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1 The neotropical reforestation hotspots: A biophysical and socioeconomic
2 typology of contemporary forest expansion

3 A. Sofía Nanni^{a,*1}, Sean Sloan^{b,*1}, T. Mitchell Aide^c, Jordan Graesser^d, David Edwards^e,

4 H. Ricardo Grau^a

5 a Instituto de Ecología Regional and Consejo Nacional de Investigaciones Científicas y
6 Técnicas (CONICET), Universidad Nacional de Tucumán, CC. 34, 1407, Yerba

7 Buena, Tucumán, Argentina

8 b Center for Tropical Environmental and Sustainability Science, College of Science and
9 Engineering, James Cook University, Cairns, Qld, 4870, Australia

10 c Department of Biology, University of Puerto Rico, San Juan 00931-3360, Puerto Rico

11 d Department of Earth and Environment, Boston University, 685 Commonwealth Avenue,
12 Boston, MA, 02215, USA

13 e Department of Animal and Plant Sciences, University of Sheffield, S10 2TN, UK

14

15 **Abstract**

16 Tropical reforestation is a significant component of global environmental change that is far
17 less understood than tropical deforestation, despite having apparently increased widely in
18 scale during recent decades. The regional contexts defining such reforestation have not
19 been well described. They are likely to differ significantly from the geographical profiles
20 outlined by site-specific observations that predominate in the literature. In response, this
21 article determines the distribution, extent, and defining contexts of apparently spontaneous
22 reforestation. It delineates regional ‘hotspots’ of significant net reforestation across Latin
23 America and the Caribbean and defines a typology of these hotspots with reference to the
24 biophysical and socioeconomic characteristics that unite and distinguish amongst them.
25 Fifteen regional hotspots were identified on the basis of spatial criteria pertaining to the
26 area, distribution, and rate of reforestation 2001–2014, observed using a custom continental
27 MODIS satellite land-cover classification. Collectively, these hotspots cover 11% of Latin
28 America and the Caribbean and they include 167,667.7 km² of new forests. Comparisons
29 with other remotely sensed estimates of reforestation indicate that these hotspots contain a
30 significant amount of tropical reforestation, continentally and pantropically. The extent of
31 reforestation as a proportion of its hotspot was relatively invariable (3–14%) given large
32 disparities in hotspot areas and contexts. An ordination analysis defined a typology of five
33 clusters, distinguished largely by their topographical roughness and related aspects of agro-
34 ecological marginality, climate, population trends, and degree of urbanization: ‘Urban
35 lowlands’, ‘Mountainous populated areas’, ‘Rural highlands’, ‘Rural humid lands’ and
36 ‘Rural dry lands’. The typology highlights that a range of distinct, even oppositional
37 regional biophysical, demographic, and agricultural contexts have equally given rise to

38 significant, regional net reforestation, urging a concomitant diversification of forest
39 transition science.

40

41 **1. INTRODUCTION**

42 Changes in tropical forest cover are primary features of global environmental
43 change. Most studies addressing tropical forest cover change have focused on deforestation
44 and its drivers (Gibbs et al., 2010; Hansen et al., 2013; Graesser et al. 2015, Curtis et al.,
45 2018), identifying the loss of ~150 million hectares of tropical forest between 1990 and
46 2015 (Keenan et al., 2015). Tropical reforestation is, however, also a significant component
47 of global environmental change (Meyfroidt & Lambin, 2008; Aide et al. 2013; Chazdon et
48 al., 2016) that is far less understood, and that has reportedly increased in extent during
49 recent decades (Aide & Grau, 2004; Hecht & Saatchi, 2007). Reforestation would have
50 major implications for global bio-geoclimatic and ecological dynamics, such as carbon
51 sequestration (Chazdon et al., 2016), environmental services (Wilson et al., 2017), and
52 biodiversity conservation (Catterall et al., 2008). Early research on spontaneous tropical
53 reforestation was framed on the “forest transition” model (Mather, 1992), which is based on
54 patters and processes operating during the 19th and 20th centuries. Given the fast
55 socioeconomic changes during the present, 21st century forest expansion patterns and
56 processes are likely to differ. To further understanding of reforestation as an emergent land-
57 cover change, we delineate and characterize the reforestation hotspots of Latin America.

58 The forest transition narrative is based largely on early European precedents, and
59 anticipates that reforestation arises from an “agriculture land-use adjustment” whereby
60 agricultural modernization over fertile lands coincides with the abandonment of marginal

61 agricultural land use (Mather & Needle, 1998). Localized case studies of recent tropical
62 reforestation similarly purport that reforestation concentrated in agro-economically
63 ‘marginal’ regions (Helmer, 2000; Helmer, 2004; ; Sloan et al., 2016). In Latin America,
64 emerging forests were observed predominantly in topographically steep uplands (Asner et
65 al., 2009; Redo et al., 2012; Aide et al., 2013; Nanni & Grau, 2014), peri-urban zones
66 offering non-farm livelihood alternatives (Grau et al. 2003; Baptista, 2008; Grau et al.,
67 2008; Gutierrez Angonese & Grau 2014), and in areas of land abandonment following
68 major socioeconomic shifts, such as loss of subsidies for sugar production in Cuba (Alvarez
69 et al., 2013), or outmigration from Oaxaca, Mexico (Bonilla-Moheno et al., 2012). The
70 land-use adjustment was considered to be induced or otherwise enhanced by urban-
71 economic growth, rural emigration, and the globalization of land-use systems (Aide and
72 Grau, 2004; Hecht and Saatchi, 2007) broadly aligned with modernistic notions of
73 ‘development’ (Perz, 2007; Redo et al. 2012).

74
75 However, the direct application of the forest-transition narrative to contemporary
76 tropical reforestation risks its undue corroboration at the expense of alternative or
77 complementary processes (Sloan, 2015). This can occur because studies have focused
78 exclusively on generalized ‘drivers’ nominated by theory, e.g., ‘urbanization’ (DeFries &
79 Pandrey, 2010; DeFries et al., 2010), or on reforesting regions where the expected drivers
80 are known to operate. Comprehensive assessments of reforestation encompassing all
81 possible host contexts would alleviate this issue to some degree. Such assessments across
82 the Neotropics have observed higher rates of reforestation in marginal, high-elevation
83 areas, as well as high rates of deforestation in the lowland moist forest biome (Aide et al.,
84 2013; Hansen et al., 2013; Rudel et al., 2016), suggesting that reforestation and

85 deforestation may arise differentially amongst biomes due to their respective land-use
86 constraints (Redo et al., 2012; Aide et al., 2013).

87 Although reforestation is increasingly recognized as an emergent regional
88 phenomenon, only recently has it been observed at such scales (Redo et al., 2012; Aide et
89 al., 2013; Hansen et al., 2013, Rudel et al. 2016). The regional contexts defining
90 reforestation, which have not been described well, could to differ significantly from the
91 geographical profiles prominent in the literature (Perz, 2007; Sloan, 2015; Sloan et al.,
92 2016). Case studies provide a tenuous, potentially biased means of articulating overarching
93 regional contexts or dynamics of reforestation (Sloan, 2015), particularly as many conflate
94 small-scale reforestation and localized dynamics with a broader, long-term forest transition
95 (Grau & Aide, 2008). Meta-analyses of case studies similarly extrapolated local
96 observations to regional scales (Rudel et al., 2005) and relied on theoretical suppositions to
97 fill empirical gaps (Meyfroidt & Lambin, 2011). Large-scale assessments of reforestation
98 (e.g. Aide et al., 2013; Hansen et al., 2013) have given scant attention to the contexts of
99 regional net reforestation, instead tending to quantify aggregate gross tree cover gains
100 without differentiating planted from natural forests or ephemeral from sustained trends.
101 Narrative assertions regarding the role of ‘development’ and ‘marginality’ and their
102 variation amongst contexts, or indeed other drivers of tropical reforestation thus remain
103 somewhat unrefined.

104 A definitive characterization of the regional contexts of reforestation across Latin
105 America is critical for three reasons. First, it would provide missing information about the
106 biophysical and socioeconomic conditions under which reforestation occurs. In effect, a
107 comprehensive regional geography of Neotropical reforestation would provide an

108 authoritative complement to the continued reliance on case studies (Sloan, 2015) and
109 narratives based on northern hemisphere systems (Perz, 2007a, b). Improved contextual
110 resolution is also essential for supporting reforestation and conservation initiatives that are
111 frequently assuming ambitious scales (Chazdon & Guariguata, 2016). Amongst these are
112 various continental forest-landscape restoration schemes, such as the 20x20 Initiative
113 (World Resources Institute, 2015) and the Bonn Challenge (The Bonn Challenge, 2015), as
114 well as programs for Reducing Emissions from Deforestation and forest Degradation
115 (REDD+; Sloan, 2015), which are rapidly improvising national-scale schemes (Sloan et al.,
116 2018).

