Title

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Journal

Global Change Biology, 21(2)

ISSN

13541013

Authors

Anderson-Teixeira, Kristina J
Davies, Stuart J
Bennett, Amy C
et al.

Publication Date

2015-02-01

DOI

10.1111/gcb.12712

Global Change Biology
celebrating 20 years

Global Change Biology (2014), doi: 10.1111/gcb.12712

REVIEW

CTFS-ForestGEO: a worldwide network monitoring forests in an era of global change

KRISTINA J. ANDERSON-TEIXEIRA[1,2], STUART J. DAVIES[1,3], AMY C. BENNETT[2], ERIKA B. GONZALEZ-AKRE[2], HELENE C. MULLER-LANDAU[1], S. JOSEPH WRIGHT[1], KAMARIAH ABU SALIM[4], ANGÉLICA M. ALMEYDA ZAMBRANO[2,5,6], ALFONSO ALONSO[7], JENNIFER L. BALTZER[8], YVES BASSET[1], NORMAN A. BOURG[2], EBEN N. BROADBENT[2,5,6], WARREN Y. BROCKELMAN[9], SARAYUDH BUNYAVEJCHEWIN[10], DAVID F. R. P. BURSLEM[11], NATHALIE BUTT[12,13], MIN CAO[14], DAIRON CARDENAS[15], GEORGE B. CHUYONG[16], KEITH CLAY[17], SUSAN CORDELL[18], HANDANAKERE S. DATTARAJA[19], XIAOBAO DENG[14], MATTEO DETTO[1], XIAOJUN DU[20], ALVARO DUQUE[21], DAVID L. ERIKSON[3], CORNEILLE E.N. EWANGO[22], GUNTER A. FISCHER[23], CHRISTINE FLETCHER[24], ROBIN B. FOSTER[25], CHRISTIAN P. GIARDINA[18], GREGORY S. GILBERT[26,1], NIMAL GUNATILLEKE[27], SAVITRI GUNATILLEKE[27], ZHANQING HAO[28], WILLIAM W. HARGROVE[29], TERESE B. HART[30], BILLY C.H. HAU[31], FANGLIANG HE[32], FORREST M. HOFFMAN[33], ROBERT W. HOWE[34], STEPHEN P. HUBBELL[1,35], FAITH M. INMAN-NARAHARI[36], PATRICK A. JANSEN[1,37], MINGXI JIANG[38], DANIEL J. JOHNSON[17], MAMORU KANZAKI[39], ABDUL RAHMAN KASSIM[24], DAVID KENFACK[1,3], STALINE KIBET[40,41], MARGARET F. KINNAIRD[42,43], LISA KORTE[7], KAMIL KRAL[44], JITENDRA KUMAR[33], ANDREW J. LARSON[45], YIDE LI[46], XIANKUN LI[47], SHIRONG LIU[48], SHAWN K.Y. LUM[49], JAMES A. LUTZ[50], KEPING MA[20], DAMIAN M. MADDALENA[33], JEAN-REMY MAKANA[51], YADVINDER MALHI[13], TOBY MARTHEWS[13], RAFIZAH MAT SERUDIN[52], SEAN M. MCMAHON[1,53], WILLIAM J. McSHEA[2], HERVÉR. MEMIAGHE[54], XIANGCHENG MI[20], TAKASHI MIZUNO[39], MICHAEL MORECROFT[55], JONATHAN A. MYERS[56], VOJTECH NOVOTNY[57,58], ALEXANDRE A. DE OLIVEIRA[59], PERRY S. ONG[60], DAVID A. ORWIG[61], REBECCA OSTERTAG[62], JAN DEN OUDEN[63], GEOFFREY G. PARKER[53], RICHARD P. PHILLIPS[17], LAWREN SACK[35], MOSES N. SAINGE[64], WEIGUO SANG[20], KRIANGSAK SRI-NGERNYUANG[65], RAMAN SUKUMAR[19], I-FANG SUN[66], WITCHAPHART SUNGPALEE[65], HEBBALALU SATHYANARAYANA SURESH[19], SYLVESTER TAN[67], SEAN C. THOMAS[68], DUNCAN W. THOMAS[69], JILL THOMPSON[70,71], BENJAMIN L. TURNER[1], MARIA URIARTE[72], RENATO VALENCIA[73], MARTA I. VALLEJO[74], ALBERTO VICENTINI[75], TOMÁŠ VRŠKA[44], XIHUA WANG[76], XUGAO WANG[30], GEORGE WEIBLEN[77], AMY WOLF[78], HAN XU[46], SANDRA YAP[60] and JESS ZIMMERMAN[71]

[1]*Center for Tropical Forest Science-Forest Global Earth Observatory, Smithsonian Tropical Research Institute, Panama, Republic of Panama,* [2]*Conservation Ecology Center, Smithsonian Conservation Biology Institute, National Zoological Park, Front Royal, VA, USA,* [3]*Department of Botany, National Museum of Natural History, Washington, DC, USA,* [4]*Environmental and Life Sciences, Faculty of Science, Universiti of Brunei Darussalam, Tungku Link Road, Bandar Seri Begawan, BE 1410, Brunei Darussalam,* [5]*Stanford Woods Institute for the Environment, Stanford University, Stanford, CA, USA,* [6]*Department of Geography, University of Alabama, Tuscaloosa, AL, USA,* [7]*Center for Conservation Education and Sustainability, Smithsonian Conservation Biology Institute, National Zoological Park, Washington, DC, USA,* [8]*Department of Biology, Wilfrid Laurier University, Waterloo, ON, N2L 3C5, Canada,* [9]*Department of Biology, Mahidol University, Bangkok, Thailand,* [10]*Research Office, Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand,* [11]*School of Biological Sciences, University of Aberdeen, Aberdeen, UK,* [12]*School of Biological Sciences, University of Queensland, St. Lucia 4072, Australia,* [13]*Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, UK,* [14]*Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, 88 Xuefu Road, Kunming 650223, China,* [15]*Instituto Amazónico de Investigaciones Científicas Sinchi, Bogotá, Colombia,* [16]*Department of Botany and Plant Physiology, University of Buea, Buea, Cameroon,* [17]*Department of Biology, Indiana University, Bloomington, IN, USA,* [18]*Institute of Pacific Islands Forestry, USDA Forest Service, Hilo, HI, USA,* [19]*Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India,* [20]*Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China,* [21]*Departamento de Ciencias Forestales, Universidad Nacional de Colombia, Medellin, Colombia,* [22]*Centre de Formation et de Recherche en Conservation Forestière (CEFRECOF) Epulu, Ituri Forest, Reserve de Faune a Okapis, Epulu, Democratic Republic of Congo,* [23]*Kadoorie Farm and Botanic Garden, Tai Po, Hong Kong,* [24]*Forest*

Research Institute Malaysia, Selangor, Malaysia, [25]Botany Department, The Field Museum, Chicago, IL, USA, [26]Environmental Studies Department, University of California, Santa Cruz, Santa Cruz, CA, USA, [27]Faculty of Science, Department of Botany, University of Peradeniya, Peradeniya, Sri Lanka, [28]State Key Laboratory of Forest and Soil Ecology, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110164, China, [29]Eastern Forest Environmental Threat Assessment Center, USDA-Forest Service Station Headquarters, Asheville, NC, USA, [30]Tshuapa-Lomami-Lualaba Project, Lukuru Wildlife Research Foundation, Kinshasa BP 2012, Democratic Republic of the Congo, [31]Kadoorie Institute and School of Biological Sciences, The University of Hong Kong, Pokfulam, Hong Kong, [32]Department of Renewable Resources, University of Alberta, Edmonton, AB, Canada, [33]Computational Earth Sciences Group, Oak Ridge National Laboratory, Oak Ridge, TN, USA, [34]Department of Natural and Applied Sciences, University of Wisconsin-Green Bay, Green Bay, WI 54311, USA, [35]Department of Ecology and Evolutionary Biology, University of California, Los Angeles, Los Angeles, CA, USA, [36]College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa, Honolulu, HI, USA, [37]Resource Ecology Group, Wageningen University, Wageningen, The Netherlands, [38]Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan 430074, China, [39]Graduate School of Agriculture, Kyoto University, Kyoto, Japan, [40]National Museums of Kenya, P.O. Box 40658 -00100, Nairobi, Kenya, [41]Land Resource Management & Agricultural Technology Department, University of Nairobi, P.O. Box 29053-00625 Nairobi, Kenya, [42]Mpala Research Centre, PO Box 555, Nanyuki 10400, Kenya, [43]Global Conservation Programs, Wildlife Conservation Society, 2300 Southern Blvd., Bronx, NY 10460, USA, [44]Department of Forest Ecology, Silva Tarouca Research Institute, Brno, Czech Republic, [45]Department of Forest Management, College of Forestry and Conservation, The University of Montana, Missoula, MT, USA, [46]Research Institute of Tropical Forestry, Chinese Academy of Forestry, Guangzhou, China, [47]Guangxi Institute of Botany, Chinese Academy of Sciences, Guilin, Guangxi, China, [48]Research Institute of Forest Ecology, Environment and Protection, Chinese Academy of Forestry, Beijing, China, [49]Natural Sciences & Science Education Academic Group, National Institute of Education, Nanyang Technological University, Singapore, [50]Wildland Resources Department, Utah State University, Logan, UT, USA, [51]Wildlife Conservation Society, Brazzaville, Democratic Republic of the Congo, [52]Environmental and Life Sciences, Faculty of Science, Universiti of Brunei Darussalam, Tungku Link Road, BE 1410, Bandar Seri Begawan, Brunei Darussalam, [53]Forest Ecology Group, Smithsonian Environmental Research Center, Edgewater, MD, USA, [54]Institut de Recherche en Ecologie Tropicale/Centre National de la Recherche Scientifique et Technologique, Libreville, GABON, [55]Natural England, Sheffield, England, UK, [56]Department of Biology, Washington University in St. Louis, St. Louis, MO, USA, [57]New Guinea Binatang Research Centre, PO Box 604, Madang, Papua New Guinea, [58]Biology Centre, Academy of Sciences of the Czech Republic and Faculty of Science, University of South Bohemia, Branisovska 31, Ceske Budejovice 370 05, Czech Republic, [59]Departamento Ecologia, Universidade de São Paulo,Instituto de Biociências, Cidade Universitária, São Paulo, SP, Brazil, [60]Institute of Biology, University of the Philippines Diliman, Quezon City, Philippines, [61]Harvard Forest, Harvard University, Petersham, MA, USA, [62]Department of Biology, University of Hawaii, Hilo, HI, USA, [63]Forest Ecology and Forest Management Group, Wageningen University, Wageningen, The Netherlands, [64]Tropical Plant Exploration Group (TroPEG), P.O. Box 18 Mundemba, Southwest Region, Cameroon, [65]Faculty of Architecture and Environmental Design, Maejo University, Chiang Mai Province, Thailand, [66]Department of Natural Resources and Environmental Studies, National Dong Hwa University, Hualian, Taiwan, [67]Sarawak Forest Department, Kuching, Sarawak, Malaysia, [68]Faculty of Forestry, University of Toronto, 33 Willcocks St., Toronto, ON M5S 3B3, Canada, [69]School of Biological Sciences, Washington State University, Vancouver, WA, USA, [70]Centre for Ecology & Hydrology, Bush Estate, Penicuik, Midlothian EH26 0QB, UK, [71]Institute for Tropical Ecosystem Studies, Department of Environmental Science, University of Puerto Rico, Rio Piedras Campus, PO Box 70357, San Juan 00936-8377, Puerto Rico, [72]Department of Ecology, Evolution & Environmental Biology, Columbia University, New York, NY, USA, [73]Department of Biological Sciences, Pontifical Catholic University of Ecuador, Apartado Postal 17-01-2184, Quito, Ecuador, [74]Calle 37, Instituto Alexander von Humboldt, Number 8-40 Mezzanine, Bogotá, Colombia, [75]Instituto Nacional de Pesquisas da Amazônia, Manaus, Brazil, [76]School of ecological and environmental sciences, East China Normal University, Shanghai, China, [77]Department of Plant Biology, University of Minnesota, St. Paul, MN, USA, [78]Departments of Biology & Natural & Applied Sciences, Lab Sciences 435, UW-Green Bay, Green Bay, WI 54311, USA

Abstract

Global change is impacting forests worldwide, threatening biodiversity and ecosystem services including climate regulation. Understanding how forests respond is critical to forest conservation and climate protection. This review describes an international network of 59 long-term forest dynamics research sites (CTFS-ForestGEO) useful for characterizing forest responses to global change. Within very large plots (median size 25 ha), all stems ≥1 cm diameter are identified to species, mapped, and regularly recensused according to standardized protocols. CTFS-ForestGEO spans 25°S–61°N latitude, is generally representative of the range of bioclimatic, edaphic, and topographic conditions experienced by forests worldwide, and is the only forest monitoring network that applies a standardized protocol to each of the world's major forest biomes. Supplementary standardized measurements at subsets of the sites provide additional information on plants, animals, and ecosystem and environmental variables. CTFS-ForestGEO sites are experiencing multifaceted anthropogenic global change pressures including warming (average 0.61 °C), changes in precipitation (up to ±30% change), atmospheric deposition of nitrogen and sulfur compounds (up to 3.8 g N m^{-2} yr^{-1} and 3.1 g S m^{-2} yr^{-1}), and forest fragmentation in the surrounding landscape (up to 88% reduced tree cover within 5 km). The broad suite of measurements made at CTFS-ForestGEO sites makes it possible to investigate the complex ways in which global change is impacting forest dynamics. Ongoing research across the CTFS-ForestGEO network is yielding insights into how and why the forests are changing, and continued monitoring will provide vital contributions to understanding worldwide forest diversity and dynamics in an era of global change.

