chen, Richard Birdsey, Kevin McCullough, Liming He, and Feng Deng. 2011. "Age Structure and Disturbance Legacy of North American Forests." *Biogeosciences* 8: 715–32. www.fs.usda.gov/treesearch/pubs/all/37680.

Peng, S. S., S. Piao, Z. Zeng, P. Ciais, L. Zhou, L. Z. Li, R. B. Myneni, Y. Yin, and H. Zeng. 2014. "Afforestation in China Cools Local Land Surface Temperature." *Proceedings of the National Academy of Sciences* 111(8): 2915–19.

Petersen, R., D. Aksenov, E. Goldman, S. Sargent, N. Harris, A. Manisha, E. Esipova, V. Shevade, and T. Loboda. 2016. "Mapping Tree Plantations with Multispectral Imagery: Preliminary Results for Seven Tropical Countries." Technical Note. Washington, DC: World Resources Institute. www.wri.org/publication/mapping-treeplantations.

Roy, P. S. , M. D. Behera, M. S. R. Murthy, A. Roy, S. Singh, S. P. S. Kushwaha, C. S. Jha, S. Sudhakar, P. K. Joshi, C. S. Reddy, and S. Gupta. 2015. "New Vegetation Type Map of India Prepared Using Satellite Remote Sensing: Comparison with Global Vegetation Maps and Utilities." *International Journal of Applied Earth Observation and Geoinformation* 39: 142–59.

Ruefenacht, B, M. V. Finco, M. D. Nelson, R. Czaplewski, E. H. Helmer, J. A. Blackard, G. R. Holden, A. J. Lister, D. Salajanu, D. Weyermann, and K. Winterberger. 2008. "Conterminous U.S. and Alaska Forest Type Mapping Using Forest Inventory and Analysis Data." *Photogrammetric Engineering & Remote Sensing* 74(11): 1379–88.

San-Miguel-Ayanz, J., D. De Rigo, G. Caudullo, T. Durrant, and A. Mauri. 2015. *European Atlas of Forest Tree Species*. Luxembourg: Publications Office of the European Union. http://forest.jrc.ec.europa.eu/european-atlas-of-forest-tree-species.

Stanturf, J. A., and D. Zhang. 2003. "Plantations Forests in the United States of America: Past, Present and Future." Paper submitted to the XII World Forestry Congress 2003, Quebec City, Canada. www.fao.org/docrep/article/wfc/xii/0325-b1.htm.

USGS (U.S. Geological Survey, Gap Analysis Program). 2016. Protected Areas Database of the United States (PAD-US), Version 1.4 Combined Feature Class. https://gapanalysis.usgs.gov/padus/data.

ACKNOWLEDGMENTS

We are pleased to acknowledge our institutional strategic partners, who provide core funding to WRI: Netherlands Ministry of Foreign Affairs, Royal Danish Ministry of Foreign Affairs, and Swedish International Development Cooperation Agency.

This publication represents a first attempt by the Global Forest Watch (GFW) partnership to provide reliable information about the extent and location of planted forests and agricultural tree crops around the world as mapped from satellite imagery and other spatially explicit data. Our efforts were made possible by financial support from Norway's International Climate and Forest Initiative (NICFI) and the U.S. Agency for International Development (USAID).

We also gratefully acknowledge the contributions of the many individuals listed below who offered their time and expertise to the development and improvement of this product.