117 Second, identifying regions of consistent reforestation would help identify the long-
118 term benefits and beneficiaries of new forests (e.g. rural population livelihoods,
119 biodiversity conservation, ecosystem services provision; Rey Benayas et al., 2009;
120 Chazdon & Uriarte 2016), as well as distinguish them from often widespread areas of
121 sporadic or ephemeral reforestation readily visible in satellite classifications (e.g., Hansen
122 et al., 2013). Indeed, the persistence of new forests (Raid et al., 2017) and the scale of
123 forest transitions are major but largely unexplored uncertainties, that regional delineations
124 of contiguous, consistent reforestation would help addressing.

125 Third, a regional account of Neotropical reforestation would provide a necessary
126 ontological correction to perspectives on the human dimensions of forest-cover change,
127 which are still steeped in the rampant deforestation that characterized the latter half of the
128 20th century. Significant regional net reforestation is, by definition, the culmination of a
129 longer-term forest transition (Mather, 1992). Thus, the identification of the regional

130 contexts of reforestation would shed light on the generality and diversity of conditions
131 supporting forest transitions.

132 To improve understanding of reforestation as an emergent regional phenomenon,
133 this article presents the first continental depiction of the significant regional reforestation
134 areas during the early 21st century. It offers two novel insights into Neotropical
135 reforestation to address the uncertainties in its geography and contexts. Drawing upon
136 comprehensive satellite-imagery analysis, it delineates ‘hotspots’ of extensive, significant,
137 and consistent net reforestation across Latin America and the Caribbean between 2001 and
138 2014. Subsequently, it defines a typology of these hotspots with reference to the
139 biophysical and socioeconomic characteristics that unite and distinguish amongst them.
140 Finally, hotspots types are discussed with reference to case studies elaborating the
141 biophysical and socioeconomic forces shaping regional conditions. In this way, we provide
142 an empirical framework for further exploration of the conditions and processes of
143 contemporary Neotropical reforestation.

144 **2. MATERIALS AND METHODS**

145 2.1. Overview

146 Four methodological steps defined the reforestation hotspots and their socio-
147 biophysical typology. First, land cover was mapped annually between 2001 and 2014
148 across the Latin America and the Caribbean via satellite-image classification. Second,
149 reforestation hotspots were delineated based on three spatial criteria ensuring significant
150 rates and patterns of regional reforestation. Third, hotspots were characterized based on 14
151 social and biophysical attributes from which a socio-biophysical typology was statistically

152 derived. Fourth, the contribution of the hotspots to forest-cover gain by biome was
153 estimated.

154 2.2. Mapping 2001-2014 annual land cover in Latin America and the Caribbean

155 Annual land cover across Latin America and the Caribbean (LAC) was mapped
156 over 2001-2014 using MODIS satellite data at 250-m spatial resolution. Following methods
157 outlined elsewhere (Clark et al. 2012; Aide et al., 2013; Graesser et al. 2015), we used
158 MODIS imagery, 60,000 land cover samples collected from visual interpretation of very
159 high-resolution satellite imagery (~1-2 m resolution), and Random Forest (RF)
160 classification models, to classify land cover across LAC. The extensive area and diverse
161 landscapes across LAC limited the success of continental-scale classification test models.
162 Therefore, we defined separate classification models bounded by the 191 terrestrial
163 ecoregions (Olson et al., 2001) to more effectively capture differences in vegetation
164 radiometric characteristics (e.g., dry Chaco forests compared to the Atlantic or Amazon
165 forests) across the study area. A series of trials revealed that this approach improved land
166 cover predictions over global estimates (e.g., MODIS MCD12Q1), with a trade-off of
167 artificial transitions between some ecoregion zones. For each ecoregion, we trained a RF
168 model with intersecting land cover samples from the LAC-wide pool of 60,000 samples to
169 predict eight possible land covers: cropland, pastureland/grassland, natural tree cover,
170 shrubs, tree plantations, barren land, (e.g., ice, snow, rock, sand dunes), built-up structures,
171 and water. This study focuses on natural trees and shrubs (hereafter referred to as “woody”)
172 to restrict analyses to spontaneous reforestation to the extent that is possible, though
173 inevitably some planted forests were confused with natural forest predictions (SI Table A).

174 A post-classification temporal smoothing filter was applied to the annual land-cover
175 predictions to reduce the number of artificial year-to-year fluctuations of land-cover class
176 predictions. Specifically, a three-year moving window was used to average the RF class-
177 conditional posterior probabilities of membership to a given land-cover class, for a given
178 year. For example, for a given pixel initially classified as natural tree cover in 2002 (based
179 on the maximum class RF posterior probability), the three-year (2001—2003) average of
180 RF probabilities for the natural tree-cover class for the pixel in question replaced the RF
181 2002 class probability. This process was repeated for each of the land-cover classes
182 separately, for each year of our time series, per pixel. A two-year average was used for
183 2001 (2001 and 2002) and 2014 (2013 and 2014). For a given pixel in a given year, the
184 maximum of the averaged probabilities of land-cover class membership ultimately
185 determined its land-cover class for further analysis.

186 2.3. Delineating the reforestation hotspots

187 Rates of woody expansion (reforestation hereafter) between 2001 and 2014 across
188 Latin America and the Caribbean were summarized individually by 15,969 hexagons of
189 1200 km² (average area of municipalities across Latin America and the Caribbean, Aide et
190 al., 2013). These hexagons were subsequently iteratively linked with each other to define
191 larger semi-contiguous networks representing the reforestation hotspots. Two hexagons
192 were linked if: (i) the reforestation rates (2001 to 2014) of both hexagons were statistically
193 significant ($p = 0.001$, using F – test); ii) they were within 1 degree (~111 km) of each
194 other; and iii) the reforestation rates of both hexagons were greater than 100 ha yr⁻¹ over
195 2001-2014. The first criterion ensured that hotspots were uniformly characterized by
196 significant reforestation throughout the observation period, while the second condition

197 incorporated disjointed hexagons into nearby developing networks or ‘clusters’ of
198 hexagons. Developing networks were allowed to merge with other networks as the criteria
199 were iteratively satisfied. The search radius of 1 degree was chosen after an exhaustive
200 examination of alternative radii. An excessively large radius distance would have unduly
201 limited the number of unique hotspots and missed the discrimination between functionally
202 distinctive reforestation regions, while an excessively small radius would have over-
203 segmented biogeographically integral clusters across the continent. The third criterion
204 ensured that hotspots uniformly experienced aerially meaningful reforestation, as by
205 excluding hexagons with statistically significant reforestation but negligible areas of
206 reforestation. Hexagons were linked to progressively develop a hotspot if they met all three
207 criteria. The hotspots are non-overlapping, meaning that a hexagon can only belong to one
208 hotspot. This process was repeated for every hexagon across Latin America, creating an
209 undirected, inductive network of an indeterminate number of reforestation hotspots.

210 Hotspots with fewer than 10 hexagons were removed from consideration in order to
211 focus on major regional reforestation events. These omitted hotspots were Puerto Rico,
212 another hotspot centered on Macapá city at the mouth of the Amazon river, and a third
213 hotspot spanning the eastern stretch of the border between the Brazilian states of Goiás and
214 Tocantis. Also, two initial hotspots resultant from the network analysis were subsequently
215 sub-divided according to ecoregion boundaries, as these hotspots were relatively extensive,
216 spanned numerous major ecoregions, and had relatively tenuous contiguity between these
217 ecoregions. Such sub-division resulted in three Brazilian hotspots (Atlantic Forests,
218 Cerrado, Caatinga) and three Mexican and Central American hotspots (Southern Mexico &
219 Guatemala, Central America Pine Forests, Costa Rica & Panama). This subdivision was

220 neither appropriate nor realized for the remaining hotspots as it would have resulted in
221 over-segmentation, counteracting the criterion for regional continuity.

222 2.4. Hotspot accuracy assessment

223 The classification accuracy of the woody class (i.e., trees + shrubs) in each of the
224 reforestation hotspots was assessed to verify the fidelity of the hotspots (SI Table A).
225 Within the hotspots, 2,233 pixels (250m) from the 2014 land-cover classification were
226 sampled. If a pixel occurred within a high-resolution image from 2010-2015 in Google
227 Earth (typically ~1-2 m resolution) we classified its land cover on the basis of visual
228 interpretation. Pixels interpreted as mixed (e.g., 50% pasture and 50% trees) were excluded
229 from the validation. The average MODIS land-cover classification accuracy within the
230 hotspots was 85% (SI Table A). Accuracy for the woody class alone was 91%, while for
231 plantations it was 83.1%. These are considered to be upper estimates. The sample data
232 consisted of pixels with homogenous land cover, whereas the majority of MODIS pixels
233 are heterogeneous, especially in Mexico and Central America.

