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REDD

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Readiness for REDD: A preliminary global assessment of tropical forested land suitability for agriculture

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Introduction and Goals

As UNFCCC negotiations lead to a powerful new mechanism for compensating tropical countries for their nation-wide reductions of greenhouse gas emissions from deforestation and forest degradation (REDD), an important question is: "how much will it cost?" One of the biggest costs of REDD will be the foregone profits from deforestation-dependent agricultural expansion as nations succeed in slowing future deforestation. Although the mapping and quantification of potential profits of competing uses of forest land can be achieved through economic modeling (see companion report "The costs and benefits of reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon"), faster, simpler approaches are needed that will allow nations to conduct preliminary analyses of the cost of their REDD programs. This report responds to this need. **We present preliminary maps and statistics about the area and carbon content of forests on lands that are highly suitable for industrial agriculture and those forests that have high concentrations of forest-dependent people.** These two drivers of deforestation—the expansion of industrial agriculture and smallholder farming—may represent the most expensive component of the REDD programs that are in development.

Beyond these preliminary maps and statistics, an important goal of this report is to provide **a conceptual approach** to the mapping of the constraints to agricultural expansion imposed by soils, drainage, and climate as **one component** of the analyses that each nation must undertake in projecting future deforestation trends. For some nations, the potential financial benefits of participation in the emerging REDD regime will be negligible unless projected increases in emissions are added to the historical emission baseline. In developing REDD programs, each nation will need reliable information on the portions of their forests that are **not suitable** for highly profitable agriculture or are very sparsely populated with forest-based farmers, allowing them to better constrain their estimates of the opportunity costs of REDD.