Keywords: biodiversity, Center for Tropical Forest Science (CTFS), climate change, demography, forest dynamics plot, Forest Global Earth Observatory (ForestGEO), long-term monitoring, spatial analysis

Received 31 May 2014 and accepted 6 July 2014

Introduction

Forests play key roles in biodiversity maintenance and climate regulation. Globally, they support over half of all described species and provide a range of valuable ecosystem services (Groombridge, 2002; Pan *et al.*, 2013). Forests play a particularly significant role in climate regulation; they contain ~45% of carbon (C) in the terrestrial biosphere and influence climate on local to global scales through their low albedo and high rates of evapotranspiration (Snyder *et al.*, 2004; Bonan, 2008; Anderson-Teixeira *et al.*, 2012; Pan *et al.*, 2013). Global change pressures – including climate change, pollution, agricultural expansion, logging, nontimber forest product extraction, hunting, and the spread of invasive species – are affecting forests worldwide, threatening biodiversity, altering community composition, and driving feedbacks to climate change (Foley *et al.*, 2005; Chapin *et al.*, 2008; Wright, 2010). Understanding and predicting such changes will be critical to biodiversity conservation, management of ecosystem services, and climate protection.

The Center for Tropical Forest Science (CTFS) – Forest Global Earth Observatory (ForestGEO) is a global network of forest research sites that is strategically poised for monitoring, understanding, and predicting forest responses to global change. This international partnership currently includes 59 long-term forest dynamics research sites in 24 countries (Fig. 1), which have been monitored continuously since as early as 1981 (Barro Colorado Island; Condit, 1995). The network applies a unique standardized tree census protocol across all of the world's major forest biomes, allowing comparison across sites (e.g., Condit, 2000; Muller-Landau *et al.*, 2006a,b; Chave *et al.*, 2008; Chisholm *et al.*, 2013, 2014). Supplementary measurements, also following standardized procedures, provide additional information on plants, animals, and ecosystem processes, making it possible to identify ecological interactions that might otherwise be missed (e.g., Harrison *et al.*, 2013). This review describes the defining features of a CTFS-ForestGEO plot, the distribution and representativeness of CTFS-ForestGEO sites, supplementary measurements and their applications, global change pressures across the CTFS-ForestGEO network, and the impacts of these drivers documented to date.

Attributes of a CTFS-ForestGEO plot

The unifying measurement at all CTFS-ForestGEO sites is an intensive census of all freestanding woody stems ≥1 cm diameter at breast height (DBH), typically repeated every 5 years, that characterizes forest structure, diversity and dynamics over a large spatial area (Table 1). Plot sizes are large, ranging from 2 to 120 ha, with a median size of 25 ha and 90% ≥10 ha (Table 2). Following standardized methodology, each individual (genet) is mapped, tagged, and identified to species when it first enters the census. In the case of multi-stemmed individuals, each stem ≥1 cm DBH (ramet) is censused. On each stem, diameter is measured at breast height (1.3 m) or above stem irregularities (Manokaran *et al.*, 1990; Condit, 1998). The census includes both trees and shrubs; henceforth, the term "trees" will refer to all individuals in the census. An accompanying fine-scale topographic survey allows identification of topographically defined habitat types (e.g., ridges, valleys, slopes; Condit, 1998). This core CTFS-ForestGEO protocol has proved useful for a wide range of analyses (Table 1).

Site distribution and representativeness

This core tree census protocol has been applied to 59 sites distributed among all of the world's major forest biomes, making CTFS-ForestGEO the only international forest monitoring network with global distribution (Fig. 1; Table 2). In total, 1653 ha of forest (>5.68

Correspondence: Kristina J. Anderson-Teixeira,
tel. 1 540 635 6546, fax 1 540 635 6506, e-mail: teixeirak@si.edu

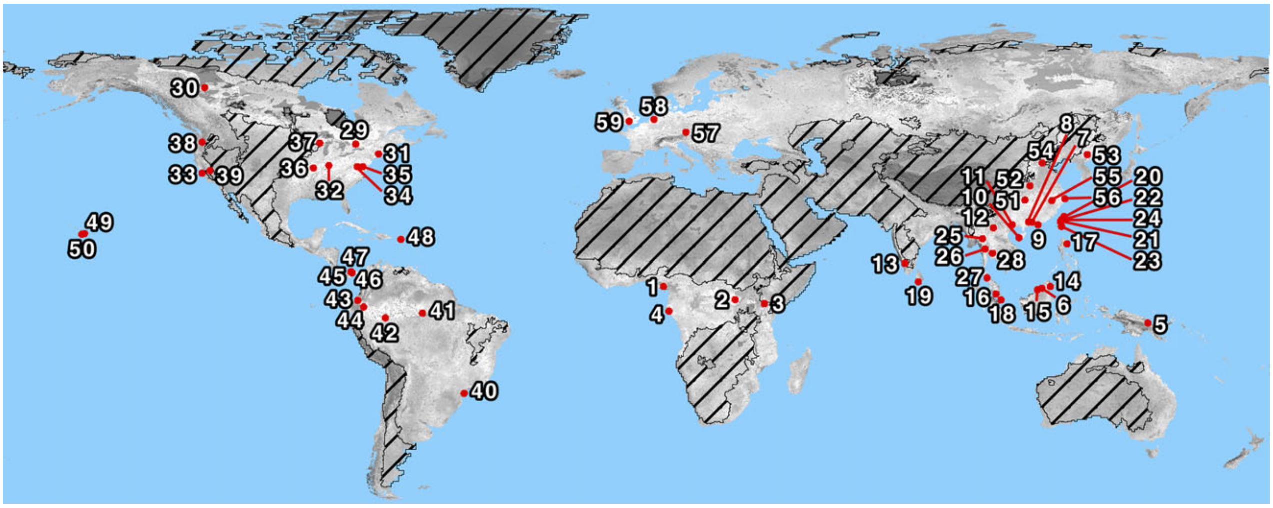

Fig. 1 Map of the CTFS-ForestGEO network illustrating its representation of bioclimatic, edaphic, and topographic conditions globally. Site numbers correspond to ID# in Table 2. Shading indicates how well the network of sites represents the suite of environmental factors included in the analysis; light-colored areas are well-represented by the network, while dark colored areas are poorly represented. Stippling covers nonforest areas. The analysis is described in Appendix S1.

Table 1 Attributes of a CTFS-ForestGEO census

Attribute	Utility
Very large plot size	Resolve community and population dynamics of highly diverse forests with many rare species with sufficient sample sizes (Losos & Leigh, 2004; Condit *et al.*, 2006); quantify spatial patterns at multiple scales (Condit *et al.*, 2000; Wiegand *et al.*, 2007a,b; Detto & Muller-Landau, 2013; Lutz *et al.*, 2013); characterize gap dynamics (Feeley *et al.*, 2007b); calibrate and validate remote sensing and models, particularly those with large spatial grain (Mascaro *et al.*, 2011; Réjou-Méchain *et al.*, 2014)
Includes every freestanding woody stem ≥1 cm DBH	Characterize the abundance and diversity of understory as well as canopy trees; quantify the demography of juveniles (Condit, 2000; Muller-Landau *et al.*, 2006a,b).
All individuals identified to species	Characterize patterns of diversity, species-area, and abundance distributions (Hubbell, 1979, 2001; He & Legendre, 2002; Condit *et al.*, 2005; John *et al.*, 2007; Shen *et al.*, 2009; He & Hubbell, 2011; Wang *et al.*, 2011; Cheng *et al.*, 2012); test theories of competition and coexistence (Brown *et al.*, 2013); describe poorly known plant species (Gereau & Kenfack, 2000; Davies, 2001; Davies *et al.*, 2001; Sonké *et al.*, 2002; Kenfack *et al.*, 2004, 2006)
Diameter measured on all stems	Characterize size-abundance distributions (Muller-Landau *et al.*, 2006b; Lai *et al.*, 2013; Lutz *et al.*, 2013); combine with allometries to estimate whole-ecosystem properties such as biomass (Chave *et al.*, 2008; Valencia *et al.*, 2009; Lin *et al.*, 2012; Ngo *et al.*, 2013; Muller-Landau *et al.*, 2014)
Mapping of all stems and fine-scale topography	Characterize the spatial pattern of populations (Condit, 2000); conduct spatially explicit analyses of neighborhood influences (Condit *et al.*, 1992; Hubbell *et al.*, 2001; Uriarte *et al.*, 2004, 2005; Rüger *et al.*, 2011, 2012; Lutz *et al.*, 2014); characterize microhabitat specificity and controls on demography, biomass, etc. (Harms *et al.*, 2001; Valencia *et al.*, 2004; Chuyong *et al.*, 2011); align on the ground and remote sensing measurements (Asner *et al.*, 2011; Mascaro *et al.*, 2011).
Census typically repeated every 5 years	Characterize demographic rates and changes therein (Russo *et al.*, 2005; Muller-Landau *et al.*, 2006a,b; Feeley *et al.*, 2007a; Lai *et al.*, 2013; Stephenson *et al.*, 2014); characterize changes in community composition (Losos & Leigh, 2004; Chave *et al.*, 2008; Feeley *et al.*, 2011; Swenson *et al.*, 2012; Chisholm *et al.*, 2014); characterize changes in biomass or productivity (Chave *et al.*, 2008; Banin *et al.*, 2014; Muller-Landau *et al.*, 2014)

Table 2 Characteristics of the CTFS-ForestGEO sites. Sites are ordered alphabetically by biogeographic zone (*sensu* Olson *et al.*, 2001), then by country, and finally by site name. More site data are given in the appendix (Tables S1–S7) and online (http://www.ctfs.si.edu/Data)