234 2.5. Describing a socioecological Typology of Reforestation Hotspots

235 A non-metric multidimensional scaling ordination approach (NDMS) was used to
236 define a continental typology of reforestation hotspots on the basis of 14 biophysical and
237 socioeconomic attributes (Table 1). In contrast to other ordination techniques, NMDS
238 makes no assumptions about how variables are distributed along gradients (Kenkel &
239 Orłóci, 1986). The ordination was based on a matrix of euclidean distances (Legendre &
240 Legendre, 1998) calculated using all 14 biophysical and socioeconomic attributes,
241 described below. The final ordination featured two main dimensions of social and
242 biophysical traits. The final “stress” value (an index of agreement between the distances in

243 the graph configuration and the distances in the original data matrix) was 12.3, which is
244 well within the recommended threshold of 20 (Legendre & Legendre, 1998). Pearson
245 correlations between the 14 attributes and the individual hotspot scores in the ordination
246 space were also estimated, and their significance was assessed via 1000 random
247 permutations of the data (Oksanen et al., 2015). All analyses were performed using the
248 vegan package in R software (Oksanen et al., 2015). Once the ordination was performed,
249 clusters or typologies were defined, and hotspots belonging to the same cluster were
250 connected by its group centroid.

251 The 14 attributes describing the reforestation hotspots capture themes observed or
252 theorized to be relevant to reforestation at different scales (Grau & Aide 2008, Meyfroidt &
253 Lambin, 2011). They include topographic / agro-ecological marginality, rural
254 depopulation, settlement intensity (urbanization), socioeconomic development, and
255 agricultural productivity. Climatic attributes for 1950-2000 provide an additional layer of
256 information to explain the distribution of reforestation. All attributes are spatially explicit,
257 with varying scales/resolutions typically of ~1 km² (Table 1). Prior to the NMDS
258 ordination, attributes were summarized (i.e., averaged, summed) and standardized per
259 hotspot.

260 Attributes related to agricultural productivity were mean agricultural yield, relative
261 change in agricultural area, and relative change in pasture area (2001-2014) (Table 1). The
262 agricultural yield attribute refers to yields of 19 major crops (barley, cassava, cotton,
263 groundnut, maize, millet, oilpalm, potato, rapeseed, rice, rye, sorghum, soybean, sugarbeet,
264 sugarcane, sunflower and wheat), based on a global map of croplands for 2000 and national
265 agriculture yield statistics (Monfreda et al., 2008). Yields for each crop were standardised

266 across the hotspots to derive a summary value of mean standardised yield for all crops
267 combined, per hotspot. The relative areas of agricultural change and pastoral change pertain
268 to agricultural and pastoral changes over 2001-2014 as proportions of agricultural and
269 pastoral areas in 2001, respectively, as derived from the land-cover estimates. It is assumed
270 that observed grassland changes corresponded mostly to trends in planted pastures rather
271 than natural grasslands.

272 Four attributes summarized population dynamics within the hotspots: population
273 density, rural/urban population ratio, rural population change, and urban population change.
274 For all these attributes, LandScan (2000 and 2012) 1-km population data (Bhaduri et al.,
275 2002; Bright et al., 2012) were used. Estimates for population change in rural and urban
276 areas were performed by overlapping LandScan population data sets of 2001 and 2012 with
277 the urban-extent map of CIESIN (2011). This urban-extent map distinguishes urban from
278 rural areas based on a combination of local population counts (persons), settlement points,
279 and the presence of nighttime lights.

280 Settlement intensity was further estimated with reference to built-up and roaded
281 areas. Satellite-observed nightlight luminosity (Maus et al., 2010), which captures a wide
282 range of persistent electric illumination from dim villages to bright city centers, indicates
283 urban and peri-urban settlement intensity but also indirectly their economic intensity, thus
284 complementing our population density attributes. Road density was calculated by dividing
285 the sum of road length in each hotspot by its area. Road data pertains largely to arterial and
286 inter-urban roadways as of 1980-2010, depending on the country (CIESIN, 2013).

287 Finally, the Human Development Index (HDI) values were estimated for each
 288 reforestation hotspot. HDI values were originally derived directly for individual
 289 municipalities, which were then averaged for each encompassing hotspot, with municipality
 290 values weighted by the number of hexagons comprising the municipality. The HDI reflects
 291 economic income, education, and life expectancy to describe levels of ‘development’
 292 observed to correlate with reforestation at regional scales (Redo et al., 2012). HDI values
 293 for each municipality were obtained from the latest source available, including national and
 294 international sources (e.g. Klugman et al., 2009).

295 Once the hotspot typology was obtained, case studies of land-cover change within
 296 the regional hotspots were revised and considered, to elaborate and qualify the local
 297 dynamics and conditions that collectively define the regional typology or contexts of
 298 reforestation.

299 **Table 1.** Biophysical and socioeconomic attributes used to typify reforestation hotspots.

Theme	Description	Spatial Scale	Temporal Scale/Year	Source
Bioclimatic	Mean annual temperature (°C)	1 km ²	1950-2000	Hijmans et al., 2005
	Mean annual precipitation (mm/year)	1 km ²	1950-2000	Hijmans et al., 2005
Topographic Marginality	Elevation (m.a.s.l)	90 m ²	-	Jarvis et al., 2008
	Topographic roughness: SD of Elev. (m.a.s.l)	90 m ²	-	GIS-derived from Elev.
Agriculture production	Mean agriculture yield (T)	10 km ²	2000	Monfreda et al., 2008
	Relative Change in Agricultural Area	250 m	2001-2014	MODIS classification
	Relative Change in Pasture Area	250 m	2001-2014	MODIS classification
Population dynamics	Population density (N° people/km ²)	1 km ²	2012	LandScan, 2012
	Rural-urban ratio	-	2012	LandScan (2000 & 2012) and CIESIN, 2005.

	Rural Population Change	1 km ²	2000-2012	LandScan (2000 & 2012) and CIESIN, 2005.	300
	Urban Population Change	1 km ²	2000-2012	LandScan (2000 & 2012) and CIESIN, 2005.	301
Urbanization	NightlightDensity (DN/km ²)	6km ²	2010	NGDC, 2010	302
	Road Density (km/km ²)	m/km ²	1980-2010	CIESIN, 2013	303
Socioeconomic development	Human Development Index (0-1)			Various sources	304
					305

306 2.5. Contribution of the hotspots to forest cover by biome

307 Rates of forest loss and gain are variable across biomes (Hansen et al., 2013),
308 possibly reflecting inter-biome differences in predominant land uses, land-use constraints,
309 and remnant-vegetation coverage (Sloan et al., 2014). Therefore, the contribution of the
310 hotspots to reforestation by biome was also evaluated by two comparative measures. First,
311 the extent of reforestation in a given biome within the hotspots (2001-2014) was compared
312 to the continental area of that biome, as defined by Olson et al. (2001). This allowed us to
313 explore whether larger biomes had proportionally large areas of reforestation from the
314 hotspots. Such proportionality was an uncertainty, given that larger biomes (particularly
315 the Tropical and Subtropical Moist Broadleaf Forest biome, and the Tropical and
316 Subtropical Dry Broadleaf Forest biome) have experienced extensive deforestation due to
317 historical agricultural colonization (Achard et al., 2002; Miles et al., 2006; Aide et al.,
318 2013; Rudel et al., 2016). Second, the extent of reforestation within each biome was
319 compared with the representation of the biomes within the hotspots, to explore whether
320 higher reforestation rate in a given biome could be due to its higher representation within
321 the hotspots.