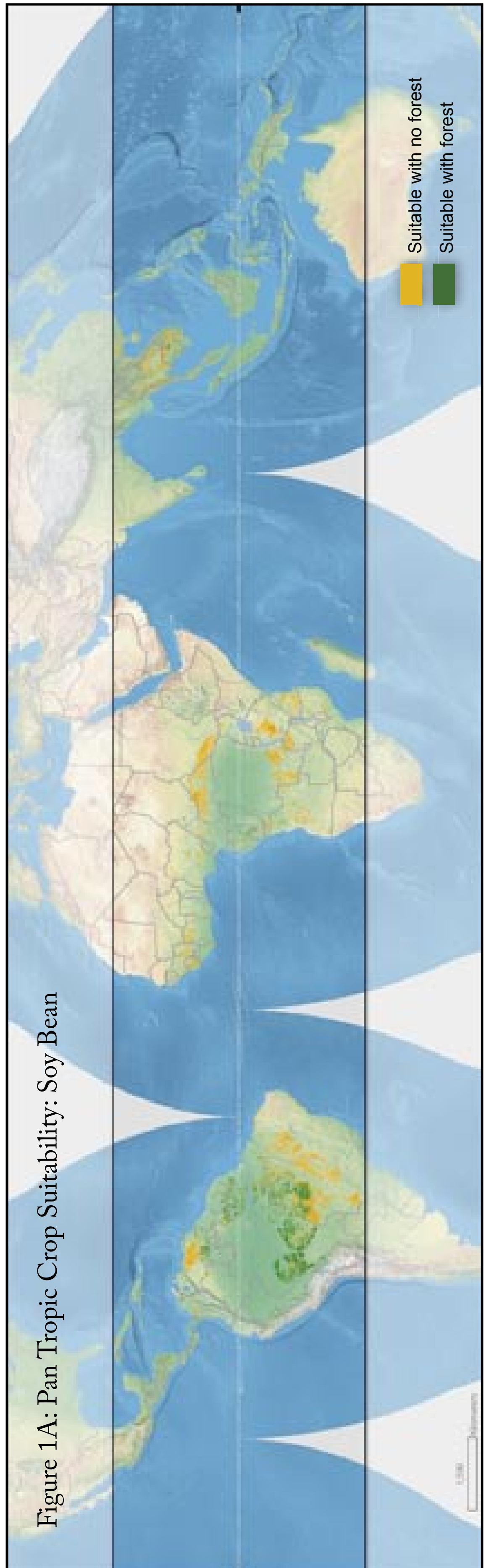
Executive Summary

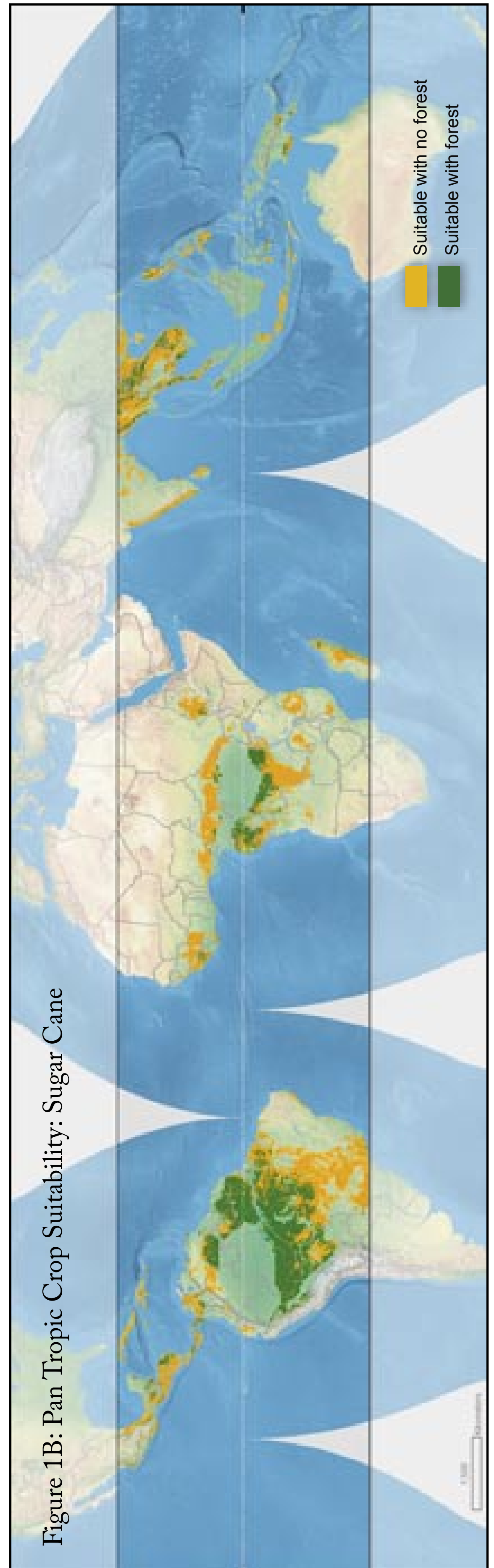
- Tropical forest nations vary greatly in both the absolute area of their forest estates and the portion of this forest area that is either suitable for industrial agriculture or the home of large concentrations of farm families
- Of the ca. 125 billion tons of carbon stored in tropical forests with high biophysical potential for industrial agriculture, 75% is contained in five countries (Brazil, DRC, Indonesia, Peru, Colombia) and 41% is contained in Brazil
- Tropical nations vary greatly in the portion of their forests that have low potential for industrial agriculture and sparse concentrations of forest farmers. In some countries (Malaysia, French Guiana, Cameroon) virtually all forested lands have high agricultural potential or high population densities, while in other nations (Bolivia, Congo, Venezuela, Guyana) one third to one half of the forests are unsuitable or with low concentrations of farmers. These "unsuitable" and sparsely populated forests should be prioritized for protection within REDD programs.

Table 1. Estimated tropical forested area suitable for crops, with high densities of people, or neither, and the carbon contained in those forests.

Country	Total forested suitable area (1000s km2)				Total carbon (million tons)				Forest (1000s km2)			
	soy	palm	sugar	com-bined	soy	palm	sugar	com-bined	dense popu-lation	unsuit-able/ low pop	total	unsuit-able/low (%total)
Brazil	**390**	**2283**	**1988**	**2746**	**6964**	**42543**	**36023**	**49823**	**4**	**426**	**2730**	16
Congo, DRC	2	**778**	**285**	**1015**	39	**14420**	**4781**	**16048**	1	**261**	**888**	29
Indonesia	1	**617**	41	**765**	11	**10857**	515	**11045**	**1**	**282**	**633**	45
Peru	6	**458**	**133**	**513**	108	**8585**	2225	**9076**	0	154	**497**	31
Colombia	0	**417**	28	**438**	2	**7551**	293	**7646**	**2**	81	**428**	19
Venezuela	**20**	150	**157**	270	**337**	2653	**2362**	3571	**2**	**156**	224	70
Malaysia	0	146	2	193	0	2475	30	2475	**2**	58	146	40
Bolivia	**66**	90	**184**	189	**1184**	1554	**3140**	3163	0	**161**	186	87
Papua New Guinea	0	144	21	185	1	2512	275	2604	0	104	151	69
Cameroon	0	83	14	166	0	1523	226	1608	0	81	89	91
Gabon	7	81	127	134	**142**	1559	**2431**	2469	0	19	129	15
Myanmar	6	25	119	119	53	431	1064	1064	0	6	119	5
Laos	**9**	13	115	115	72	133	850	850	0	2	115	2
Congo	4	66	52	111	78	1253	957	1861	0	96	98	98
Suriname	5	101	87	103	83	1671	1452	1704	0	17	103	16
Guyana	**12**	81	46	99	**212**	1471	829	1770	0	53	97	55
French Guiana	1	70	28	70	17	1330	544	1330	0	3	70	4
Ecuador	0	55	3	65	0	980	22	1002	1	36	58	62
Vietnam	4	5	62	62	45	58	630	630	0	3	62	5
Philippines	1	31	33	56	9	396	390	648	0	6	52	12
Thailand	4	24	38	42	41	347	458	507	0	19	42	46
Total	539	5717	3562	7457	9396		59497		15	2025	6918	