No.	Site	Country	Köppen Climate zone†	MAT (°C)‡	MAP (mm yr^{-1})‡	Dominant Soil order(s)§	Dominant vegetation type(s)**	Natural Dist. Regime††	N species	Plot Size (ha)	Year established‡‡
Afrotropics											
1	Korup	Cameroon	Am	26.6	5272	Ult, Ox	BE	W	494	55	1996
2	Ituri (Edoro and Lenda)	Democratic Republic of Congo	Af	*24.3*	1682	Ox	BE	W; A	445	40	1994
3	Rabi	Gabon	Aw	26.0	2282	Ox	BE	W	342	25	2010
4	Mpala	Kenya	Cfb	*17.9*	657	Alf; Ve	BdD	Fi, A	22	120	2011
Australasia											
5	Wanang	Papua New Guinea	Af	26.0	3500	Alf; In	BE	L; E	500*	50	2009
Indo-Malaya											
6	Kuala Belalong	Brunei Darussalam	Af	*26.5*	5203	Ult	BE	L	850–1050*	25	2009
7	Dinghushan	China	Cfa	20.9	1985		BE		210	20	2005
8	Heishiding	China	Cfa	*22.0*	1744		BE		245	50	2013
9	Hong Kong	China	Cwa	23.3	2399	Ox	BE	H	67–147*	21	2012
10	Jianfengling	China	Aw	19.8	*1657*	Ult	BE	H	291	60	2012
11	Nonggang	China	Cwa	22.0	*1376*	Ox	BE; BdD	D	223	15	2011
12	Xishuangbanna	China	Cwa	21.8	1493	Ox	BE	W; D	468	20	2007
13	Mudumalai	India	Aw	22.7	1255	Alf	BdD	Fi; A; D	72	50	1987
14	Danum Valley	Malaysia	Af	26.7	2822	Ult	BE	D; A	*	50	2010
15	Lambir	Malaysia	Af	26.6	2664	Ult	BE	L; D	1182	52	1991
16	Pasoh	Malaysia	Af	27.9	1788	Ult	BE	W	814	50	1986
17	Palanan	Philippines	Af	26.1	3380	Ult; In	BE	H	335	16	1994
18	Bukit Timah	Singapore	Af	26.9	2473	Ult	BE	A	347	4	1993
19	Sinharaja	Sri Lanka	Af	22.5	5016	Ult	BE	W	204	25	1993
20	Fushan	Taiwan	Cfa	18.2	4271	Ult; In	BE	H	110	25	2004
21	Kenting	Taiwan	Am	25.4	1964		BE	H	95	10	1996
22	Lienhuachih	Taiwan	Cwb	20.8	2211	Ult	BE	H; L	144	25	2008
23	Nanjenshan	Taiwan	Aw	23.5	3582	Ult	BE; BdD	W; H	125	6	1989
24	Zenlun	Taiwan	Am	*22.7*	*2620*		NE	H		12	2005
25	Doi Inthanon	Thailand	Aw	20.9	1908	Ult	BE	–	162	15	1997
26	Huai Kha Khaeng (HKK)	Thailand	Aw	23.5	1476	Alf	BE; BdD	Fi; D	251	50	1992
27	Khao Chong	Thailand	Am	27.1	2611	Ult; In	BE	W; L	593	24	2000
28	Mo Singto	Thailand	Aw	*23.5*	2100		BE; BdD	W	262	30.5	2000

Table 2 (continued)

No.	Site	Country	Köppen Climate zone†	MAT (°C)‡	MAP (mm yr^{-1})‡	Dominant Soil order(s)§	Dominant vegetation type(s)**	Natural Dist. Regime††	N species	Plot Size (ha)	Year established‡‡
Nearctic											
29	Haliburton	Canada	Dfb	*4.2*	*962*		BcD	–	30	13.5	2007
30	Scotty Creek	Canada	Dfc	−3.2	369	Ge	NE	PT; Fi	12–15*	21	2013
31	Harvard Forest	USA	Dfb	9.0	1050	In	BdD	H	60	35	2010
32	Lilly Dickey Woods	USA	Cfa	11.6	1203	In; Ult; Alf	BcD	W; D; Ic	35	25	2009
33	Santa Cruz	USA	Csb	14.8	778	Mo	BE; NE	Fi,W	33	16	2007
34	Smithsonian Conservation Biology Institute (SCBI)	USA	Cfa	12.9	1001	Alf	BcD	W, Ic	64	25.6	2008
35	Smithsonian Environmental Research Center (SERC)	USA	Cfa	*13.2*	*1068*	Ult; In; En	BcD	H; W	79	16	2007
36	Tyson Research Center	USA	Cfa	13.5	957	Alf	BcD	D; Fi; Ic; W	42	20	2013
37	Wabikon	USA	Dfb	*4.2*	805	Alf	BcD	W	42	25.6	2008
38	Wind River	USA	Csb	9.2	2495	An	NE	Fi; W; In	26	25.6	2010
39	Yosemite National Park	USA	Csb	10.2	1065	Alf	NE	Fi; W; D; In	23	25.6	2009
Neotropics											
40	Ilha do Cardoso	Brazil	Cfa	22.4	2100	S	BE		106	10.2	2004
41	Manaus	Brazil	Af	*26.7*	2600	Ox	BE	W	1440*	25	2004
42	Amacayacu	Colombia	Af	25.8	3215	Ult	BE	Fl	1133	25	2006
43	La Planada	Colombia	Cfb	19.0	4087	An	BE	W	240	25	1997
44	Yasuni	Ecuador	Af	28.3	3081	Ult	BE	–	1114	50	1995
45	Barro Colorado Island (BCI)	Panama	Am	27.1	2551	Ox	BdD; BE	D; W	299	50	1981
46	Cocoli	Panama	Am	*26.6*	1950	Ox; In	BdD; BE	D; W	176	4	1994
47	San Lorenzo/ Sherman	Panama	Am	*26.2*	3030		BE	D; W	238	6	1996
48	Luquillo	Puerto Rico, USA	Am	22.8	3548	Ox; Ult	BE	H; L	138	16	1990
Oceania											
49	Laupahoehoe	USA	Cfb	16.0	3440	An	BE	W	21	4	2008
50	Palamanui	USA	Cfb	20.0	835	Hi	BE	W	15	4	2008
Palearctic											

Table 2 (continued)

No.	Site	Country	Köppen Climate zone†	MAT (°C)‡	MAP (mm yr^{-1})‡	Dominant Soil order(s)§	Dominant vegetation type(s)**	Natural Dist. Regime††	N species	Plot Size (ha)	Year established‡‡
51	Badagongshan	China	Cfa	*15.9*	*1410*	In	BE; BdD	Fl	238	25	2011
52	Baotianman	China	Cwa	15.1	886		BdD	A; D	126	25	2009
53	Changbaishan	China	Dwb	2.9	700	Alf	NE; BcD		52	25	2004
54	Donglingshan	China	Dwb	*4.7*	570	Alf	BcD	Fi	58	20	2010
55	Gutianshan	China	Cfa	15.3	1964	Ult	BE; BdD	Ic	159	24	2005
56	Tiantongshan	China	Cfa	16.2	1375	Ox	BE	H; D	153	20	2008
57	Zofin	Czech Republic	Cfb	6.2	866	S; In; Hi	BcD; NE	W; In	12	25	2012
58	Speulderbos	Netherlands	Cfb	10.1	833	In	BcD	W; A	13	27	2013
59	Wytham Woods	UK	Cfb	10.0	717	E	BcD		23	18	2008

*Measurement in progress.

†Af: Tropical with significant precipitation year-round; Am: Tropical monsoon; Aw: Tropical wet and dry; Csb-Dry-summer subtropical/mid-latitude climate with dry summers (a.k.a.: Warm-summer Mediterranean); Cfa: Humid subtropical/mid-latitude climate with significant precipitation year-round; Cwa: Humid subtropical/midlatitude climate with dry winters; Cfb: Oceanic with significant precipitation year-round; Cwb: Oceanic with dry winters; Dfb: Humid Continental with significant precipitation year-round; Dwb: Humid continental with dry winters; Dfc: Subarctic.

‡Climate data are the best available for each site (based on judgment of site PIs; years vary). For sites where local data are not available or not reported, values (*italicized*) are mean 1950–2000 climate from WorldClim at 30 arcsecond resolution (Table S4; Hijmans *et al.*, 2005).

§Categorical following the USDA Soil Taxonomy System (Soil Survey Staff, 1999): Alf, Alfisols; An, Andisols; E, Entisoils; Ge, Gelisols; Hi, Histosols; In, Inceptisols; Ox, Oxisols; Ult, Ultisols; S, Spodosols; Ve, Vertisols.

**BE, broadleaf evergreen; BdD, broadleaf drought deciduous; BcD, broadleaf cold deciduous; NE, needleleaf evergreen.

††A, animal activity (destructive); D, Drought; E, Erosion; Fi, Fire; Fl, flood; H, hurricane/typhoon; Ic, Ice storms; Ininsect outbreaks; L, landslides; PT, permafrost thaw; W, wind storms (local); ‘–’, no major natural disturbances.

‡‡When census spanned multiple years, the first year is listed.

million individuals) are currently monitored, with a cumulative sum of >17 000 ha-years of forest monitoring.

CTFS-ForestGEO sites cover a wide diversity of physical and biotic environments (Figs 1 and 2; Table 1, Table S1). The network spans latitudes 25°S–61°N, with sites in every biogeographic realm (*sensu* Olson *et al.*, 2001; Table 1, Table S1). Climate varies widely (Fig. 2; Table 1, Table S2): mean annual temperature (MAT) ranges from −3.2 °C (Scotty Creek, Canada) to 28.3 °C (Yasuni, Ecuador), and mean annual precipitation (MAP) from 369 mm yr^{-1} (Scotty Creek, Canada) to 5272 mm yr^{-1} (Korup, Cameroon). Elevation ranges from 3 m.a.s.l. (Ilha do Cardoso, Brazil) to 1911 m.a.s.l. (Yosemite, USA), and relief from 4 m (SERC, USA) to 298 m (Tiantongshan, China; Table S1). According to the Soil Survey Staff (1999) soil classification, 11 of the world's 12 soil orders are represented (the exception is Aridisols; Table 1), with corresponding marked variation in fertility.

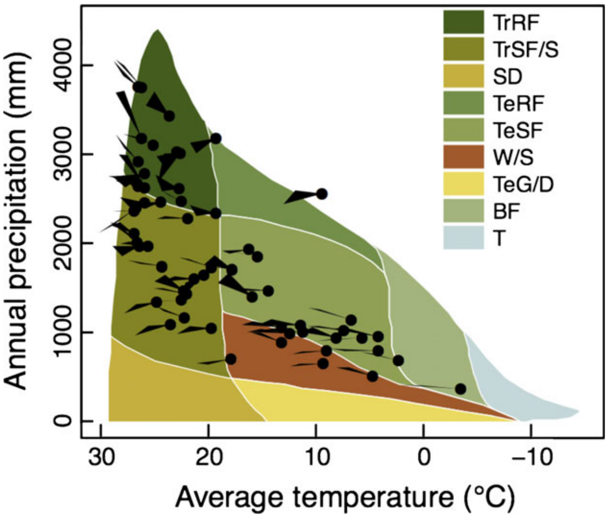

Fig. 2 Current and projected future (2050) mean annual temperature and precipitation of CTFS-ForestGEO sites superimposed upon Whittaker's classic climate-biomes diagram (Whittaker, 1975; Ricklefs, 2007). Dots represent average climate from 1950 to 2000. Wedges represent the range of projected climates through 2050 as projected by the HADGEM2-ES model; specifically, smaller and larger temperature increases represent IPCC's RCP 2.6 and RCP 8.5 scenarios, respectively. Biome codes are as follows: TrRF, tropical rain forest; TrSF/S, tropical seasonal forest/savanna; SD, subtropical desert; TeRF, temperate rain forest; TeSF, temperate seasonal forest; W/S, woodland/shrubland; TeG/D, temperate grassland/desert; BF, boreal forest; T, tundra. Data from WorldClim (worldclim.org); recent climate data differ from those in Table 1. Details on climate data and analysis are given in Appendix S1; data are listed in Table S4.

The CTFS-ForestGEO network is generally representative of the range of bioclimatic, edaphic, and topographic conditions experienced by forests globally (Fig. 1), as evidenced by a multivariate spatial clustering analysis with 4 km resolution (Hargrove *et al.*, 2003; Hoffman *et al.*, 2013; Maddalena *et al.*, 2014; Appendix S1). Particularly well-represented regions include tropical rain forests on upland or 'tierra firme' habitats – especially in the Indo-Malay biogeographic zone – and temperate forests of Eastern China and Eastern North America. Underrepresented regions include temperate forests in the Southern Hemisphere; seasonal forests and woodland savannas south and east of the Amazon and in Africa; the Rocky Mountains of North America; and boreal forests – particularly in the Palearctic biogeographic zone. On a finer scale, many of the CTFS-ForestGEO sites in Asia, Europe, and North America are on more topographically complex terrain compared to the original forest distribution, as are most remaining intact forests in these regions. Forests with extreme edaphic conditions – for example, mangrove, swamp, and peat forests – remain almost completely unrepresented.

Dominant vegetation types of the CTFS-ForestGEO sites include broadleaf evergreen, broadleaf drought deciduous, broadleaf cold deciduous, and needle-leaf evergreen forests (Table 1). Floristically, the network has extensive coverage, with >10 000 tree and shrub species (and >14 000 unique site-species combinations). Unique tree floras that are not yet represented include the high-endemism forests of Madagascar; southern temperate forests in New Zealand, Australia, and southern South America; and dry forests in Africa and the southern and eastern Amazon.

The sites are generally in old-growth or mature secondary forests and are commonly among the most intact, biodiverse, and well-protected forests within their region. They are subjected to a range of natural disturbances (Table 1), and a number of sites have experienced significant natural disturbances in recent years (e.g., fire at Yosemite, typhoons at Palanan). In addition, most sites have experienced some level of anthropogenic disturbance (discussed below; Table S5).