322 3. RESULTS

323 3.1. Delineating the reforestation hotspots

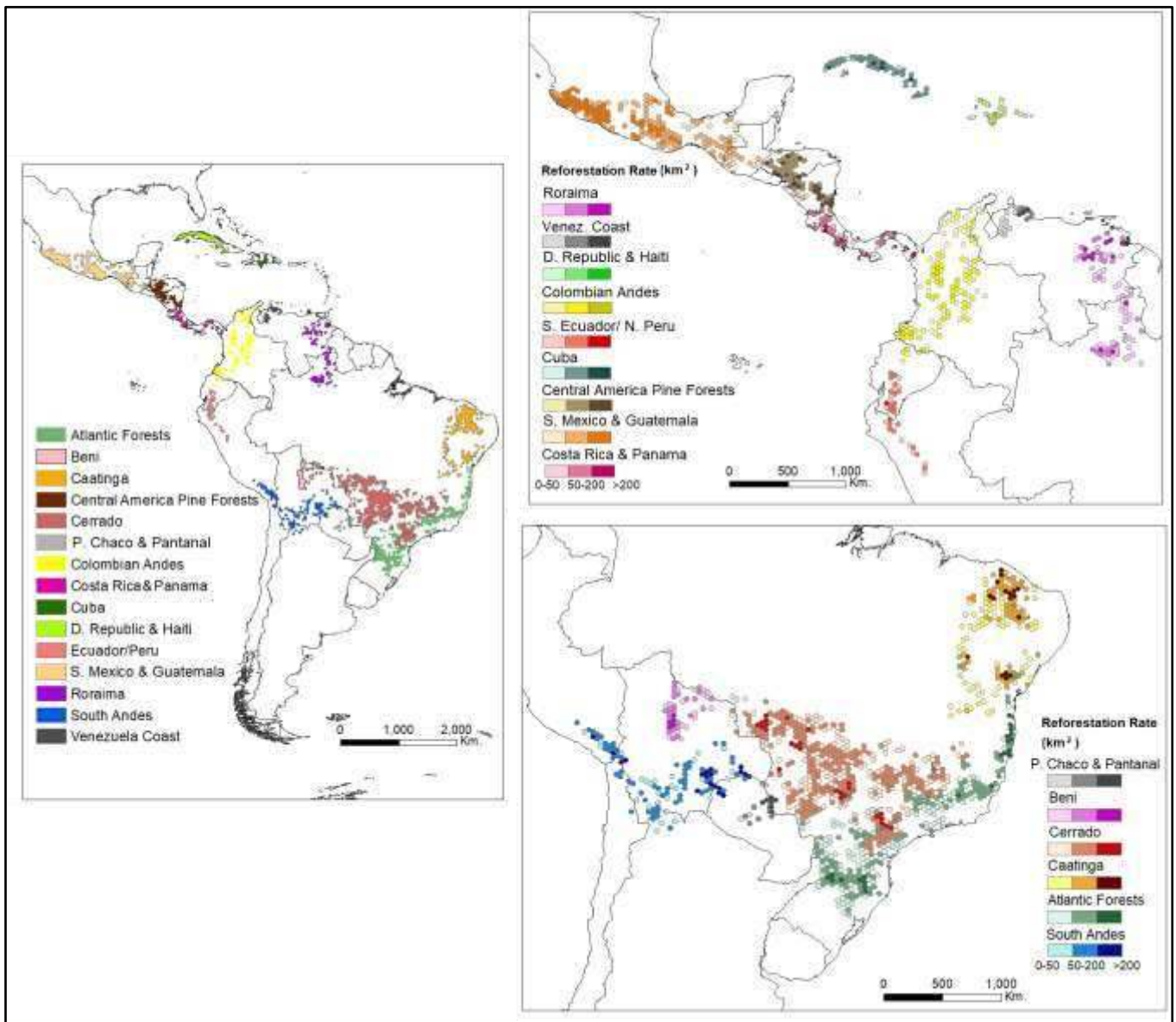
324 Our analysis identified 15 regional hotspots of sustained net reforestation in Latin
325 America and the Caribbean between 2001 and 2014 (Figure 1): Southern Mexico &
326 Guatemala, Central America Pine Forests, the Pacific realm of Costa Rica/Panama, Cuba,
327 Dominican Republic & Haiti, Colombian Andes, uplands of south Ecuador/north Peru,
328 Venezuelan Coast, Roraima of Venezuela/Brazil, Caatinga of Brazil, Atlantic Forests of
329 Brazil, Cerrado of Brazil, Beni of Bolivia, Pantanal & Paraguayan Chaco, and Southern
330 Tropical Andes. These hotspots covered 2,209,930 km², representing 11.2% of Latin
331 America and the Caribbean. Collectively, the hotspots accounted for 167,667.7 km² of net
332 reforestation occurring over 2001-2014, defining a 7.6% reforestation rate for this period.

333 The extent of reforestation within the hotspots is appreciable. Net reforestation
334 during 2001-2014 added between 7% and 55% of the extant forest area of 2001 across the
335 hotspots. In comparison, the percentages of the hotspot extents recovered by reforestation
336 was relatively constant across the hotspots (3% to 14%), despite notable discrepancies in
337 hotspot extents (Figure 2). High ratios of reforestation to extant forest occurred both in
338 hotspots with low and high extant (2001) woody cover, the latter of which are represented
339 by Cuba and the Southern Mexico & Guatemala hotspots (SI Table B).

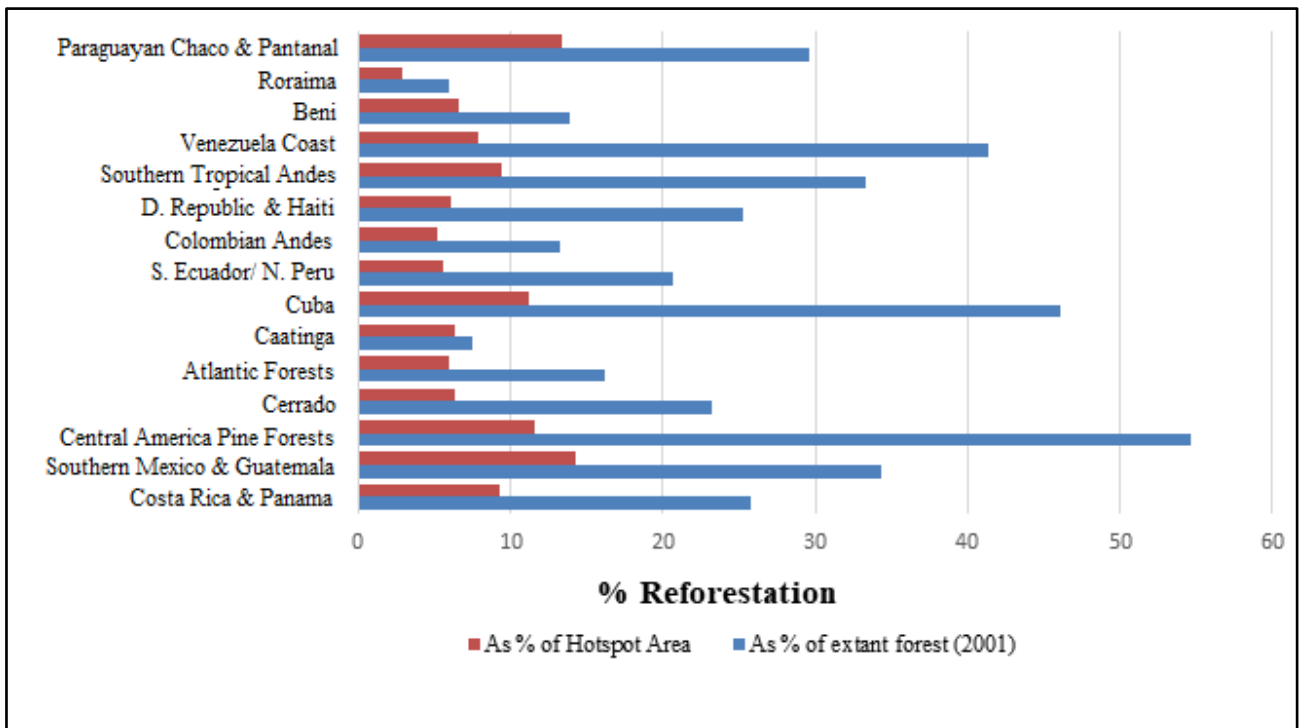
340 3.2. A Socioecological Typology of Reforestation Hotspots

341 The NMDS ordination defined five overarching types of Neotropical reforestation
342 hotspots, distinguished largely by topographic roughness and related aspects of agro-
343 ecological marginality, climate, population trends, and degree of urbanization. The hotspot
344 types are “Urban lowlands” (Costa Rica/Panama, Atlantic Forests, Cuba, and Venezuela

345 Coast); “Mountainous populated areas” (Colombian Andes, Central-America Pine Forests,
 346 Southern Mexico & Guatemala, and Dominican Republic & Haiti); “Rural highlands”
 347 (Southern Tropical Andes, and uplands of south Ecuador-north Peru); “Rural humid lands”
 348 (Roraima, Cerrado, and Beni) and “Rural dry lands” (Caatinga and Pantanal & Paraguayan
 349 Chaco) (Figure 3).



350
 351 **Figure 1.** Reforestation hotspots of Latin America and the Caribbean (left side). Right side: Rate of net reforestation
 352 (2001-2014) in each hexagon, for northern South America, Central America and North America (top right), and the rest of
 353 South America (bottom right). Graduated color pallet indicates the amount of net reforestation between 2001 and 2014 per
 354 hexagon (km²): 0-50 (light); 50-200 (medium) and >200 (dark).