Contributors

Dmitry Aksenov (Transparent World, Russia)
Natalia Alatortseva (Transparent World, Russia)
Freddy Argotty (Centro Agronómico Tropical de Investigación y Enseñanza [CATIE], Costa Rica)
Bruno Arias (Instituto Nacional de Bosques [INAB], Guatemala)
Kemen Austin (Duke University and RTI International, United States)
Brian Bean (Vietnam Forests and Deltas Program of the United States Agency for International Development)
Katie LaJeunesse Connette (Smithsonian Conservation Biology Institute, United States)
Irina Danilova (Transparent World, Russia)
Elena Esipova (Transparent World, Russia)
Matthew Fagan (University of Maryland—Baltimore County, United States)
Paul Furumo (University of Puerto Rico, Rio Piedras [UPR-RP], Puerto Rico)
Basanta Gautam (Arbonaut, Finland)
David Gaveau (CGIAR, France)
Alfred Gichu (Kenya Forest Service, Kenya)
Claire Halleux (World Resources Institute, Democratic Republic of the Congo)
Henry Hernandez (Instituto Nacional de Bosques [INAB], Guatemala)
Martin Herold (Wageningen University & Research, the Netherlands)
Brian Johnson (Institute for Global Environmental Strategies [IGES], Japan)
Anish Joshi (Arbonaut, Pakistan)
Irina Kurakna (Transparent World, Russia)
Hector Lagos (Instituto de Conservación Forestal [ICF], Honduras)
Nara Lee (Korea Forest Service, South Korea)
Peter Leimgruber (Smithsonian Conservation Biology Institute, United States)
Tapio Leppanan (Forestry Sector Monitoring and Information System [FORMIS], Vietnam)
Manuel Llano (CartoCrítica, Mexico)
Alexander Manisha (Transparent World, Russia)
Jukka Miettinen (Centre for Remote Imaging, Sensing and Processing [CRISP], Singapore)
Susan Minnemeyer (World Resources Institute, United States)
Gert Jan Nabuurs (Wageningen University, the Netherlands)
Mark Nelson (USDA Forest Service, United States)
Ruth Noguerón (World Resources Institute, United States)
Rodrigo Oscar Sagardía Parga (Instituto Forestal [INFOR], Chile)
Margie Parinas (National Mapping and Resource Information Authority [NAMRIA], Philippines)
Shushi Peng (Peking University, China)

Gerson Samuel Perdomo (Instituto de Conservación Forestal [ICF], Honduras)
Katie Reytar (World Resources Institute, United States)
Alfred Rungol (Climate Change and Development Authority, Papua New Guinea)
Parth Sarathi (P.S.) Roy (University of Hyderabad, India)
Taryn Sánchez (Reforestamos México, Mexico)
María Sanz Sánchez (Basque Center for Climate Change [BC3], Spain)
Ryan Sarsfield (World Resources Institute, United States)
Maria Sementsova (Transparent World, Russia)
Graham Stinson (Canadian Forest Service, Canada)
Daniela Requena Suarez (Wageningen University, the Netherlands)
Peter Tiangco (National Mapping and Resource Information Authority [NAMRIA], Philippines)
Alexandra Tyukavina (University of Maryland—College Park, United States)
Pieter Johannes Verkerk (European Forest Institute [EFI], Finland)
Nadezhda Vladimirova (Transparent World, Russia)
Pete Watt (Indufor, New Zealand)
Arief Wijaya (World Resources Institute, Indonesia)
Qing Ying (University of Maryland—College Park, United States)
Eugenia Yolkina (Transparent World, Russia)
Julia Zenkevich (Transparent World, Russia)

ABOUT THE AUTHORS

Nancy Harris is the Research Manager for Global Forest Watch in WRI's Forest Program. She leads GFW's work on identifying thematic and geographic research priorities for GFW and leads the acquisition and generation of new data and analytical content.

Contact: nharris@wri.org

Elizabeth Goldman is a GIS Research Associate for Global Forest Watch (GFW). She conducts geospatial analysis on global forest change data and supports the creation of new GFW data, maps, and research publications.

Samantha Gibbes is a former GIS Research Associate and software engineer for Global Forest Watch (GFW).

ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

Maps are for illustrative purposes and do not imply the expression of any opinion on the part of WRI, concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

Copyright 2019 World Resources Institute. This work is licensed under the Creative Commons Attribution 4.0 International License.
To view a copy of the license, visit http://creativecommons.org/licenses/by/4.0/