Supplementary measurements and applications

At all sites, the core census is complemented by one or more supplementary measurements that provide further basis for standardized comparisons across the world's major forest biomes. Supplementary measurements provide additional information on plants, animals, and ecosystem and environmental variables (Table 3). In this section, we review CTFS-ForestGEO -specific protocols and other relatively standard

Table 3 Summary of supplementary CTFS-ForestGEO measurement protocols applied at five or more sites

Measurement	N sites*	Description	Utility
Plants			
Lianas	7 (15)	Lianas are included as part of the core census; they are mapped, identified to species, and measured at breast height (1.3 m)	Characterize liana abundance and diversity and changes therein (Schnitzer, 2005; DeWalt *et al.*, 2015; Thomas *et al.*, 2015); understand liana impacts on tree community (Ingwell *et al.*, 2010).
Functional traits	33 (39)†	Traits characterized include three dimensions (maximum height and crown diameter); leaf traits [size, specific leaf area, thickness, (N), (P), dry matter content]; wood traits (stem wood density, C content); and reproductive traits (dispersal mode; fruit, diaspore, and seed fresh and dry masses).	Characterize species' differences in physiology and ecological roles (Condit *et al.*, 1996; Santiago & Wright, 2007; Muller-Landau *et al.*, 2008; Kraft *et al.*, 2010; Wright *et al.*, 2010; Westbrook *et al.*, 2011; Katabuchi *et al.*, 2012; Liu *et al.*, 2012); detect directional changes in functional composition (Feeley *et al.*, 2011; Hietz *et al.*, 2011; Swenson *et al.*, 2012; Harrison *et al.*, 2013); improve inventory-based C stock estimates (Martin & Thomas, 2011; Cushman *et al.*, 2014); parameterize models
High-precision diameter growth	28 (32)	Diameter growth is measured weekly to annually using dendrometer bands on a subset of trees.	Understand effects of tree size, species, and environmental conditions on growth; characterize seasonal growth patterns (McMahon & Parker, 2014); estimate the woody stem growth component of aboveground net primary productivity ($ANPP_{wood}$)
Flower & seed production	24 (33)	Species-level flower & seed production are quantified using weekly to bimonthly censuses of 60–336 0.5-m^2 traps.	Quantify reproductive phenology (Zimmerman *et al.*, 2007); infer seed dispersal distances (Muller-Landau *et al.*, 2008); quantify interannual variation and its ecological implications (Wright *et al.*, 1999, 2005; Harms *et al.*, 2000; Usinowicz *et al.*, 2012); detect directional changes (Wright & Calderon, 2006)
Seedling performance	21 (30)	Seedling establishment, growth and survival are quantified annually in three 1-m^2 plots associated with each seed trap.	Characterize density- and distance-dependent effects on con- and hetero-specific seedling recruitment (Harms *et al.*, 2000; Comita *et al.*, 2010; Lebrija-Trejos *et al.*, 2013); Understand postdisturbance successional dynamics (Dalling *et al.*, 1998; Dalling & Hubbell, 2002)
DNA barcoding	27 (28)	Short DNA sequences from a standard position within the genome are used to construct phylogenies and distinguish individual species from one another. Can be applied to all tissues of the plants (e.g., roots, pollen, leaves, and bark) or animals. Over 3000 plant species have been barcoded to date.	Build phylogenetic trees of local community relationships and investigate constraints on the assembly of communities (Pei *et al.*, 2011; Swenson *et al.*, 2011; Lebrija-Trejos *et al.*, 2013); identify tree roots to species (Jones *et al.*, 2011); reconstruct networks of feeding, pollination, and parasitism −(Hrcek *et al.*, 2011)
Animals			
Arthropods	5 (13)		

Table 3 (continued)

Measurement	N sites*	Description	Utility
		A variety of key taxa are monitored 1–4 times annually‡using a variety of techniques (light traps, Winkler extractors, McPhail traps, butterfly transects, termite transects, and bee baits).	Elucidate the role of arthropods in forest ecosystems (Novotny *et al.*, 2002; Novotny & Basset, 2005); evaluate the impact of global change on the full range of forest trophic levels
Vertebrates	14 (34)	Camera trapping is used to monitor terrestrial mammals.	Elucidate the role of vertebrates in forest ecosystems; detect directional changes
Ecosystem & Environmental			
Aboveground biomass	59	Ground based: Biomass is estimated from core census data using best available allometries, often in combination with site-specific height and wood density data.	Characterize spatial variation in biomass within sites in relation to environmental gradients and species diversity (Valencia *et al.*, 2009; Chisholm *et al.*, 2013); detect directional changes in C stocks (Chave *et al.*, 2008; Muller-Landau *et al.*, 2014); calibrate and evaluate models of biomass based on airborne LiDAR (Asner *et al.*, 2011; Mascaro *et al.*, 2011; Réjou-Méchain *et al.*, 2014)
	(15)	Airborne: LiDAR flights (one-time or repeated) provide data on biomass and tree architecture.	
Dead wood/CWD	21 (25)	Standing dead wood and fallen coarse woody debris are surveyed by transect or comprehensive survey.	Quantify C stocks in dead wood and changes therein
Fine root biomass & soil carbon	16 (32)	Measured to 3 m depth on every hectare, with additional replicates to shallower depths.	Understand the role of associations between plants and mycorrhizal fungi in driving soil carbon storage (Peay *et al.*, 2010; Averill *et al.*, 2014)
Soil nutrients	23 (26)	Extractable soil cations, available N, nitrogen mineralization rates, and extractable phosphorus at 0 to 10-cm depths are measured at high spatial resolution.	Characterize species' microhabitat associations (Lee *et al.*, 2002; Davies *et al.*, 2003; John *et al.*, 2007; Tan *et al.*, 2009; Baldeck *et al.*, 2013a,b,c; De Oliveira *et al.*, 2014); characterize plant performance in relation to soil nutrients (Russo *et al.*, 2005, 2013)
Litterfall	21 (29)	Litter is collected biweekly to monthly from traps, oven-dried, sorted (to leaves, woody, reproductive, and other), and weighed.	In combination with woody growth data, quantify aboveground net primary productivity (ANPP) and its phenology and environmental drivers
Bio-micrometeorology	(13)	Eddy-covariance technique is used to continuously measure CO_2, H_2O, and energy exchange between ecosystem and the atmosphere.	Understand forest ecophysiology and C cycling on half-hourly to multiannual time scales
Meteorology	5(33)	Some sites have local meteorological stations within 10 km of the plot.	Characterize climatic controls on forest processes such as flower and fruit production, tree growth and mortality, and ecosystem-atmosphere gas exchange (Condit *et al.*, 2004; Wright & Calderon, 2006; Feeley *et al.*, 2007a; Dong *et al.*, 2012; Li *et al.*, 2012)

*Numbers indicate sites where measurements have been made or are in progress following a specific CTFS Forest GEO protocol. Numbers in parentheses indicate total number of sites with measurements using any protocol.
†Varies by trait. Number indicates sites with measurements of one or more functional traits.
‡Varies by protocol. See Appendix S1 for details.

measurements that are comparable across sites. The Supplementary Information section provides further information on methodologies (Appendix S2) and details which measurements have been made at each site (Tables S6 and S7).

Plants

Supplementary measurements on plants include liana abundance and diversity, functional traits, high-precision diameter growth, flower and seed production, seedling performance, and DNA barcoding (Table 3). Liana censuses help to characterize the important role of lianas in forest dynamics. Measurements of functional traits – well-defined, measurable properties of organisms that are strongly associated with ecological performance – provide information on key attributes and ecological roles of the species included in the census. High-precision growth measurements provide fine-scale understanding of temporal and spatial variation in tree growth and forest productivity. Flower, seed and seedling censuses enable study of complete tree life cycles, which are critically important for forest regeneration and long-term species persistence. DNA barcoding provides a powerful means of species identification that allows elucidation of phylogenetic relationships and ecological roles (Dick & Kress, 2009; Kress *et al.*, 2009, 2010).

Animals-

Arthropod and vertebrate initiatives (Table 3) yield understanding of the roles of these taxa in forest dynamics through their roles as herbivores, pollinators, seed dispersers, predators, ecosystem engineers, and vectors of microbial diversity. In a unique effort to monitor multitaxon assemblages in tropical rainforests (Basset *et al.*, 2013; but see Leidner *et al.*, 2010 for long-term monitoring of a single taxon), key arthropod groups are being monitored to better understand how interactions between arthropods and plants affect forest dynamics and to evaluate the impact of global change on the full range of forest trophic levels. Vertebrate monitoring is helping to elucidate how mammals differentially affect tree species and how modification of the fauna may impact the future forest (e.g., Wright *et al.*, 2007; Harrison *et al.*, 2013; see below).

Ecosystem and environmental

Supplementary measurements of ecosystem and environmental variables include major aboveground C stocks and fluxes (aboveground biomass, standing dead wood and coarse woody debris, $\mathrm{ANPP_{wood}}$, litterfall, net ecosystem exchange); soil nutrients, C, and fine root biomass; bio-micrometeorology, and meteorology (Table 3). These measurements provide a basis for understanding environmental and biotic controls on C stocks and fluxes within forest ecosystems and how these may respond to global change. Soils measurements provide a basis for understanding the critical role of soils in determining species composition, forest structure, and primary productivity, as well as their globally significant role as an important C reservoir. Bio-micrometeorological measurements further elucidate the important role of forests in climate regulation through ongoing exchange of CO_2, H_2O, and energy between the ecosystem and the atmosphere. Meteorological data are critical for understanding how the biotic community and whole ecosystem processes respond to climate variables over half-hourly to multiannual time scales.

Combined applications

In combination, the core tree census and supplementary measurements enable unique analyses of the many interacting components of forest ecosystems, yielding a holistic picture of forest dynamics. For instance, core census data have been combined with data on lianas, vertebrates, seeds, seedlings, and reproductive functional traits to link decreasing populations of seed dispersers to changing patterns of plant reproduction, liana abundance, and tree growth and survival (Wright & Calderon, 2006; Wright *et al.*, 2007; Ingwell *et al.*, 2010; Harrison *et al.*, 2013). Core census, functional trait, and DNA barcoding data have been combined to understand the roles of phylogeny and functional traits in shaping habitat associations and diversity in space and time (Pei *et al.*, 2011; Swenson *et al.*, 2011). The combination of core census data, plant functional traits, ecosystem measurements, soils data, and weather data lend themselves to parameterizing and evaluating ecosystem and earth system models. Thus, the broad suite of standardized measurements at CTFS-ForestGEO sites (Tables 1 and 3) provides opportunities to address a multitude of questions on forest dynamics and their responses to global change pressures.