Results are for the 21 countries that constitute 95% of the forested area suitable for mechanized agriculture. Numbers in boldface are the five largest values in each category. Values are derived by summing the suitable area in each country from Figures 1a–d on the following pages. See the methods section for a description of the datasets and assumptions used in generating the values. Estimated total forested area suitable for soy, oil palm, and sugar cultivation and the combined area of all suitable lands in 1000s km². Estimated total carbon contained in those forests located in regions suitable cultivation 1000000s of tons. The carbon estimate is derived by combining the total crop suitability area (Figure 1d) with the IPCC Tier-1 Global Carbon Map (Figure 2, Gibbs et al., in press). Total forested area with high population density, the area of forest not suitable for agriculture and with low population density, the total forested area and the fraction of low-population density forest that is not suitable are shown in the final four columns.





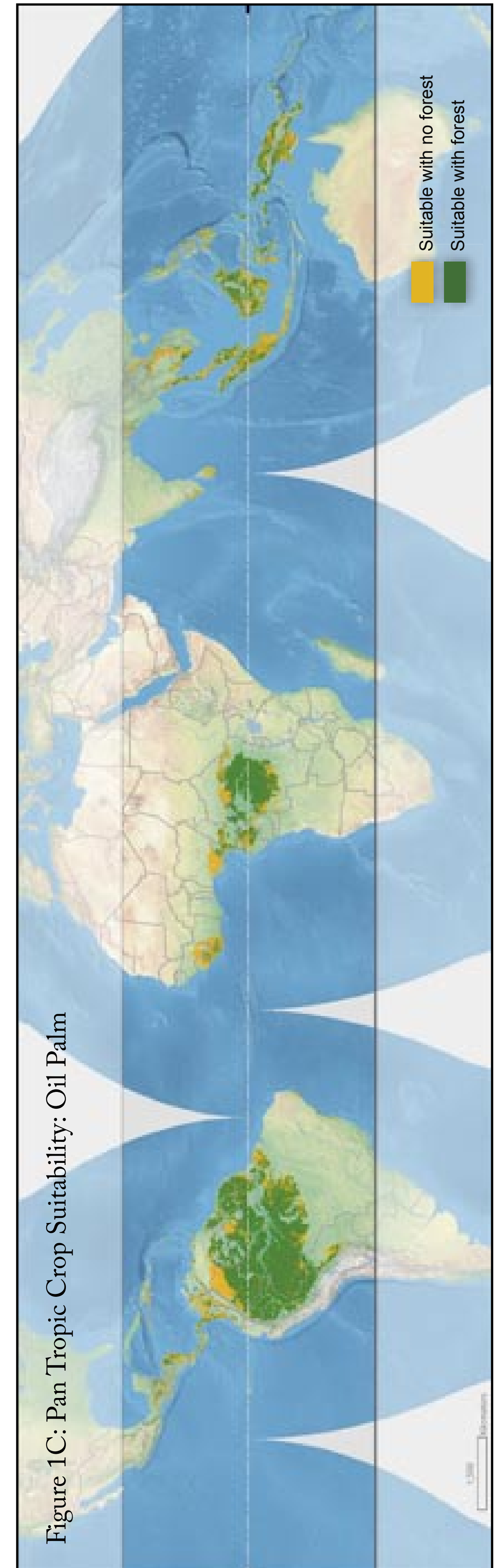


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Figure 1. Tropical land area suitable for soy (a), sugar cane (b), and oil palm (c). Areas in dark green are suitable for the individual crop and are currently forested, areas in yellow are suitable for the individual crop and currently not forested. Forest and non-forest regions are defined by the Vegetation Continuous Fields dataset (Hansen et al., 2001).