355 **Figure 2.** Reforestation in each hotspot, expressed as percent of extant forest area in the hotspot as of 2001, and as a
 356 percent of hotspot area.
 357

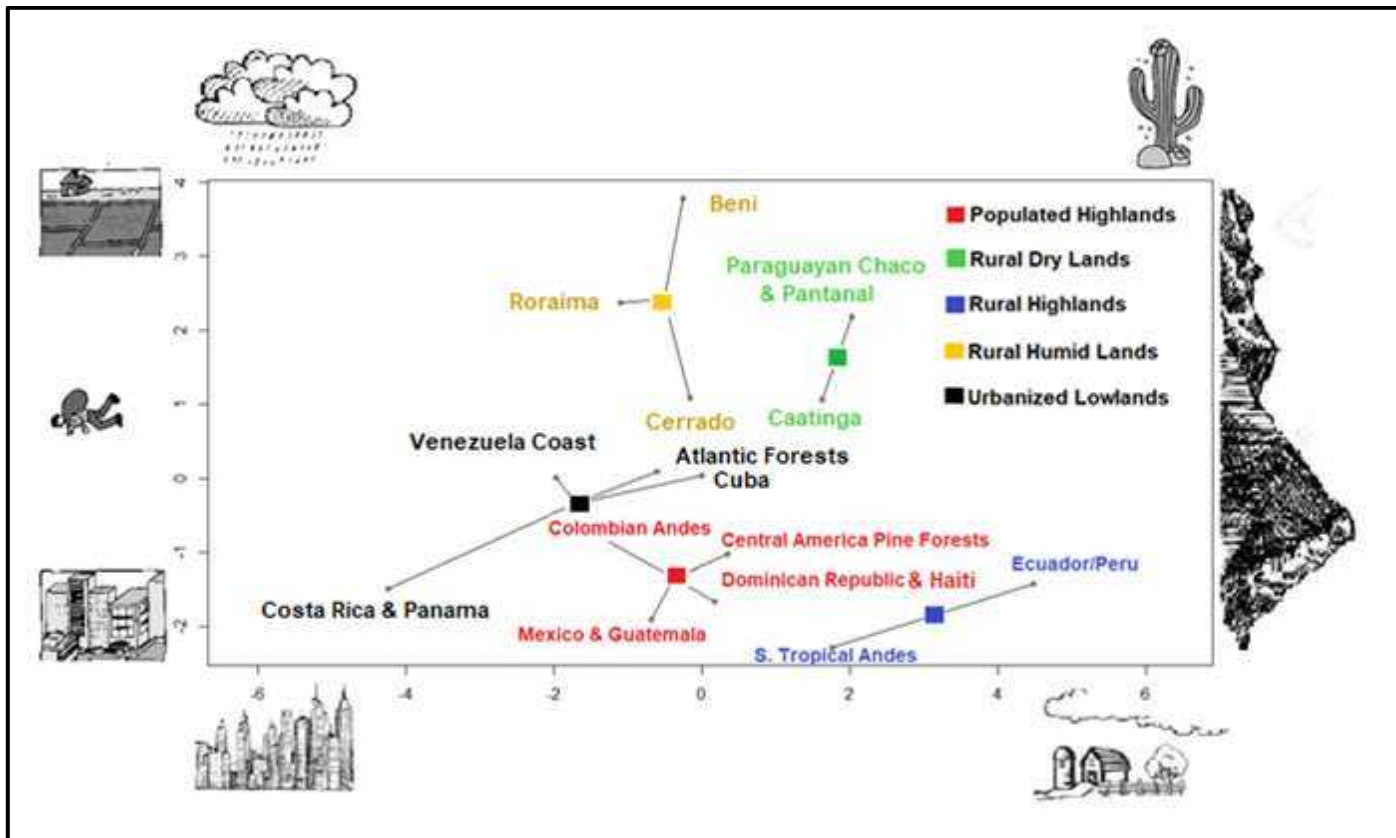
358 The first axis of the ordination represents a gradient of ‘rurality’ and ‘dryness’
 359 (Figure 3); significantly and negatively correlated with rural-to-urban population ratio, and
 360 precipitation. Positively associated hotspots (i.e., rural and dry) also exhibit declining
 361 agricultural areas (Table 2) – a trend that is marginally significant ($p < 0.1$) but consistent
 362 with theoretical expectations of land abandonment in relatively marginal agro-ecological
 363 zones. In the ordination space, this axis establishes a spectrum of hotspots, from the
 364 relatively urbanized and tropical (e.g., Costa Rica/Panama, Colombian Andes) to the rural
 365 and semi-arid (e.g. Southern Tropical Andes, Caatinga). (Figure 3, Table 2).

366 The second axis of the ordination is a gradient of topographic ‘elevation’ and
 367 ‘urbanization’. This axis significantly correlates with rural outmigration and urban
 368 population growth, thus distinguishing urbanizing hotspots positively associated with this
 369 second axis from the already relatively urban hotspots positively associated with the first

370 axis. This second axis also significantly correlates with settlement intensity (nightlight
371 density population density, road density) and agricultural yield, characterizing hotspots
372 positively associated with this axis as sparsely settled and relatively unproductive (Figure 3,
373 Table 2). A significant positive association with temperature and a negative association
374 with elevation is also evident (Table 2). Accordingly, the hotspots towards the positive side
375 of the second axis correspond with relatively underproductive, lowland, warm rural areas
376 undergoing rural population decline (e.g. Beni, Roraima), including areas affected by
377 frequent flooding (Pantanal, Beni). In contrast, the negative side of the axis corresponds
378 with urbanized regions in lowlands (e.g., Venezuela Coast) and uplands (e.g., Central
379 American Pine Forests) with greater agricultural productivity. Towards the extreme
380 negative end of axis 2, two mountainous hotspots (uplands of south Ecuador/ north Peru,
381 and Southern Tropical Andes) constitute a Rural Highlands cluster, differentiated from the
382 Populated Highlands cluster by even higher elevation, lower temperature, denser and more
383 stable rural population, and greater agricultural productivity.

384 3.3. Contribution of the hotspots to forest cover by biome

385 The reforestation hotspots spanned eight of the 11 biomes that comprise Latin
386 America and the Caribbean, excepting the Temperate Grasslands, Savannas and
387 Shrublands, the Temperate and Mixed Forests, and the Mediterranean Forests, Woodlands
388 and Scrub (SI Table B). The contributions of hotspot reforestation to the Neotropical
389 biomes area varied from 0.53% for the Tropical and Subtropical Moist Broadleaf Forests
390 biome to 5.7% for the Tropical and Subtropical Coniferous Forests biome (Figure 4a). The
391 large reforestation rate of this biome is due to the high reforestation rate in the Southern
392 Mexico & Guatemala hotspot (Figure 2; SI Table B).



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Figure 3. Non-metric multidimensional scaling ordination (NMDS) of the hotspots based on 14 biophysical and socioeconomic attributes. Centroids of the five clusters are represented by colored squares: Rural Dry Lands (green), Rural Humid Lands (orange), Urbanized Lowlands (black), Mountainous Populated (red) and Rural Highlands (blue). Figures in the border of the ordination diagram capture the main attributes correlated with each axis. Axes values are unitless.