Global change pressures at CTFS-ForestGEO sites

All ecosystems on Earth – including CTFS-ForestGEO's relatively intact forests – are affected by anthropogenic influences (Fig. 3). Human appropriation of land and water for agriculture and other purposes; emission of extraneous compounds to the atmosphere (e.g., CO_2, CH_4, N_2O, NO_y, NH_x, SO_2) and water (e.g., NO_3^-, PO_4^{3-}); extraction of food, fuel, and fiber from natural

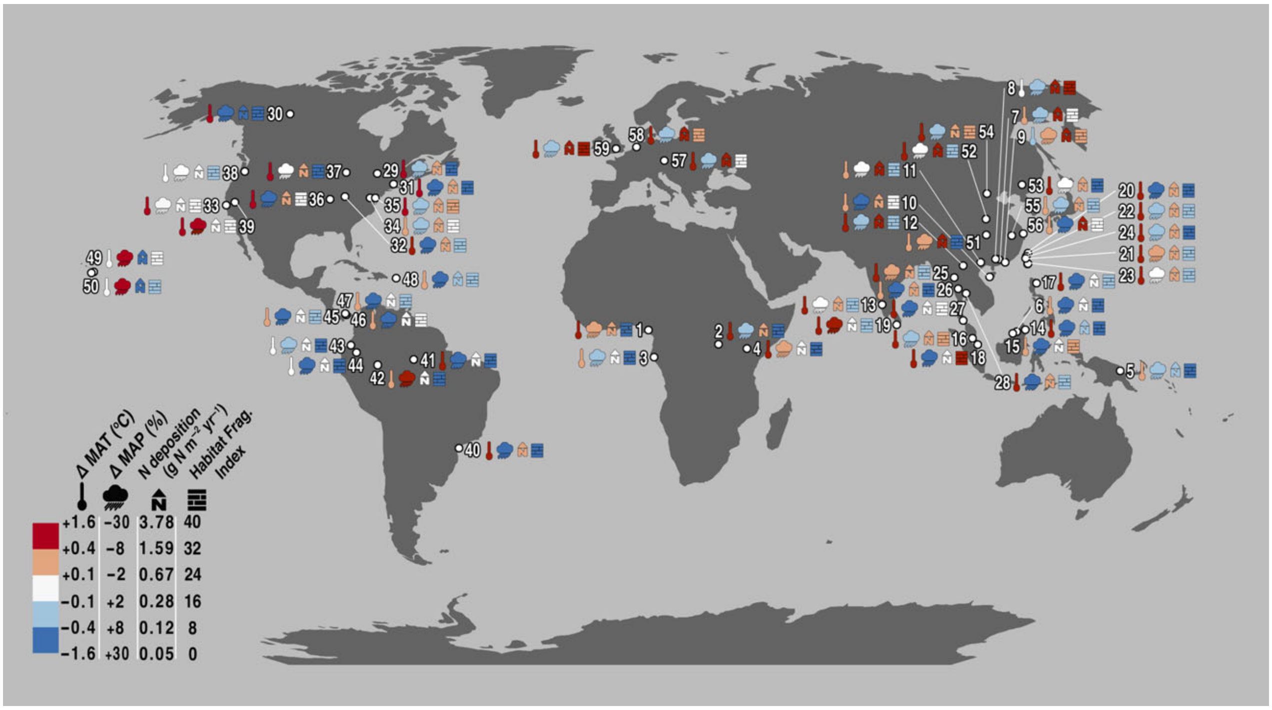

Fig. 3 Map of CTFS-ForestGEO sites illustrating the severity of four global change pressures: changes in mean annual temperate and precipitation relative to the 1951–1980 climatic average (MAT and MAP, respectively; Table S3), total N deposition (Table S5), and an index of habitat fragmentation (see Appendix S1; Table S5). Numbers correspond to ID#'s in Table 2. Analyses are detailed in Appendix S1.

ecosystems; and transport of species around the globe has so pervasively influenced Earth's climate, hydrology, biogeochemistry, land cover, and species diversity as to warrant classification of a new geologic period in Earth's history – the Anthropocene (Schlesinger, 2012; Vitousek *et al*., 1997a; Zalasiewicz *et al*., 2010, 2011).

Over the lifetime of the CTFS-ForestGEO network, atmospheric CO_2 has increased 16%, from 340 ppm in 1981 to 396 ppm in 2013 (Tans & Keeling, 2014), with variable effects on climate globally. Over a similar time frame, temperatures have increased across the network by an average of 0.61 °C, with greater increases at colder sites (Figs 3 and 4; Table S3; details on data and analysis in Appendix S1). On both annual and daily time scales, minimum temperatures have increased more than maximum temperatures, leading to decreases in the diurnal temperature range. Frost-day frequency has decreased at sites that experience frost. Potential evapotranspiration (PET) has increased slightly on average (+2.5%) – particularly at low-PET sites. A tendency for increased cloud cover has offset the increases in PET that would be expected based on temperature increases alone, and high-PET sites have therefore experienced little change in PET on average (Fig. 4). Changes in mean annual precipitation (MAP) and wet-day frequency have been variable, with an overall tendency toward increases (averaging 6.0% and 2.7%, respectively) – particularly at high-precipitation sites (Fig. 4). Changes to the difference between annual MAP and PET have also been variable, with a tendency for wet sites (high MAP-PET) to become wetter – particularly in the Neotropical and Indo-Malay biogeographic zones – and low MAP-PET sites to become drier (Fig. 4). Changes in seasonality and the number of months with precipitation<PET have been variable across the network. In summary, CTFS-ForestGEO sites have experienced warming and variable changes in precipitation and aridity.

Ongoing climate change is inevitable, with its course dependent upon future greenhouse gas emissions and land use patterns (IPCC, 2013). The IPCC AR5 examines four representative concentration pathways (RCP's), the most optimistic of which has greenhouse gas emissions going to zero before 2100 (RCP 2.6) and the most pessimistic of which denotes continuously increasing emissions leading to a radiative forcing of 8.5 W m^{-2} by 2100 (RCP 8.5; IPCC, 2013). Across this range of future scenarios, the HADGEM2-ES model predicts MAT increases averaging 2.0 °C under RCP 2.6 (range: 1.2–3.6 °C) to 3.0 °C under RCP 8.5 (range: 1.9–5.7 °C) across the CTFS-ForestGEO sites (Fig. 2; Table S4). This warming will push some tropical forests

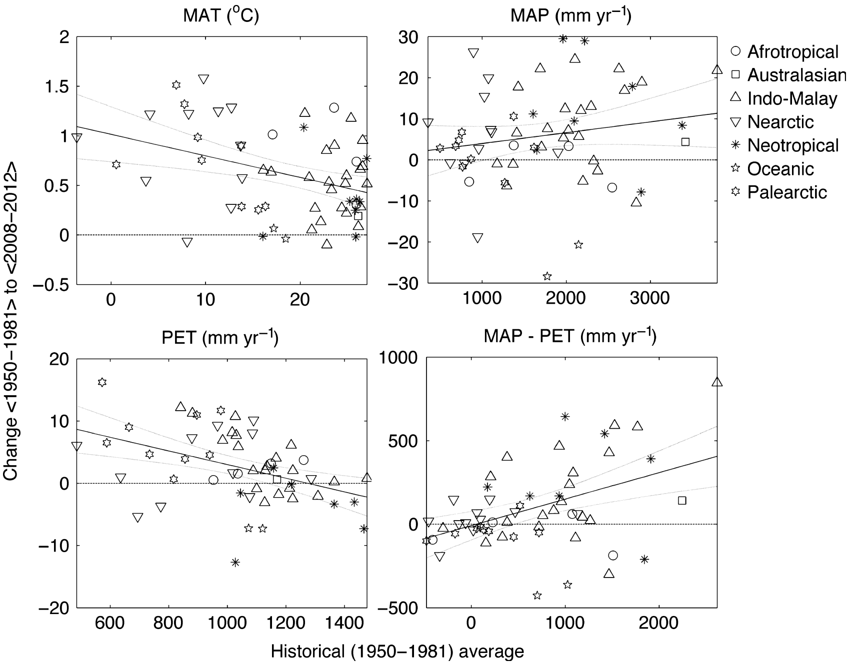

Fig. 4 Recent climate change at CTFS-ForestGEO sites. Specifically, shown is the change from the 1951–1981 average to the 2008–2012 average plotted as a function of the historical (1950–1981) average for four variables: mean annual temperature (MAT), mean annual precipitation (MAP), mean annual potential evapotranspiration (PET), and the difference between mean annual precipitation and potential evapotranspiration (MAP−PET). Solid and dotted lines represent the linear fit and its 95% CI, respectively; dashed horizontal lines represent zero change. Based on CGIAR-CSI climate data (www.cgiar-csi.org/data; CRU-TS v3.10.01 Historic Climate Database and PET estimates from Zomer, 2007; Zomer *et al.*, 2008). Analyses are detailed in Appendix S1.

into climates with no current analog (Fig. 2). Predicted changes in annual precipitation at these sites range from −8.6% to +19.0% under RCP 2.6 and −13.6% to +7.3% under RCP 8.5 (Fig. 2; Table S4). When coupled with predicted warming and associated increases in potential evapotranspiration, constant or decreasing precipitation – which is predicted for approximately half the sites (Fig. 2, Table S4) – implies that conditions will become more arid. At most CTFS-ForestGEO sites, soil moisture and relative humidity are predicted to decline in the near-term (i.e., 2016–2035), even under a modest emissions scenario (Kirtman *et al.*, 2013; Sherwood & Fu, 2014).

The biogeochemistry of these sites has also been modified by human activities. The global nitrogen (N) cycle has been dramatically transformed by human activities (Schlesinger, 2012; Vitousek *et al.*, 1997a; Galloway *et al.*, 2008; Canfield *et al.*, 2010). Atmospheric deposition of reactive N can fertilize forests that are N limited (Magnani *et al.*, 2007; Yu *et al.*, 2014), and can also impair ecosystem function through soil acidification and N saturation (Aber *et al.*, 1989; Schlesinger, 2012; Vitousek *et al.*, 1997b). At CTFS-ForestGEO sites, current N deposition has a median value of 0.9 g N m^{-2} yr^{-1} and ranges from 0.05 (Scotty Creek) to 3.8 g N m^{-2} yr^{-1} (Badagongshan, China; Fig. 3), implying that N deposition at many sites may exceed critical loads for soil acidification (Bouwman *et al.*, 2002). In addition, sulfuric acid deposition reduces soil fertility (e.g., Likens *et al.*, 1996) and increases tree mortality (Dietze & Moorcroft, 2011). Across the network, annual SO_x deposition has a median value of 0.5 g S m^{-2} yr^{-1} (range 0.08 g S m^{-2} yr^{-1} at Mpala, Kenya to 3.1 g S m^{-2} yr^{-1} at Tiantongshan, China; Table S5; data from Dentener *et al.*, 2006; see Appendix S1 for details). Nitrogen and sulfur deposition is predicted to continue to increase in the future (Dentener *et al.*, 2006).

At the local level, CTFS-ForestGEO sites have also been directly exposed to a range of past and ongoing anthropogenic perturbations. Some sites and their surrounding areas were partially to fully logged in the past, and in some cases the land was used for farming or pasture (Table S5). Historical and contemporary forest loss (through deforestation or natural stand-clearing disturbance) in surrounding areas has exposed some sites to severe habitat fragmentation, whereas others are surrounded by vast expanses of near-pristine forest (Figs 3 and 5; Table S5). By the year 2012, 27 sites (primarily in Europe, North America, and Asia) had tree cover within a 5 km radius reduced by more than 10%

relative to tree cover in the plot, and seven sites even had reductions >40%. Generally speaking, percent tree cover on the landscape decreases with distance from the site, while recent (2000–2012) forest loss rates and forest fragmentation increase (Fig. 5; data from Hansen *et al.*, 2013; see Appendix S1 for details). In addition to forest loss in the surrounding landscapes, the majority of sites have been exposed to past and/or ongoing extraction of timber or nontimber forest products, hunting, or invasive species (Table S5). A few sites are have high human population density in the surrounding areas and are affected by urbanization.

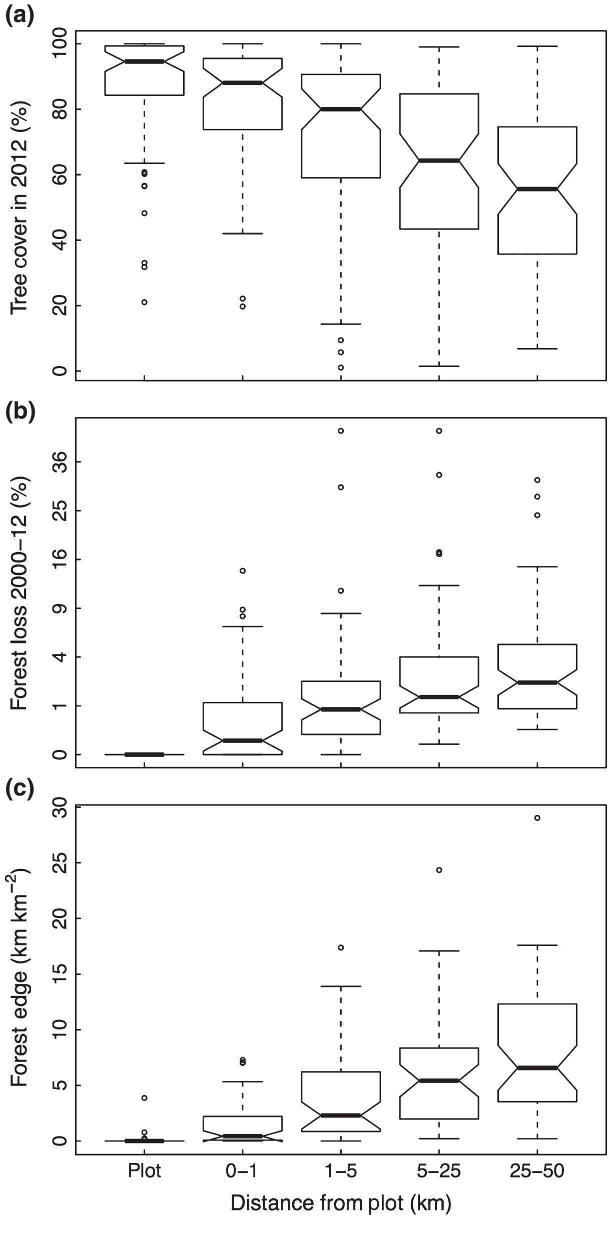

Fig. 5 Characterization of forest cover, fragmentation, and loss in the landscapes surrounding CTFS-ForestGEO sites, with distance zones describing concentric circles centered at each site. (a) Average % tree cover in year 2012; (b) % loss of existing tree cover from 2000 to 2012 (note the vertical scale is the square of forest loss); (c) Forest fragmentation, as characterized by forest edge: area ratio in year 2012. Note that 'forest' can include agroforestry areas. Data from (Hansen *et al.*, 2013). Analysis methods given in Appendix S1. Data for each site given in Table S5.