Next page:

Figure 1 continued (d) All three crops combined and shown in red. (e) Protected areas overlain on total crop suitability (see the data sources section of this report for information on how the crop and protected areas are defined).

Figure 2. Global forest carbon stocks in ton/ha (derived from Gibbs et al., 2007).

Figure 3. Rural population density (persons/km2) derived from the CIESIN Global Rural Urban Mapping Project.

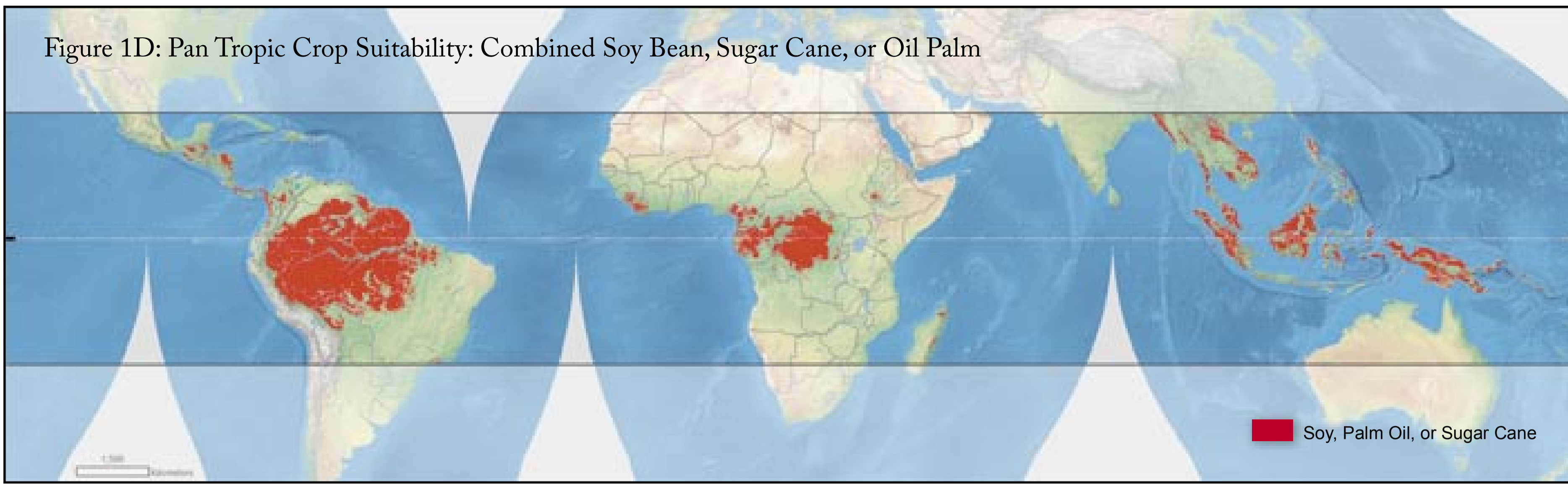

Figure 1D: Pan Tropic Crop Suitability: Combined Soy Bean, Sugar Cane, or Oil Palm