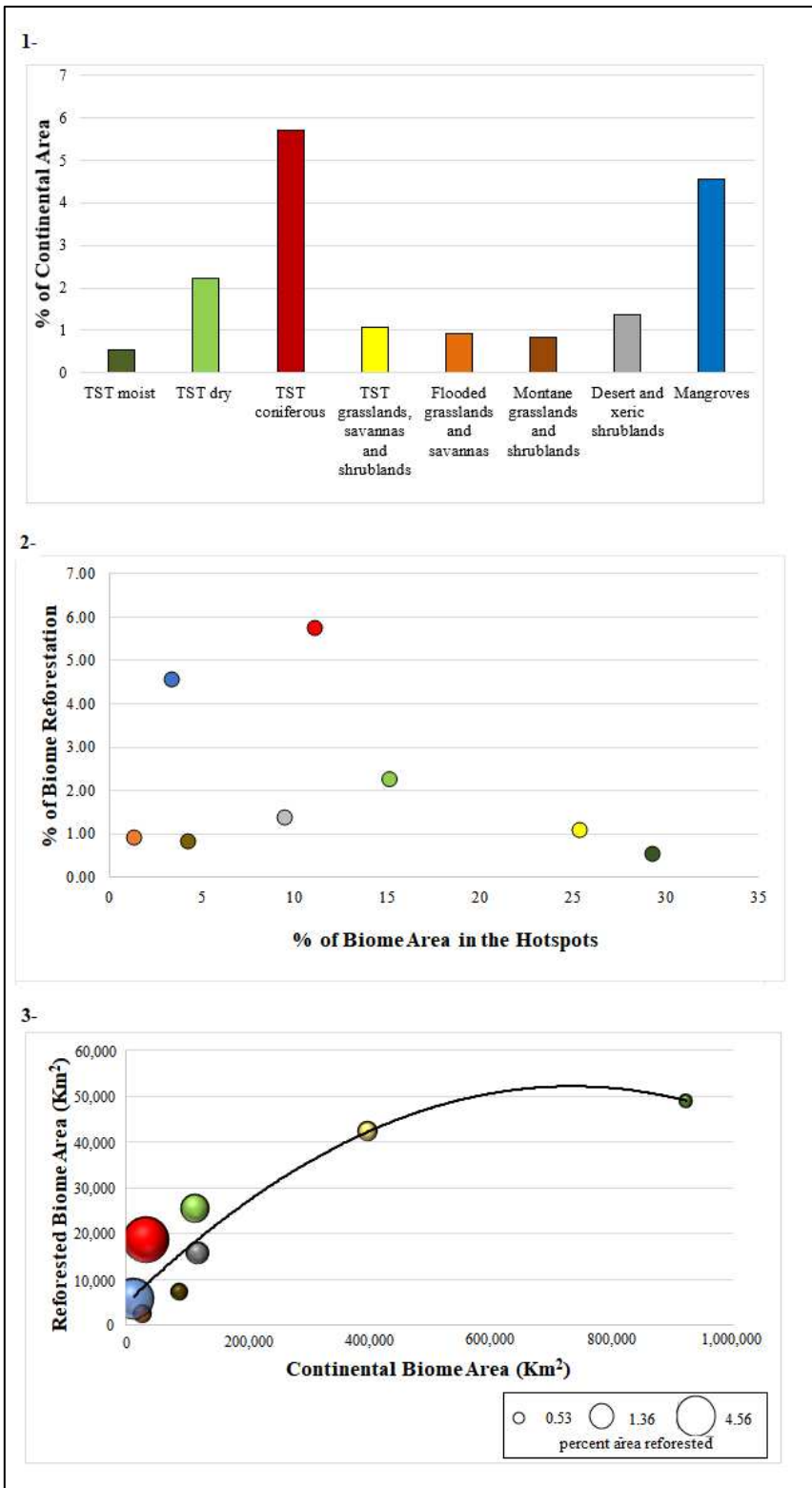
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A greater representation of a biome within the hotspots did not generally correspond with higher percentage area reforested (Figure 4b). While a subtle correspondence is apparent for some biomes (Figure 4b left side), any overall trend is upset by significant variations in the continental areas of biomes (e.g., mangrove vs. moist forests), and their historical exposure to forest change (e.g., montane grasslands vs. coniferous forests). The area reforested in each biome attributable to the hotspots increased roughly linearly with the continental biome area in all biomes except the moist forest biome (Figure 4c). Upon including the moist forest biome, a nonlinear relationship is observed, reflecting the

409 relatively low reforestation rate of this extensive biome (Figure 4c), much of which is
 410 remote and subject to changes in forest cover. Overall, smaller biomes were reforested
 411 disproportionately more, considering their continental areas (Figure 4c), particularly the
 412 coniferous forest and the dry forest biomes. Otherwise, reforestation within the hotspots
 413 appears to have not favored specific biomes, including those well-represented within the
 414 hotspots.

415 **Table 2.** Pearson correlations for axes 1 and 2 scores and the 14 biophysical and socioeconomic attributes values.
 416 Socioeconomic and biophysical attribute loadings on each axis are bold when they are ≥ 0.75 and significantly correlated
 417 at $p < 0.05$.

Attribute	Axis 1	Axis 2	Variance Explained (R^2)	Significance (p)
Elevation	0.5994	-0.8004	0.668	0.001
Roughness	0.3719	-0.9283	0.577	0.007
Mean Yield	-0.4538	-0.8911	0.443	0.030
Precipitation	-0.9977	0.0670	0.634	0.004
Temperature	-0.6409	0.7676	0.688	0.002
Rural Change	0.2784	-0.9605	0.411	0.030
Urban Change	0.2279	0.9737	0.482	0.020
Rural/Urban Ratio	0.7978	0.6029	0.511	0.010
Population Density	-0.4153	-0.9097	0.526	0.009
Nightlight Density	-0.6138	-0.7894	0.642	0.004
Road Density	-0.6256	-0.7801	0.444	0.030
Rel. change in agricultural area	-0.9780	-0.2084	0.386	0.090
Rel. Change in pasture Area	-0.9646	-0.2636	0.259	0.160
HDI	-0.8844	0.4667	0.234	0.208



418 **Figure 4.** Hotspot reforestation by biome: (a) reforestation as percent of continental biome area, for the eight Neotropical
 419 biomes coincident with the reforestation hotspots; (b) Percent of area reforested per biome versus the percent biome area
 420 within the hotspots (c) Reforested area per biome versus continental biome area.
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423 **4. DISCUSSION**

424 **4.1 Regional Concentrations of Reforestation**

425 Despite occurring in a context of extensive deforestation across Latin America
426 (Aide et al. 2013; Hansen et al. 2013; Sloan & Sayer 2015), this study identified regional
427 Neotropical reforestation hotspots defined by significant trends in net expansion of woody
428 cover between 2001 and 2014. These hotspots and their new forest cover represent 11%
429 and 1% of the continental area, respectively. Notwithstanding the challenges of direct
430 comparisons between remotely-sensed estimates, our hotspots apparently account for large
431 proportions of total reforestation, both continentally and pantropically. Although spanning
432 only 11% of Latin America and the Caribbean, the hotspots account for 37% of gross
433 continental reforestation (woody gain) according to our land-cover classification, 50% of
434 similar continental estimates of gross reforestation by Aide et al., 2013, and 67% of finer-
435 scale gross pantropical reforestation estimated by Hansen et al. (2013). Regardless, the
436 proportion of total reforestation confined to our hotspots is likely greater in the long term
437 than such proportions suggest, considering the likely greater persistence of reforestation
438 within the hotspots. Part of gross reforestation observed by Aide et al. (2013), Hansen et
439 al. (2013) and others (Beuchle et al., 2015) is relatively ephemeral and often associated
440 with nearby forest losses (Rudel et al., 2016). In contrast, our hotspots delineate expansive,
441 semi-contiguous, regional zones of net reforestation. As such, their reforestation
442 presumably reflects underlying ecological conditions and societal transformations yielding
443 woody gains that are likely to be relatively enduring.

444 The relative constancy of reforestation percentages (between 3 and 14%) amongst
445 hotspots of marked geographical and contextual disparities hints at a potential upper limit
446 on the ultimate extent of forest recovery, in keeping with forest-transition narratives. The
447 new forests identified here occurred in all the major Neotropical biomes, with greater
448 extents of reforestation in smaller biomes, which contrasts with continued predominance of
449 deforestation in larger biomes (Sloan et al., 2014), especially the Tropical and Subtropical
450 moist Forests (Aide et al., 2013). The relatively high levels of reforestation in the Tropical
451 and Subtropical Dry Forests and Desert and Xeric Shrublands biomes, particularly in
452 Brazil, are especially noteworthy due to the critical status of these biomes, which harbor
453 less than 10% of their natural area (Sloan et al., 2014). The potential contributions of these
454 new forested areas to ecological recovery are promising but remain uncertain. Continuous,
455 appreciable reforestation relative to the 2001 extant forest across hotspots (average 26%),
456 will likely favor biodiversity conservation. For example, woody expansion in the tropical
457 Andes and Mesoamerican mountains, is particularly important for biodiversity and
458 conservation of water resources. Even more important is the remarkable recovery in the
459 Atlantic forest hotspot, given its extent, biodiversity, and limited remnant forest cover
460 (<15%) (Ribeiro et al., 2009; SOSMA, 2012; Sloan et al., 2014). However, confident
461 assertions to this end ultimately await regional analyses of the coincidence of new forests
462 and threatened species, accounting for species' tolerance of secondary-forest habitat
463 (Gibson et al., 2011), and the persistence and contiguity of reforestation (Latawiec et al.,
464 2016; Reid et al., 2017).