Forest responses to global change

As described above, all CTFS-ForestGEO sites are experiencing multifaceted global change pressures (Fig. 3). With spatially explicit dynamic tree data for large forest dynamics plots and the additional measurements summarized above (Table 2), the network is poised to advance mechanistic understanding of the impact of global and environmental change on the world's forests.

Are forests changing?

Change is the natural condition of forests (e.g., Baker *et al.*, 2005; Laurance *et al.*, 2009), which makes it challenging to detect and attribute directional responses to global change pressures. A key finding from the network is that forests generally, and in particular tropical forests, are highly dynamic; for instance, in the first 18 years of monitoring at BCI, >40% of trees ≥1 cm DBH (or 34% ≥10 cm DBH) turned over, and 75% of all species changed in abundance by >10% (Leigh *et al.*, 2004). Superimposed upon this dynamism, forests are responding to global change pressures. Data from the network reveal some generalities and long-term trends of change in forests worldwide.

Forest composition in terms of species and functional groups has changed at multiple sites across the network, in different directions at different sites (Condit *et al.*, 1996; Chave *et al.*, 2008; Feeley *et al.*, 2011; Makana *et al.*, 2011; Swenson *et al.*, 2011). An analysis of data from twelve CTFS-ForestGEO sites reveals that environmental variability – as opposed to demographic stochasticity – is the most important factor driving tree population dynamics on decadal time scales (Chisholm *et al.*, 2014). Across relatively undisturbed tropical forests, the dominance of slow-growing species increased at nine of ten sites analyzed (significantly so at five sites), indicating that these forests may be recovering from past disturbances, even as they are impacted by a variety of global change pressures (Chave *et al.*, 2008). In addition, at six tropical sites monitored over more than 10 years, there have been long term increases in the proportions of flowers and seeds produced by lianas (Fig. 6; Wright & Calderon, 2006; Wright, unpublished analysis) – a trend that corresponds with long

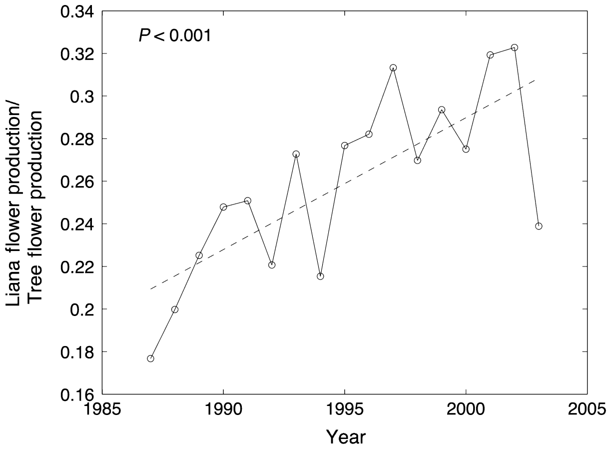

Fig. 6 Ratio of flower production by lianas (33 species) to that of trees (48 species) over 17 years on Barro Colorado Island, Panama. Redrawn from Wright & Calderon (2006).

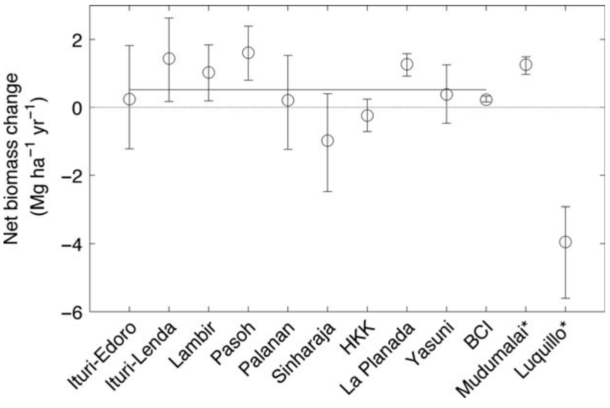

Fig. 7 Aboveground biomass change in twelve tropical forests. Solid line represents mean for ten undisturbed sites; *indicates disturbed plots. Replotted from Chave *et al.* (2008) with an updated value for BCI (Muller-Landau *et al.*, 2014; K.C. Cushman, personal communications).

term increases in the abundance of lianas observed on BCI (Panama) and elsewhere in the tropics (Ingwell *et al.*, 2010; Schnitzer & Bongers, 2011). While community change appears to be the rule rather than the exception across the network, and while there have been some instances of rapid change in forest composition (e.g., Condit *et al.*, 1995; Chave *et al.*, 2008), there have not been any hugely dramatic changes such as a forest die-off affecting the majority of large trees at the network sites.

Trends in various components of aboveground net primary productivity (ANPP) have also been monitored at some sites. Across the network, the woody component of NPP ($\mathrm{ANPP_{wood}}$) has increased or decreased, as a function of both climate change and succession. Forests globally are mixed in terms of their productivity trends (Laurance *et al.*, 2004; Clark *et al.*, 2010; Gedalof & Berg, 2010; Wright, 2010). For instance, decreases in $ANPP_{wood}$ were observed in tropical forests in Panama (BCI) during 1981–2005 and Malaysia (Pasoh) during 1990–2000 (Feeley *et al.*, 2007b) and increases in $\mathrm{ANPP_{wood}}$ were observed in secondary forests in Maryland, USA (SERC; McMahon *et al.*, 2010). Notably lacking is evidence of consistent increases in ANPP, as might be expected based solely on increasing atmospheric CO_2 concentration (e.g., Norby *et al.*, 2005). In the tropics, allocation of NPP to reproduction appears to have shifted; at five of six tropical sites where flower and seed production has been monitored for more than 10 years, there has been a long-term increase in flower production but not seed production (Wright & Calderon, 2006; Wright, unpublished analysis). Ongoing monitoring of NPP and flower and seed production will be vital to characterizing trends in productivity and C allocation.

Finally, changes in standing biomass over time have been detected. Across ten relatively undisturbed tropical forests, highly resolved estimates of net biomass change show that aboveground biomass increased on average 0.24 ± 0.16 Mg C ha^{-1} yr^{-1} (Fig. 7; Chave *et al.*, 2008). This value is comparable to (though slightly lower than) values recorded for networks of small forest plots in Amazonia (0.62 ± 0.23 Mg C ha^{-1} yr^{-1}; Baker *et al.*, 2004), and Africa (0.63 ± 0.36 Mg C ha^{-1} yr^{-1}; Lewis *et al.*, 2009a). Combining published data for the CTFS-ForestGEO, RAINFOR, and AfriTRON tropical forest sites leads to an overall average of 0.34 ± 0.11 Mg C ha^{-1} yr^{-1} based on a total of 8243 ha-years of monitoring (Muller-Landau *et al.*, 2014). Ongoing monitoring will be important for quantifying trends in biomass in the global forests represented by CTFS-ForestGEO.

What are the mechanisms by which global change impacts forests?

While data from the CTFS-ForestGEO network add to abundant evidence that forests globally are changing (e.g., Soja *et al.*, 2007; Lewis *et al.*, 2009b; Allen *et al.*, 2010; Wright, 2010), it is difficult to identify the mechanisms underlying such changes given ubiquitous and simultaneous changes in multiple global change drivers (Fig. 3). The information-rich nature of CTFS-ForestGEO sites has yielded insights into the mechanisms of response to global change pressures.

Warming is expected to alter forest dynamics, but predicting effects at the ecosystem scale remains a major scientific challenge (e.g., U.S. DOE, 2012). Monitoring, physiological measurements, and nearby warming experiments combine to yield insights into how warming may impact forest dynamics. The effects of warming are perhaps most dramatic at Scotty Creek, Canada – the highest latitude site, which is experiencing rapid warming (Figs 2 and 3; Tables S3 and S4) – where accelerating permafrost thaw is resulting in tree functional decline near forested plateau edges (i.e., reduced sap flow, radial growth, and leaf area) and driving loss of forest area at a rate of 0.5% yr^{-1} (Baltzer *et al.*, 2014). At another Canadian site (Haliburton Forest), a heat wave event during spring leaf-out in 2010 resulted in a >50% decline in leaf area of the dominant tree species (Filewod & Thomas, 2014), and a large net ecosystem carbon loss in the same year (Geddes *et al.*, 2014). However, at most temperate and tropical sites, the impacts of warming are less obvious and tend to be confounded by other aspects of global change (Fig. 3). Data from four tropical forest sites (BCI, Huai Kha Khaeng, Lambir, and Pasoh) indicate that tree growth rate correlates negatively with nighttime temperature, as expected from increased respiration rates causing a reduced carbon balance (Feeley *et al.*, 2007a; Dong *et al.*, 2012) – a trend that has also been observed at an external site in Costa Rica (Clark *et al.*, 2010). In contrast, warming experiments associated with two of the sites reveal that warming may also directly or indirectly increase woody productivity; specifically, soil warming at Harvard Forest has increased tree growth through increased N mineralization (Melillo *et al.*, 2011), and chamber warming experiments in Panama revealed that increased nighttime temperatures increased seedling growth rates (Cheesman & Winter, 2013). Ongoing monitoring, experimentation, and modeling will be necessary to disentangle the diverse productivity responses of forests to warming. Warming may also shift C allocation to reproduction; flower production at BCI, Panama has increased with increasing temperature (Pau *et al.*, 2013). Future warming (Fig. 2) will inevitably impact forests, and ongoing monitoring at CTFS-ForestGEO sites should help to document and explain these changes.

Changes in aridity and drought severity have the potential to impact forests worldwide, including those in wet climates (Allen *et al.*, 2010; Choat *et al.*, 2012). Across the tropics, increases in aridity or the occurrence of severe droughts have led to forest "browning", mortality episodes, or fires (Van Nieuwstadt & Sheil, 2005; Lewis *et al.*, 2011; Zhou *et al.*, 2014), and there is concern that potential future increases in aridity in some parts of the tropics could result in severe tropical forest dieback (e.g., U.S. DOE, 2012). Research across the CTFS-ForestGEO network has yielded insights into the role of aridity in shaping tropical forest dynamics. Droughts in Panama (BCI, San Lorenzo, and Cocoli) and Malaysia (Lambir) have revealed differential drought sensitivity by size class, microhabitat association, and functional type (Condit *et al.*, 1995, 2004; Potts, 2003). In Panama, mild or even fairly strong drought increased both woody productivity and production of flowers and seeds – presumably because of increased solar radiation (Condit *et al.*, 2004; Wright & Calderon, 2006). At a tropical dry forest in India (Mudumalai), drought increased mortality rate, but with a 2–3 year lag for larger trees (Suresh *et al.*, 2010). These findings yield insight into how moist tropical forests may respond to predicted changes in aridity (Fig. 2; Table S4; IPCC, 2013).

Beyond climate, impacts of other global change drivers have been observed across the CTFS-ForestGEO network. Nitrogen deposition (Fig. 1; Table S5) has altered forest biogeochemistry across the globe. Temperate forests are typically N limited; however, high N deposition at Haliburton Forest, Canada, has caused a shift from N to P limitation (Gradowski & Thomas, 2006, 2008), providing evidence of constraints on increases in temperate forest productivity driven by elevated CO_2 and/or nitrogen deposition. Because tropical forests are typically limited by elements other than N, N deposition is not expected to increase the productivity of these forests (Matson *et al.*, 1999). At the two tropical CTFS-ForestGEO sites where relevant measurements have been made, increased ^{15}N concentrations in plant tissues suggests substantial N deposition and altered N cycles (Hietz *et al.*, 2011). Specifically, on BCI, leaf N and $\delta^{15}N$ in recent (2007) samples were elevated relative to herbarium samples (~1968) (Hietz *et al.*, 2011). These changes have been mechanistically linked to increased N availability through a nearby fertilization experiment, which increased foliar N concentrations and $\delta^{15}N$ by similar amounts but did not affect productivity (Wright *et al.*, 2011; Mayor *et al.*, 2014a,b). A similar increase in $\delta^{15}N$ was observed in wood from Huai Kha Khaeng, Thailand (Hietz *et al.*, 2011). These results imply that, in tropical forests, N deposition is accelerating N cycling without increasing productivity, and reduced cation availability resulting from N deposition may be one potential explanation for observed declines in tree growth rates at some tropical sites (see above; Matson *et al.*, 1999).