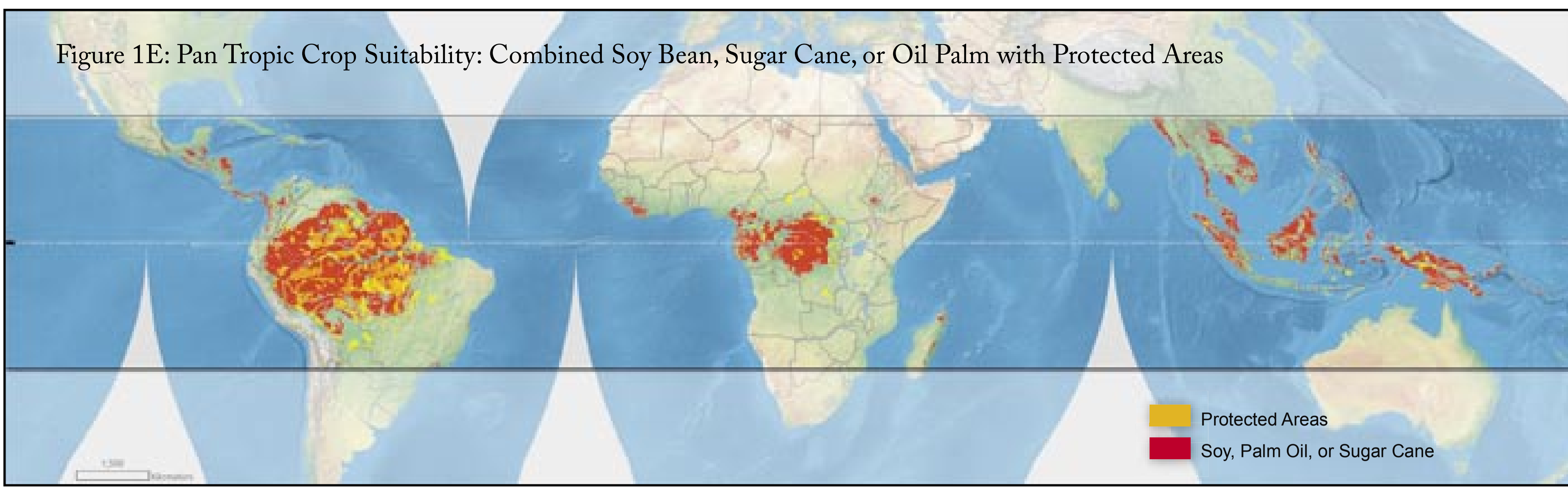

Figure 1E: Pan Tropic Crop Suitability: Combined Soy Bean, Sugar Cane, or Oil Palm with Protected Areas