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467 **4.2 Limitations and Caveats**

468 While our approach ensured the delineation of hotspots defined by extensive, significant,
469 and potentially persistent regional reforestation, it entails limitations that should not be
470 overlooked. First, by focusing on major regional reforestation events deemed likely to
471 indicate transformative underlying trends, our delineation excluded smaller, dispersed
472 reforestation events, particularly across small Caribbean islands, such as the Dutch
473 Caribbean, Saint Lucia, and Puerto Rico (Rudel et al., 2000; Grau et al., 2003; van Andel et
474 al., 2016; Walters, 2017). Despite their small contribution to continental-scale processes,
475 reforestation in these Caribbean islands is of great conservation importance due to the
476 islands' distinctive biodiversity and the reliance of their populations on forest ecosystem
477 services (Myers et al., 2000).

478 Second, our analysis observes forest gains only since 2001, due to MODIS satellite
479 image availability. Transitions from deforestation to reforestation were not observable
480 within such a brief period. Any correspondence between the hotspots and forest transitions
481 is therefore implicit. Hotspots are assumed to be indicative of emergent forest transitions,
482 considering that they were all widely characterized by deforestation over most 20th century.
483 Indeed, our focus on 'recent' reforestation allows for historical continuity. By capturing
484 consistent reforestation trends, rather than spurious reforestation events, our hotspots
485 exhibit an affinity with reforestation epicenters of the late 20th century, as in Costa Rica
486 (Calvo-alvarado, 2000), Panama (Sloan, 2015), Brazil (Baptista & Rudel, 2006) and
487 Mexico (Galicia et al., 2008). Reforestation in many hotspots commenced before 2001, and
488 may continue well into the future, as suggested by the case studies discussed below.

489 Third, potential confusion between natural and planted forest cover cannot be
490 entirely discounted. Our land-cover classification was accurate (SI Table A) and
491 distinguished natural from planted forest cover; yet the nature of our analysis and its coarse
492 pixel size may still allow for confusion among these forest classes. Such confusion is most
493 likely in hotspots where reforestation is known to encompass both planted and natural
494 forest expansion, namely the Atlantic Forests in Brazil (da Silva et al., 2015), or in
495 mountain regions where new forests are interspersed with shade coffee (Redo et al. 2012).
496 In hotspots affected by frequent flooding and wetland dynamic regimes (e.g. Beni, Pantanal
497 & Paraguayan Chaco), forest cover change may actually be associated to changes in water
498 cover.

499 **4.3 A Contextual Typology of Reforestation**

500 Our typology of neotropical reforestation hotspot is a typology of equals. The two
501 gradients of social and biophysical contexts that distinguish amongst hotspot types exhibit
502 marked contextual diversity, even though they were relatively consistent in terms of
503 reforestation rates. This typology implies that a range of distinct, even oppositional regional
504 biophysical, demographic, and agricultural conditions can equally give rise to significant
505 reforestation events. Conceptually, this contextual diversity resonates with theoretical
506 frameworks of multiple socio-agrarian pathways towards the forest transitions (Lambin &
507 Meyfroidt, 2010), while not corroborating any per se theory.

508 The forest-transition literature has persistently advanced reforestation narratives
509 centered on ‘agro-ecological marginality’ and ‘economic development/modernization’,
510 (Rudel, 2005; Angelsen & Rudel, 2013). The coincidence of outmigration and topographic

511 roughness with higher agricultural yields in our typology conflates, and possibly
512 challenges, these narratives. In particular, topography, a common proxy for marginality, has
513 been considered as a key influencing factor of reforestation, with farmers abandoning
514 remote, sloped lands to cultivate flatter, lower elevation lands (Aide & Grau, 2004; Aide et
515 al 2013); yet our hotspots typology features reforestation also in lowlands. This is possibly
516 the result of the separate manifestation of these narratives within different hotspots, parts of
517 which may be undergoing different dynamics (e.g. lowlands and mountains). For example,
518 in mountains “marginality” (in terms of competitive disadvantage for agriculture
519 production) may not be the result of low soil fertility (reflected in the statistics of per
520 hectare yield) but of the difficulties for mechanization, which results in higher production
521 costs. In lowlands experiencing woodland expansion, this may actually happen in
522 relatively small steep locations (hills, river coasts), not captured by the overall description
523 of topographic roughness at the scale of analysis. However, it is also possible that in other
524 areas absolute agro-ecological marginality is only a coincident or secondary factor of a
525 more complex upland reforestation dynamic. The following subsections discuss case
526 studies of reforestation exploring these processes in each of the five hotspot clusters
527 identified by our typology. Local processes vary amongst hotspots even of a given cluster,
528 challenging the generality of reforestation narratives.

529 4.3.1 Urban Lowlands (Costa Rica/Panama, Venezuela Coast, Atlantic Forests, and Cuba)

530 The four hotspots of this cluster occur in urbanized lowland regions. Notwithstanding some
531 common contextual features, the dynamics of reforestation in these hotspots are varied.

532 Conformant with our typology, case studies within the Atlantic Forests hotspot
533 highlight peri-urban forest transitions promoted by urbanization in Santa Catarina (Baptista

534 & Rudel, 2006; Baptista, 2008), as well as conservation initiatives for tourism and
535 recreation in Sao Paulo (Ehlers, 2007) and environmental protection policies leading to
536 reforestation (Costa et al., 2017). Other reforestation dynamics are also present, including
537 agroforestry landscapes with *Eucalyptus* spp., shade coffee, and cocoa in Minas Gerais and
538 Bahia states (Cardoso et al., 2001; Lobão et al., 2007).

539 In Cuba, extensive reforestation is not necessarily resulting from urbanization.
540 Instead reforestation has followed the loss of Soviet agricultural subsidies and subsequent
541 reforms to lowland agricultural estates, with sugar production particularly affected (Alvarez
542 et al., 2013); a pattern observed in many post-soviet economies (Rudel et al. 2016).
543 Although an increase in woody vegetation occurred in abandoned sugarcane fields, a large
544 proportion of this vegetation is a single exotic species (*El Marabu*, *D. cinerea*), which
545 presently covers approximately 18% of Cuba, and that results in limited environmental
546 advantages (Alvarez et al., 2013).

547 Panama and Costa Rica comprise a single hotspot, but their disparate socio-political
548 dynamics may vary the state of their new forests. In both countries, the main driver of
549 reforestation seems to be the de-agriculturalization of labor and related retractions of
550 agricultural land (Arroyo-Mora et al., 2005; Sloan, 2015); as has been observed in Puerto
551 Rico (Rudel et al., 2000, Grau et al., 2003). In Costa Rica, environmental policy/laws, eco-
552 tourism, and a heightened environmental consciousness apparently enhanced reforestation,
553 as by protecting secondary forests from conversion (Calvo-Alvarado, 2000; Fagan et al.,
554 2014). In Panama, new forests concentrate in populous rural areas host to growing urban
555 hamlets or are otherwise peripheral to the rapidly expanding Panama City (Sloan, 2015). As
556 such, they are presumably more likely to be degraded and re-converted than in Costa Rica.

557 In the Venezuelan Coast hotspot, the few available studies addressing reforestation
558 ascribe it to woody encroachment in the open savanna, influenced by changes in cattle
559 density and fire regimes (Silva et al., 2001). As in the adjacent llanos of Colombia, the
560 Venezuelan reforestation may also be attributable to the conversion of crops and exotic
561 grasses to palm oil (García-Ulloa et al., 2012; Romero-Ruíz et al., 2012), and avocado
562 plantations (E. Chacon, pers. comm). Nationally, the cultivated area of these crops has
563 increased 60.4% and 65.5%, respectively, over 2000-2015 (FAOSTAT, 2016).

564 4.3.2 Mountainous Populated Areas (Southern Mexico & Guatemala, Colombian Andes, 565 Dominican Republic, and Central America Pine Forests)

566 The four hotspots of this typology occur in contexts of high elevation and
567 topographic roughness, high yields, and high population density. Such steep elevation
568 gradient defines heterogeneous areas with a mix of market-oriented and subsistence
569 agricultural practices. Arguably more than elsewhere, forest trends in these hotspots reflect
570 regional changes in economic activities, such as the extensification of marginal agricultural
571 production, in addition to localized population dynamics. Similarly, forest-change trends in
572 these regions are relatively dynamic, with forest redistribution and turnover prevailing over
573 any given forest trend (Redo et al., 2012).

574 The Colombian and Mexican hotspots are associated with recent decreases in rural
575 population (SI Table B). In both hotspots, reforestation resulted mainly from agricultural
576 abandonment in rural areas, but with varied drivers. In the Colombian Andes, reforestation
577 occurred in tropical and montane forests over pre-existing mixed woody covers (shrubs and
578 herbs) and the abandonment of subsistence agricultural systems is mostly due to recent land

579 conflicts and economic development, with associated migration to urban centres (Sanchez
580 Cuervo et al., 2012; Rubiano et al., 2017). In Oaxaca, reforestation reflects rural
581 outmigration, but also community forest management for certified wood extraction
582 (Gómez-Mendoza et al., 2006; Bray et al., 2009; Robson & Berks, 2011). In Chiapas, the
583 main factor explaining reforestation after a century of forest loss seems to be the expansion
584 of plantation forestry, particularly oil palm, stimulated by government subsidies (Vaca et
585 al., 2012). In Guerrero, secondary dry forests have expanded in the last decades, as a
586 consequence of smallholder farm abandonment (Galicía et al., 2008).