Habitat fragmentation (Fig. 5) and faunal degradation have also been linked to altered dynamics at CTFS-ForestGEO sites. The CTFS-ForestGEO site near Manaus, Brazil, is part of the Biological Dynamics of Forest Fragments Project (BDFFP), which has revealed that forest fragmentation rapidly and profoundly alters tree, arthropod, bird, and primate communities, reducing species diversity and shifting composition toward dominance of more disturbance-adapted species (Laurance *et al.*, 2006). Across the network, more highly fragmented sites (e.g., Witham Woods, UK; Bukit Timah, Singapore; Lambir, Malaysia; Heishiding, China; Fig. 3; Table S5) tend to have degraded faunas, as indicated by the absence of apex predators and larger vertebrates that were present historically, whereas faunal communities tend to remain more intact in unfragmented forests such as Yasuni (Ecuador), Rabi (Gabon), and Scotty Creek (Canada) (Turner & T Corlett, 1996; LaFrankie *et al.*, 2005; Laurance *et al.*, 2012; Harrison *et al.*, 2013;W.F. Laurance, personal communication). As detailed below, faunal degradation – whether caused by habitat fragmentation, hunting, or other pressures – has strong impacts on forest structure and dynamics.

The strong influence of fauna on forest composition and dynamics (e.g., Wright, 2010; Estes *et al.*, 2011; Schmitz *et al.*, 2013) has been documented at several CTFS-ForestGEO sites. At Mpala, Kenya, an experiment excluding herbivores of different sizes and replicated across a rainfall gradient revealed that herbivores of different sizes influence the biomass and growth rates of trees and understory plants, plant community composition, and small mammal communities (Goheen *et al.*, 2013). At Mudumalai, elephants (*Elephas maximus*) cause high mortality among the small- to medium-sized stems, particularly in a few favored forage species (Sukumar *et al.*, 2005). At SCBI (Virginia, USA), where white-tailed deer (*Odocoileus virginianus*) populations greatly exceed their historical levels, 20 years of deer exclusion from a 4-ha subsection of the CTFS-ForestGEO plot has resulted in a >4-fold increase in sapling abundance relative to heavily browsed forest outside the exclosure (McGarvey *et al.*, 2013). Large impacts of mammalian herbivores have also been found in an exclosure study adjacent to the Pasoh plot site in Malaysia (Ickes *et al.*, 2001), where native pigs (*Sus scrofa*) have a dramatic effect on tree recruitment. In Panama, comparison of forest plots protected from bushmeat hunting with those exposed to poachers revealed that by reducing the abundance of frugivores and seed dispersers, hunting decreases the abundance of plant species with seeds dispersed by these animals while increasing the abundance of species with seeds dispersed by bats, small birds, or mechanical means (Wright *et al.*, 2007). The latter includes lianas whose seeds are much more likely to be dispersed by wind (60% of liana species vs. 25% of canopy trees and <10% of midstory and understory trees and shrubs). Lianas have thus increased disproportionately in abundance where hunters remove the frugivores that disperse the seeds of most tree species, hence hunting may have unforeseen consequences for carbon sequestration (Jansen *et al.*, 2010). Directional change in tree communities driven by faunal degradation has also been demonstrated. At Lambir, where populations of large mammals and birds have been severely impacted by hunting, tree community dynamics changed profoundly from 1992 to 2008 (Harrison *et al.*, 2013). Specifically, sapling densities increased and regeneration of tree species with animal-dispersed seeds decreased and became more spatially clustered (Harrison *et al.*, 2013). Thus, ongoing faunal degradation due to hunting and habitat fragmentation in many forests globally is expected to alter forest community composition, tree dispersal and regeneration, species diversity, forest structure, and carbon cycling.

CTFS-ForestGEO research has also shed light on community interactions that will act to either magnify or buffer forest responses to global change. Species are linked to one another through complex webs of interaction. For example, mapping of quantitative trophic foodwebs at Wanang (Papua New Guinea) and current efforts to document tritrophic foodwebs of seeds, seed predators and parasitoids at this same location, at Khao Chong (Thailand) and Barro Colorado Island (Panama) demonstrates the complexity of ecological interactions in forest ecosystems (Novotny *et al.*, 2010). Studies of seed dispersal and seedling recruitment demonstrate the critical role of vertebrates and insects in tree reproduction and the composition of future forests (e.g., Wright *et al.*, 2007; Harrison *et al.*, 2013). It is therefore unsurprising that global change impacts on one group cascade through the ecosystem. For example, as described above, dramatic reduction in large mammal and bird populations at Lambir, Malaysia has altered the dynamics of tree dispersal and regeneration (Harrison *et al.*, 2013). Similarly, in the light-limited moist tropical forests of Panama, El Niño events bring relatively cloud free, sunny conditions that enhance fruit production while subsequent La Niña events bring rainy, cloudy conditions, and lower levels of fruit production that can lead to famines, particularly among terrestrial frugivores and granivores (Wright *et al.*, 1999; Wright & Calderon, 2006). Climate change is bringing changes in cloud cover and atmospheric transmissivity to PAR (Table S3) with cascading effects on frugivores, granivores, and the plant species with which they interact.

At the same time, the diversity and complexity of forest communities may serve to provide some resilience to global change. A diversity of tree physiological strategies implies a wide range of responses to global change that helps to provide ecosystem resilience (e.g., Isbell *et al.*, 2011; Mori *et al.*, 2013). For example, Panamanian tree species have displayed a wide range of physiological responses to temperature variation (Cheesman & Winter, 2013; Slot *et al.*, 2014), and trees of different species have generally responded differently to experimental manipulation of CO_2, temperature, or precipitation globally (Anderson-Teixeira *et al.*, 2013). The resilience enabled by species diversity may be exemplified by the stability of biomass, size structure, and functional composition of the BCI forest (Chave *et al.*, 2008; Swenson *et al.*, 2012) despite severe droughts that impacted drought-sensitive species (Condit *et al.*, 1995, 1996). In addition, in the tropics, pervasive negative density dependence – i.e., elevated mortality of a plant species in areas where it is abundant – may buffer change because as a species becomes rare, it will suffer less from negative density dependence (Comita *et al.*, 2010). Thus, accounting for biodiversity in ecosystem models will be important for predicting forest responses to climate change. While such complexity makes it challenging to predict forest responses to global change, it may serve to partially buffer forest response to global change, which might otherwise be more dramatic.

Conclusions

The CTFS-ForestGEO forest dynamics sites are representative of the world's more intact forests, covering a diversity of geographical, climatic, edaphic, topographic, and biotic environments (Figs 1 and 2; Table 2). Yet, even this selection of the world's more intact forests is being impacted by multifaceted global change drivers (Figs 2–5). Because many interacting species and processes are simultaneously being affected by a variety of global change pressures, extracting a mechanistic understanding of observed forest changes is challenging, requiring a holistic understanding of the abiotic setting, site history, demography for all tree life stages, trophic interactions, and ecosystem-level processes. The broad suite of measurements made at CTFS-ForestGEO sites (Tables 1 and 3) makes it possible to understand the complex ways in which global change is impacting forest dynamics.

Ongoing research across the CTFS-ForestGEO network is yielding insights into how and why the forests are changing. As global change pressures inevitably intensify (Fig. 2; IPCC, 2013), ongoing monitoring across the network should prove valuable for documenting and understanding multifaceted forest responses and feedbacks to the climate system. To project into the future, broad suite of variables measured at CTFS-ForestGEO sites (Tables 1 and 3) will be invaluable for parameterizing and evaluating ecosystem and earth system models, particularly those that characterize forest demography and differences among species or functional groups (e.g., Moorcroft *et al.*, 2001; Medvigy *et al.*, 2009). Together, CTFS-ForestGEO's unique standardized core census (Table 1) and supplementary measurements (Table 3), applied across all of the world's major forest biomes (Fig. 1; Table 1), will provide mechanistic insight as forests change in the 21st century.

Acknowledgements

We thank everyone involved in the collection of the vast quantity of data and information in the CTFS-ForestGEO network; to F. Dentener and W. Laurance for providing data; E. Leigh, Y. Lin, J. McGarvey and A. Miller for helpful comments; E. Aikens, L. Gonzalez and M. Azimi for help with analysis and figures. Study on this manuscript was funded in part by a Smithsonian Competitive Grants Program for Science award to KJAT. The CTFS-ForestGEO network has received major support from the Smithsonian Institution – particularly the Smithsonian Tropical Research Institute, the Arnold Arboretum of Harvard University, the National Science Foundation (multiple grants), the Rockefeller Foundation, the John Merck Fund, the John D. and Catherine T. MacArthur Foundation, the Andrew W. Mellon Foundation, the Frank Levinson Family Foundation, the HSBC Climate Partnership, the Bromley Charitable Trust, John Swire & Sons Pty Ltd, Celerity, F.H. Levinson Fund, Small World Institute Fund and Jennifer and Greg Johnson. Site-specific support is listed in Table S8.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Data sources and analysis methods.
Appendix S2. CTFS-ForestGEO measurement protocols.
Table S1. Geographic coordinates, elevation data, and references to site descriptions for all CTFS-ForestGEO sites.
Table S2. Climate data for all CTFS-ForestGEO sites: average for 1980–2012 from CGIAR-CSI climate data.
Table S3. Recent climate change at CTFS-ForestGEO sites (difference between 2008–2012 and 1951–1980 average) calculated from CGIAR-CSI climate data.
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Table S5. Atmospheric deposition; forest degradation, loss, and fragmentation; and local anthropogenic disturbances at CTFS-ForestGEO sites.
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SUPPLEMENTARY INFORMATION

CTFS-ForestGEO: A worldwide network monitoring forests in an era of global change

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CONTENTS

Appendix S1. Data sources and analysis methods

1. Climate and atmospheric deposition data

CGIAR-CSI Climate Data

In order to obtain standardized climate data for all sites, global climate data with 0.5 degree spatial resolution were downloaded from the CGIAR-CSI database (http://www.cgiar-csi.org/data) in January 2014. Specifically, we retrieved monthly data for 1951 – 2012 for ten variables: daily mean temperature (°C), monthly average daily minimum temperature (°C), monthly average daily maximum temperature (°C), diurnal temperature range (°C), frost day frequency (days), precipitation (mm), wet day frequency (days), cloud cover (%), and vapour pressure (hecta-Pascals) from the CRU-TS v3.10.01 Historic Climate Database for GIS (http://www.cgiar-csi.org/data/uea-cru-ts-v3-10-01-historic-climate-database). In addition, potential evapotranspiration (PET; mm day^{-1}) estimates were obtained from the Global Potential Evapo-Transpiration (Global-PET) dataset (http://www.cgiar-csi.org/data/global-aridity-and-pet-database; Zomer, 2007; Zomer *et al.*, 2008). Data for each CTFS-ForestGEO site was extracted and is available online (www.ctfs.si.edu/Data).

Monthly data were used to calculate the annual values. Annual values were averaged over 1980-2012 to obtain climatic averages (Table S2). Recent change (Fig. 4, Table S3) was calculated as the difference between 2008-2012 and 1951-1980 average.

Note: Comparison of available local weather station data (Table 2) to CRU data revealed close correlation for MAT (R^2 >94%). However, CRU data tended to systematically underestimate MAP at sites with high MAP, particularly those receiving >3000 *mm yr*$^{-1}$ (e.g., Korup, Kuala Belalong, Sinharaja, Fushan, La Planada). *Thus, CRU precipitation values for high precipitation sites should be considered probable underestimates.*

WorldClim current and projected climate data

Current and projected future climate data (Fig. 2; Table S4) were downloaded from WorldClim (http://www.worldclim.org; Hijmans *et al.*, 2005) in November 2013 at the highest available spatial resolution (30 arc-seconds for current climate; 30 seconds for future climate). Current climate is based on an interpolation of observed data, representative of 1950-2000 (v. 1.4). Future projections are based on predictions of the *HadGEM2-ES* model as part of the CMIP$_5$ (IPPC Fifth Assessment) for the year 2050 (2041-2060 climatic average) under the lowest and highest emissions scenarios (RCP 2.6 and RCP 8.5, respectively). These data have been downscaled and calibrated using WorldClim's current climate (v. 1.4) as a baseline, which makes it appropriate to compare current and future climate data from these sources (e.g., Fig. 2).