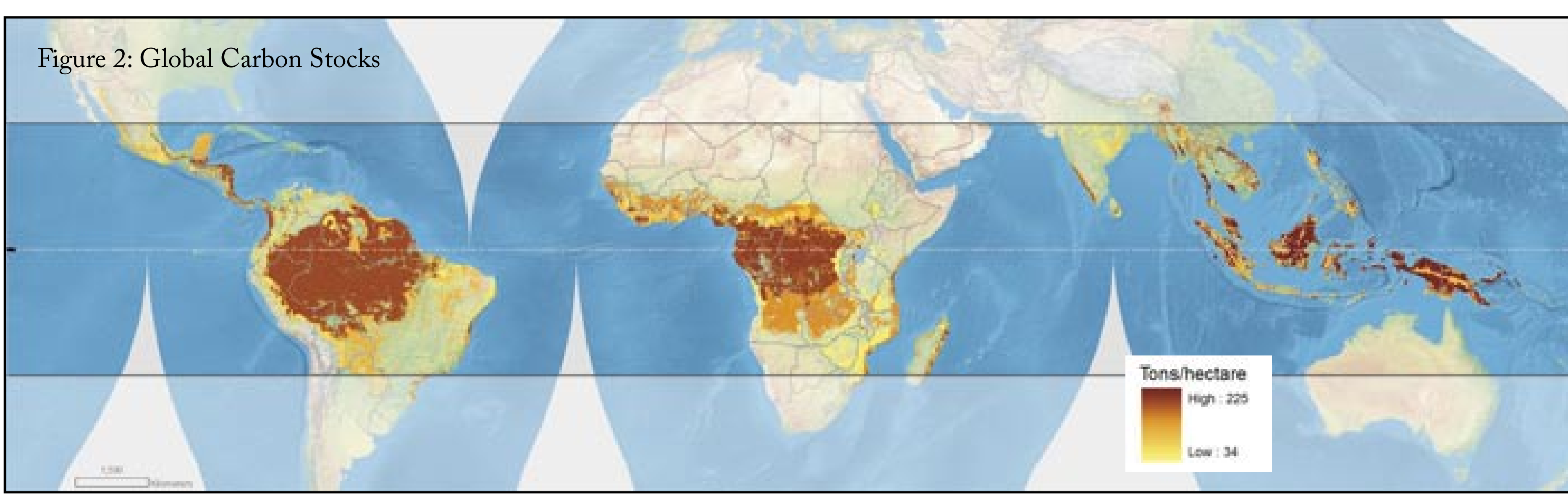

Figure 2: Global Carbon Stocks

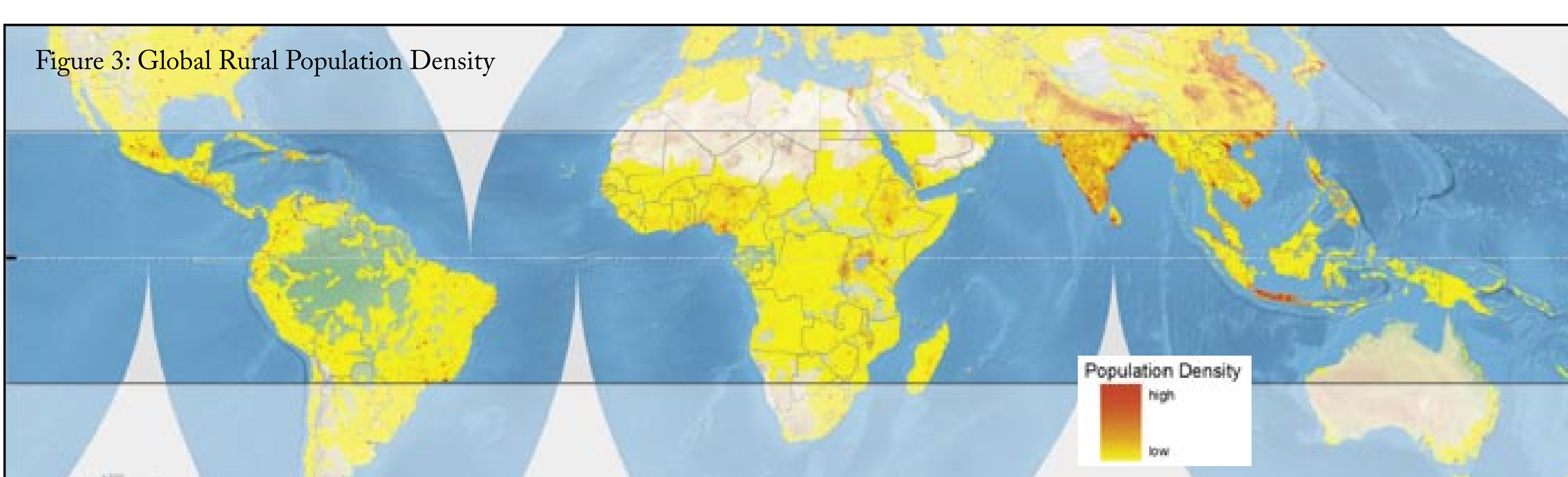

Figure 3: Global Rural Population Density

Overview of Approach

Detailed description of how we conducted these analyses can be found at: http://whrc.org/REDDready

Key Assumptions

- We assume that global trends in population growth, eating habits (e.g. the growth of meat-eating in China and other countries, Nepstad et al. 2006, Nepstad and Stickler, in press), and biofuels will apply steadily growing pressure on lands with agricultural potential and that tropical nations could incorporate the costs of restricting agricultural expansion into their forestlands as part of their REDD programs.
- We assume that a more complete assessment of future business-as-usual trends in agricultural expansion into tropical forests will necessarily involve information about infrastructure (transportation, storage), market trends, and the governance capacity of each nation.
- We carried out the analyses for all forested areas, regardless of their land tenure status, but indicate where protected areas are currently located on the assumption that these will be maintained and could be eligible for compensation.
- A more complete set of assumptions pertaining to REDD can be found in our companion report, "The costs and benefits of reducing carbon emissions from deforestation and forest degradation in the Brazilian Amazon" (available at: http://whrc.org/BaliReports).

Data Considerations

- *Data Quality and Availability*
    - o The current analysis uses relatively coarse resolution global datasets that are readily and freely available.
    - o To develop their own proposals under REDD, nations should strive to employ the best quality data they can obtain. Wherever possible, current, fine-scale datasets should be employed.
- *Crop Growth Criteria*
    - o Similarly, the current analysis uses a set of general criteria for the three crops in question.
    - o Individual nations should identify more detailed criteria, on the basis of local and expert knowledge and experience with individual crops in the region or regions with similar biophysical conditions
- *Validation of Analysis*
    - o This analysis is complementary to the Global Agro-Ecological Zones (GAEZ) map of agricultural potential developed by the UN Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA) (2000). Our analysis uses a more limited, but more recent, set of criteria and data in an effort to be accessible to developing nations with more limited resources. To this end, we compared the results of our analyses against those produced by the GAEZ. The results of this validation are available online at http://whrc.org/REDDready
    - o We also compared the results of our analyses with two datasets showing current crop distributions, including for (1) soy bean in the SE Amazon (Morton et al. 2006), and (2) oil palm in Indonesia (S. Minnenmayer, World Resources Institute, unpubl. data). The results of this validation are available online at http://whrc.org/REDDready

METHODS

Crop Potential Maps

- We developed maps of biophysical potential for three major crops (soybean, sugar cane, oil palm) in the tropics (*NB: maps for pasture are included in the supplemental information available at* http://whrc.org/REDDready*; since the profitability of cattle grazing is typically well below that of other major crops, the land use represents the low end of the opportunity cost curve for maintaining forests*). We identified the growth requirements for each crop to develop spatially-explicit variables determining whether the crop could be profitably grown in a region. In addition, we identified other impeding factors (e.g., established urban areas) and included these as variables in our analysis. In these initial analyses, suitability criteria are relatively simple (e.g., most variables are binary, no variables were weighted), but conform with published criteria for each crop (Table 2). We derived individual data layers for each criterion and superimposed the layers to derive a map for each crop and for the three crops combined (Figures 1,a-d).