587 The Central America Pine Forest and Dominican Republic hotspots are associated
588 with negligible rural population change since 2000 (SI Table B). In the former hotspot,
589 coniferous dry forest expansion occurred in Honduras, Nicaragua, and Guatemala to a
590 lesser extent, simultaneously with high deforestation rates in their humid broadleaf forest
591 frontiers (e.g., Guatemalan Peten, Nicaraguan Caribbean), resulting in a forest-
592 redistribution dynamic (Redo et al., 2012). In Honduras, reforestation is due partly to the
593 cultivation of shade-coffee in the uplands, in addition to reforestation through secondary
594 succession (Bass, 2006). In these Central American countries, community forest
595 management also seems to play a role in maintaining forest cover, including secondary
596 forests (Bray & Anderson, 2010), while economic remittances from migrants in the USA
597 have reduced agricultural activities and enhanced forest regrowth (Hecht & Saatchi, 2007;
598 Davis et al., 2010). Such factors may explain the coincidence of reforestation and high
599 rural population density in this region. In the Dominican Republic, reforestation has
600 followed the gradual abandonment of marginal grazing lands and cacao plantations,
601 accompanied by early stages of vegetation succession (Rivera et al., 2000; Slocum et al.,
602 2004; Grau et al. 2008), likely due to rural outmigration and shifts towards non-agriculture

603 activities in rural areas (Castañeda, 2003). Exotic tree species comprise an important
604 proportion of the resultant new forests (20% of all woody basal area) (Alvarez et al., 2013).

605

606 4.3.3 Rural Highlands (Ecuador/Peru and South Andes)

607 These hotspots are characterized by very high elevations (mean 2400-2600 m.a.s.l,
608 SI Table B), lower temperatures, and very rural contexts (i.e., low densities of population,
609 nightlights, and roads). Reforestation there occurred mostly over montane grasslands and
610 shrublands (South Andes) or previously-cleared montane forests (Ecuador/Peru). In both
611 hotspots, reforestation likely corresponds to the expansion of woodlands, including a mix
612 of shrubs and trees, such as *Alnus acuminata*, *Polylepys* spp. and *Prosopis* spp., (Morales et
613 al., 2005; Kintz et al., 2006; Farley, 2007; Weber et al., 2008; Araóz & Grau, 2010).

614 Interactions between fire, land use (especially grazing), and climate influence woodland
615 dynamics in these highlands (Kok et al., 1995), in some cases giving rise to reforestation as
616 rural populations and climatic patterns shift (Morales et al. 2005; Carilla & Grau 2010;
617 Araóz & Grau, 2010). The South Andes hotspot also includes lower elevation areas of the
618 Bolivian Dry Chaco and Chiquitano Dry Forests, where reforestation has reportedly
619 occurred after the abandonment of fallow agricultural fields close to extant forests, thus
620 allowing for rapid regeneration (Kennard et al., 2002). The wide elevation gradient
621 encompassed by this hotspot (SI Table B) brings it relatively close to the Mountainous
622 Populated Areas cluster in the ordination space (Fig. 3).

623 4.3.4 Rural Humid Hotspots (Roraima, Beni, and Cerrado)

624 These hotspots are defined by hot, humid, lowlands, with low rural population
625 densities and settlement intensities. However, their increasing urban populations coupled
626 with high rates of rural outmigration, underlines a nascent urbanization (Table 2).

627 In Roraima and the Cerrado, rural outmigration has been an important factor of
628 reforestation. In Roraima, reforestation corresponded with forest regeneration in formerly-
629 grazed lands situated within forest mosaics (Kammesheidt, 2000; Feldspauch et al., 2004).
630 In the Cerrado, reforestation came from spontaneous growth of both of trees and shrublands
631 within matrices dominated by pasture, following decreases in grazing as well as burning
632 (Vieira et al., 2006). Resprouting tree species seem to be highly resilient and capable of
633 regenerating even after long periods of disturbance (e.g., more than 40 years; Sampaio et
634 al., 2007). In Beni, in contrast, reforestation appears to have resulted from secondary forest
635 succession under community fallow management (Toledo & Salick, 2006), notwithstanding
636 the aforementioned decreases in rural population. The difference between the landscape
637 matrices of reforestation in Beni and Roraima (reforestation amongst forest patches) and in
638 the Cerrado (reforestation amongst pastures) likely results in very different degrees of
639 forest connectivity.

640 4.3.5 Rural Dry hotspots (Pantanal & Paraguayan Chaco and Caatinga)

641 The Pantanal & Paraguayan Chaco, and Caatinga hotspots comprise the Rural Dry
642 cluster due to their low precipitation and high degree of rurality (low rural populations,
643 settlement and road density), again coincident with apparent nascent urbanization (Figure 2,
644 SI Table B). Unlike other hotspot types, reforestation in this type did not occur in forest
645 biomes but almost exclusively in the Tropical and Subtropical Grasslands, Shrublands and
646 Savanna biome in the Pantanal & Paraguayan Chaco; and the Desert and Xeric Shrubland
647 biome in the Caatinga (SI Table C).

648 In the Pantanal & Paraguayan Chaco hotspot, the observed woody expansion might
649 be mostly attributable to biophysical constraints: in the Paraguayan Chaco, the
650 comparatively low deforestation of the last decades in comparison with other ecoregions
651 within the country, such as the Atlantic forests, has been driven by the Mennonite
652 community dominating the region. However, poor soil quality is a limiting factor for
653 agriculture expansion, thus the resultant agriculture systems are not sustainable in the long-
654 term (Huang et al., 2009; Caldas et al., 2011). This might have led to the observed
655 reforestation in these areas, which overlaps with very low cropland and pastureland
656 changes (Graesser et al., 2015). In the Pantanal, vegetation dynamics are largely influenced
657 by temporal and spatial dynamics of water, with annual and multi-annual wet and dry
658 periods resulting in large-scale changes in vegetation cover that might be the origin of our
659 observed reforestation (Nunes da Cunha et al., 2007).

660 In the Caatinga, reforestation is associated with the abandonment of indigenous
661 small-scale agriculture and cattle ranching, but the, remaining forested areas are highly
662 degraded due to poor land management, timber extraction, and increasing frequency of
663 severe droughts (Sampaio et al., 1993), retarding the regeneration of nearby abandoned
664 lands (Pereira et al., 2003). The combination of cattle ranching and the use of fire for slash-
665 and-burn agriculture in this region have limited forest propagation upon land abandonment
666 due to a reduction of the seed bank density as well as seedlings (Mamede & Araujo, 2008).

667 **4.4 Conclusion**

668 Reforestation in Latin America and the Caribbean is fairly concentrated in 15
669 hotspots defining five clusters of varied social and biophysical attributes. Echoing earlier

670 calls (Sloan, 2008), the contextual diversity inherent to our typology of reforestation
671 hotspots urges the exploration of a variety of situations promoting reforestation. Our
672 typology provides an initial framework to this end, and aligns only partially with the
673 preeminent forest-transition pathways. Our clusters differ from one another in important
674 ways, and both biophysical and social attributes equally give origin to such differentiation:
675 hotspots were found in the lowlands and in the highlands, and in rural and peri-urban
676 contexts, and reforestation occurred under decreasing, stable and growing populations (Fig.
677 3). Despite such variety of socioecological contexts, the reported underlying processes
678 influencing reforestation in each hotspot were in general not as varied, even among
679 clusters. In the majority of the hotspots, reforestation was reported to occur due to
680 socioeconomic changes leading to the abandonment of land, which emphasizes the
681 importance of identifying conditions under which agricultural lands become no profitable
682 even in a context of growing global demand for agriculture products. Other processes such
683 as explicit environmental policies gave place to reforestation in the Atlantic Forests and
684 Costa Rica, and community forest management seemed to have favored the occurrence of
685 reforestation in Central America and Oaxaca. To fully understand the significance of these
686 reforestation hotspots identified by our studies, two main issues remain to be addressed: the
687 identification of the drivers of reforestation at a regional scale; and the implications of these
688 reforested regions for biodiversity conservation and ecosystem service provision. We
689 believe that our identification of the regional Neotropical typology is an important, and
690 purposeful first step towards these ultimate goals.

691

692

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