Crop Suitability vs. Forest Carbon Maps

- We overlaid maps of crop suitability on a map of closed canopy forest (defined as having canopy cover ≥69%) to determine the total area of forests on land that could, eventually, be profitability converted to industrial agriculture (Figure 1). Table 1 shows the total area of forested land that is suitable for the three crops (individually and combined) for 21 nations representing 95% of the total suitable forest land in the tropics. A complete list may be found at http://whrc.org/REDDready

- We overlaid the agricultural potential maps with a map of forest carbon to arrive at an initial estimate of carbon supply under REDD for individual nations (Figure 2). Table 1 shows the tons of carbon contained in the areas of forest land suitable for crop production for the same limited set of nations. A complete list may be found at http://whrc.org/REDDready

- We indicate where existing protected areas are located in relation to areas of closed canopy forest that are suitable for agriculture (Figure 1e). Table 1 summarizes the amount of area of protected areas that is suitable for agriculture for a limited number of nations to provide an indication of carbon credits that might be earned from existing protected areas and indigenous lands. A complete list may be found at http://whrc.org/REDDready

Compensating Forest Farm Communities

- To determine the number of people residing in rural, forested areas that might be affected by REDD, we superimposed a map of rural population density (CIESIN 2004) on our map of forests suitable for agriculture (Figure 3). Forest area with high population density is listed in Table 1.

Table 2: Criteria used for developing agricultural potential maps in the tropics.
(For more information about data and criteria sources, please see http://whrc.org/REDDready)

(a) Oil Palm

Criterion	*Value*	*Source Data*	*Criterion Source*
Temperature	Mean annual temperature ≥ 24° C	CRU	Rieger 2006
Precipitation	Mean annual rainfall ≥ 1500 mm	CRU	Rieger 2006
	Mean monthly rainfall ≥ 75 mm; 4-month maximum dry season allowed (no month lower than 75mm)	CRU	Rieger 2006
Soils	Soils ranked as suitable for mechanized agriculture	FAO	Rieger 2006
Other	No urban areas	NGDC	

(b) Soybean

Criterion	*Value*	*Source Data*	*Criterion Source*
Precipitation	Mean annual rainfall ≥ 450 mm	CRU	FAO 2007a
	3-month maximum dry season of mean monthly rainfall ≤ 75 mm	CRU	FAO 2007a
	4-month wet season of mean monthly rainfall ≥ 100 mm allowed	CRU	FAO 2007a
Soils	Soils ranked as suitable for mechanized soy cultivation	FAO	FAO 2007a; Field data, unpubl. WHRC
Slope	Elevation deviation: -1.5 to 2.5 3x3 window	HydroSHEDS	Field data, unpubl. WHRC
Other	No urban areas	NGDC	

(c) Sugar Cane

Criterion	Value	Source Data	Criterion Source
Precipitation	Mean annual rainfall ≥ 1250 mm	CRU	FAO 2007b
	Mean monthly rainfall ≥ 100 mm; 3-month maximum dry season allowed	CRU	FAO 2007b
Soils	Soils ranked as suitable for mechanized agriculture	FAO	FAO 2007b
	No inundated areas	GLC2000	
Other	No urban areas	NGDC	

References Cited

FAO. 2007a. Soybean. Land and Water Development Division/**Water Resources, Development and Management Service. Rome: FAO. Available at http://www.fao.org/ag/agl/aglw/cropwater/soybean.stm**

FAO. 2007b. Sugar cane. Land and Water Development Division/**Water Resources, Development and Management Service. Rome: FAO. Available at** http://www.fao.org/ag/agl/aglw/cropwater/sugarcane.stm

Leff, B., Ramankutty, N., and Foley, J.A. 2004. Geographic distribution of major crops across the world. *Global Biogeochemical Cycles* **18**(1). GB1009 10.1029/2003GB002108.

Morton, D.C., DeFries, R.S., Shimabukuro, Y.E., Anderson, L.O., Arai, E., Espirito-Santo, F.D.B., Freitas, R., Morisette, J. 2006. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. *Proc. Nat. Acad. Sci.* **103**(39), 14637-14641.

Nepstad, D., C. Stickler. In press. Managing the tropical agriculture revolution. ***J. Sustainable Forestry***

Nepstad, D., C. Stickler, O. Almeida. 2006. Globalization of the Amazon beef and soy industries: opportunities for conservation. ***Conservation Biology*** **20**(6): 1595-1603.

Rieger, M. 2006. *Introduction to Fruit Crops.* Binghamton, NY: Haworth Press.

Data Sources

Source	Layer Name	Citation
FAO (Food and Agricultural Organization)	Gridded Global Soil Data Set	Zobler, L., 1986. A world soil file for global climate modeling. NASA Tech. Memo. 87802. Washington, D.C.: NASA/Greenbelt, MD: Distributed Active Archive Center (Code 902 .2), Goddard Space Flight Center http://daac.gsfc.nasa.gov/interdisc/readmes/soils.shtml
CRU (Climate Research Unit; University of East Anglia)	CRU TS 2.1 0.5 global dataset	Mitchell T. D. and P. D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25, 693-712. http://www.cru.uea.ac.uk/cru/data/hrg.htm
HydroSHEDS (USGS for Earth Resources Observation and Science (EROS))	Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales (HydroSHEDS)	Lehner, B., Verdin, K., Jarvis, A. (2006): HydroSHEDS Technical Documentation. World Wildlife Fund US, Washington, DC. Available at http://hydrosheds.cr.usgs.gov
NGDC (Earth Observation Group, NOAA National Geophysical Data Center)	Global Distribution and Density of Constructed Impervious Surfaces	Elvidge, C.D., Tuttle, B.T., Sutton, P.C., Baugh, K.E., Howard, A.T., Milesi, C., Bhaduri, B.L., and Nemani, R. 2007. Global distribution and density of constructed impervious surfaces. Sensors 7: 1962-1979. http://www.ngdc.noaa.gov/dmsp/download_global_isa.html
GLC2000 (Global Vegetation Mapping Unit, Joint Research Center, European Commission)	GLC2000: The Land Cover of the World in the Year 2000	Bartholome, E., Belward, A.S., Achard, F., Bartalev, S., Carmona-Moreno, C., Eva, H., Fritz, S., Gregoire, J.-M., Mayaux, P., and Stibig, H.J. 2002. GLC 2000: Global Land Cover mapping for the year 2000. EUR 20524 EN. Rome: Joint Research Center/Institute for Environment and Sustainability/European Commission. http://www-gvm.jrc.it/glc2000/objectives-GLC2000.htm
MODIS VCF (Global Land Cover Facility, University of Maryland & NASA)	Vegetation Continuous Fields	Hansen, M., R. DeFries, J.R. Townshend, M. Carroll, C. Dimiceli, and R. Sohlberg (2006), Vegetation Continuous Fields MOD44B, 2001 Percent Tree Cover, Collection 4, University of Maryland, College Park, Maryland, 2001. http://glcf.umiacs.umd.edu/data/vcf/
GRUMP (Socioeconomic Data and Applications Center (SEDAC), Center for International Earth Science Information Network (CIESIN), Columbia University)	Global Rural-Urban Mapping Project	Center for International Earth Science Information Network (CIESIN), Columbia University; International Food Policy Research Institute (IFPRI); The World Bank; and Centro Internacional de Agricultura Tropical (CIAT). 2004. Global Rural-Urban Mapping Project (GRUMP), Alpha Version: Population Density Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.org/gpw/. (November 28, 2007).
IPCC Tier-1 Global Carbon Map	Global Carbon Map	Gibbs, H.K., S. Brown, J. O. Niles. J.A. Foley. 2007. Monitoring and Estimating Tropical Forest Carbon Stocks: Making REDD A Reality. in press, Environmental Research Letters.
Various	Global Protected Areas	1. Indonesia Ministry of Forestry. 2007. National and Other Protected Areas of Indonesia. (Data provided courtesy of S. Minnenmayer, World Resources Institute)
		2. Centro de Sensoriamento Remoto, Universidade Federal de Minas Gerais. 2007. Protected Areas of South America. (Data provided courtesy of B. Soares, CSR/UFMG).
		3. Africa Program, Woods Hole Research Center. 2007. Protected Areas of Africa. (Data provided courtesy of N. LaPorte, WHRC).