Note: Comparison of available local weather station data (Table 2) to WorldClim data revealed close correlation for MAT (R^2 *>97%). However, WorldClim data tended to systematically underestimate MAP at sites with high MAP, particularly those receiving >3000 mm yr*$^{-1}$ (e.g., Korup, Kuala Belalong, Sinharaja, Fushan, La Planada). *Thus, WorldClim precipitation values for high precipitation sites should be considered probable underestimates.*

Atmospheric deposition

Data on deposition of nitrogen (NO_y and NH_x) and sulfur (SO_x) were obtained from the data set of N Dentener *et al.* (2006) (F. Dentener, personal communication). These data are estimates for the year 2000 and have one-degree resolution.

2. Multivariate spatial clustering analysis

Multivariate Spatio-Temporal Clustering (MSTC) (Hoffman & Hargrove, 1999; Hargrove & Hoffman, 2004; Hoffman *et al.*, 2008; Kumar *et al.*, 2011) and network representativeness analysis (Hargrove *et al.*, 2003; Hoffman *et al.*, 2013) were used to calculate representativeness for the CTFS-ForestGEO network in forested and non-forested areas. These analyses require continuous grids of each variable for the extent of the study area. The data used for both the MSTC and for the subsequent representativeness analysis of the CTFS-ForestGEO network were 17 variables on a 4 km grid comprised of 13,719,022 map cells of global land area (Baker *et al.*, 2010). The 17 variables in the dataset were: (1) precipitation during the hottest quarter (mm); (2) precipitation during the coldest quarter (mm); (3) precipitation during the driest quarter (mm); (4) precipitation during the wettest quarter (mm); (5) ratio of precipitation to potential evapotranspiration (unitless); (6) temperature during the coldest quarter (°C); (7) temperature during the hottest quarter (°C); (8) day/night diurnal temperature difference (°C); (9) sum of monthly T_{avg} where $T_{avg} \geq 5°C$ (°C); (10) integer number of consecutive months where $T_{avg} \geq 5°C$ (unitless); (11) available water holding capacity of soil (unitless); (12) bulk density of soil (g/cm^3); (13) carbon content of soil (g/cm^2); (14) nitrogen content of soil (g/cm^2); (15) compound topographic index (relative wetness; unitless); (16) solar interception (kW/m^2); (17) elevation (m).

Fifty ecoregions were delineated using MSTC (Kumar *et al.*, 2011). The regions produced by this unsupervised classification method were then labeled with ecoregion or land cover type names derived from a suite of expert maps compared with the spatial clusters using the Mapcurves algorithm developed by Hargrove *et al.* (2006). Forested areas were then extracted and combined to derive the global forested area delineated in Figure 1. Representativeness analysis provided a quantitative "dissimilarity score" for each of the CTFS-ForestGEO 59 sites using the Euclidean distance in 17-dimensional data space between each site and every other cell in the map. The 59 individual site maps were then combined to create a single map by selecting the minimum value for each grid cell from the collection of 59 individual dissimilarity scores. The final map is the minimum representativeness surface for the entire network.

For a high resolution version of Figure 1 and additional figures and information from the MSTC analysis, Mapcurves analysis, and representativeness analysis see Maddalena *et al.* (2014).

3. Analysis of forest degradation, loss, and fragmentation

To evaluate forest degradation, loss, and fragmentation surrounding CTFS-ForestGEO plots, we performed a spatial and temporal analysis using global data on deforestation and forest cover and change with 30m resolution (Hansen *et al.* 2013, data downloaded February 2014 from http://earthenginepartners.appspot.com/science-2013-global-forest). Raw raster data was downloaded for: (a) Tree canopy cover, defined as 'canopy closure for all vegetation taller than 5 m in height', in the year 2000 (%); (b) pixels converted from forest to other land uses between 2000 and 2012; and (c) areas of no data, mapped land surface, and permanent water bodies. A separate raster of forest area was calculated from the tree canopy cover raster using a threshold function that defined terrestrial land surface pixels having greater than 10% canopy cover as forest, following the definition used by FAO (2000). To define areas of original forest cover surrounding each site, a global raster map of original pre-human modification forest cover produced by UNEP-WCMC was downloaded April 2014 from http://www.unep-wcmc.org/generalised-original-and-current-forests-1998_718.html. Only four sites had less than 100% original forest coverage within 50km. All spatial statistics were limited to terrestrial land areas of original forest cover.

Spatial analyses were performed in R (R Core Team, 2013) using the raster, geosphere, and rgdal packages using parallel processing via the foreach and dosnow packages. The land surrounding each CTFS-ForestGEO plot was buffered into five distinct spatial zones: (i) within the plot (but not including the entire plot; calculated as a circle originating at the plot center with a radius of half the smaller plot dimension); (ii) from the plot to 1 km distance; (iii) from 1-5 km; (iv) from 5-25 km; and (v) from 25-50 km. Three core metrics were calculated: (a) percentage tree cover in 2012; (b) percentage of tree cover present in 2000 that was lost by 2012, and (c) forest fragmentation, defined as the length of forest edge adjacent to a deforested area (i.e., an area of original forest no longer forest) per unit forest area (units: km km^{-2}).

An index of forest degradation was calculated for the purpose of comparing the severity of forest degradation and loss across sites (e.g., Fig. 3). Specifically, the index is the average of eight numbers: % reduction in tree cover relative to plot (calculated from 'a' above) and % forest loss from 2000-2012 ('b' above), each at the four distance zones outside of the plot (ii-v above). Thus, the index integrates forest loss across a range of distances from the plot, giving more weight (on a per-area basis) to the area immediately surrounding the plot. It combines historical (pre-2000) and recent (2000-2012) forest loss, giving more weight to recent forest loss.

It is important to note that the Hansen *et al.* (2013) dataset does not distinguish between natural forest and agroforestry areas; agroforestry areas with greater than 10% canopy cover and vegetation taller than 5 m in height are included in this definition of "forest". Thus, "forest cover" in the surrounding landscapes is not necessarily primary or natural forest, and "forest loss" may include cutting of agroforestry plantations (i.e., as part of a rotation cycle). For example, at Pasoh (Malaysia), oil palm and rubber plantations are a feature of the landscape around the reserve, and "forest loss" from 2000-2012 adjacent to the reserve is attributable to the oil palm rotation, not to original forest loss. Moreover, the dataset does not distinguish between natural disturbance and deforestation; rather, "forest loss" implies either a stand-clearing disturbance or deforestation.

Selected results are provided in Table S5; full data are available for download at www.ctfs.si.edu/Data. Copies of R scripts used in the above analyses are available for download from the Harvard Dataverse Network at http://thedata.harvard.edu/dvn/dv/eben.

Appendix S2. CTFS-ForestGEO measurement protocols

This section describes the CTFS-ForestGEO core census and other protocols applied at five or more sites across the network (Table 3).

1. Plants

1.1. Core census

Protocols for the tree core census are described in detail by Condit (1998). In brief, every free-standing woody stem>1cm DBH consist is identified to species, mapped, and tagged when it first enters the census within a plot. On each stem, diameter is measured at breast height (1.3 m) or above stem irregularities (Manokaran *et al.*, 1990; Condit, 1998). The census is typically repeated every five years. Database standards and management practices are described in Condit *et al.* (2014). Analysis of CTFS-ForestGEO census data is commonly conducted using the CTFS R package, which includes functions to analyze tree abundance, growth, mortality and recruitment rates, biomass, and demographic changes (downloadable at http://ctfs.arnarb.harvard.edu/Public/CTFSRPackage/).

1.2. Lianas

Lianas (woody vines) are inventoried as part of the core census at some sites. Lianas are mapped, identified to species, and measured at breast height (1.3m) according to the protocols detailed in Gerwing *et al.* (2006) and Schnitzer *et al* (2008).

1.3. Functional Traits

Detailed methods for functional trait measurements are publicly available at www.ctfs.si.edu/group/Plant+Functional+Traits/Protocols. Below is a summary:

1.3.1. Wood density (WD)

Wood density is measured for trees and lianas. Methods for collection may differ across sites, but processing methods are identical, following Cornelissen *et al* (2003). At sites where wood collection is prohibited due to the destructive nature of the method (e.g., BCI), samples are collected opportunistically from outside the permanent plot. Wood samples are collected with an increment borer for trees larger than 10 cm DBH, and a 10-cm long, 1-cm diameter stem segment is taken from lianas and shrubs. In some cases, 1-cm diameter branch samples are used in place of cores. Wood specific gravity is measured using the water displacement method to determine fresh volume. Samples are then dried in a convection oven (at 60°C) to finally calculate oven dried wood specific gravity (i.e., density).

1.3.2. Height (H)

Tree height is measured either (1) on a size-stratified sample of trees (e.g., Bohlman & O'Brien, 2006) or (2) on the largest-diameter individuals in the plot for the purpose of estimating maximum tree height (Wright *et al.*, 2010). Methods for measuring tree height are described online (http://www.ctfs.si.edu/data///documents/Crown_traits_draft.pdf) and in Larjavaara & Muller-Landau (2013); the CTFS-ForestGEO standard is to use what Larjavaara & Muller-Landau refer to as the sine method.

1.3.3. Crown traits (C)

Crown traits measured across the network include crown diameter and crown exposure index. To estimate crown diameter (m), the crown radius is measured from the center to the edge of the crown in eight cardinal directions, then averaged. A qualitative crown exposure index serves as a proxy for light availability is recorded following a procedure adapted from Clark & Clark (1992). Full details are available online at http://www.ctfs.si.edu/data///documents/Crown_traits_draft.pdf.

1.3.4. Leaf traits (L)

Six leaf traits are measured following the procedures of Cornelissen *et al* (2003): lamina size (mm^2); specific leaf area (m^2 kg^{-1}); leaf thickness (μm); N concentration (mg g^{-1}); P concentration (mg g^{-1}); and dry matter content (mg g^{-1}). The most recent tree census is used to randomly select 5-6 of the largest and smallest individuals of each tree species for sampling. Two to five leaves are measured for each individual. Fresh mass is recorded upon leaf removal and dry mass after drying at 60° C for 72 hrs.

1.3.5. Reproductive traits (R)

Four reproductive traits are measured: dispersal mode (categorical), diaspore shape (unitless), diaspore mass (mg), and seed mass (mg). Diaspores are the unit that is dispersed by explosive force, by wind or by animals. Diaspores are dissected to isolate the embryo plus endosperms (i.e., seed). Collection of plant reproductive parts happens opportunistically and varies across sites subject to plant phenology. We attempt to collect five mature fruits from five individuals of each species, although for rare species or for those from which fruits rarely fall we collect single fruits or diaspores. Dispersal mode and shape classification follows Cornelissen *et al* (2003).

1.4. High-precision diameter growth

1.4.1. Infrequent (<1 measurement/month) dendrometer band measurements (P1)

Metal or plastic dendrometer bands are installed on trees to obtain precise estimates of diameter growth. Bands are fixed to a stratified random subset of trees (n= 225 - 3,000; varies by site) and are measured one to four times per year using precision digital calipers. In temperate regions, measurements are made at the beginning and end of the growing season. Crown exposure index, crown condition (completeness), and sometimes liana coverage of the crown are also judged on a 5-point scale at every recensus. Protocols for construction, materials and installation of metal and plastic bands are available at http://www.ctfs.si.edu/group/Carbon/Protocol+Documents.

1.4.2. Frequent dendrometer (≥1 measurement /month) band measurements (P2)

To resolve seasonal growth patterns, dendrometer bands installed on a subset of trees are measured at least once a month (commonly every two weeks) during the growing season. A workflow for optimizing the fit and interpretation of intra-annual growth measurements in a seasonal forest (SERC) is detailed in McMahon & Parker (2014). This paper outlines methods for fitting growth models to intra-annual measurements using R (R Core Team, 2013).

1.5. Flower and seed production

Flower and seed production of trees and lianas is monitored using flower/seed traps (n=60-336; varies by site). Each flower trap has a surface area of 0.5 m^2 and is elevated off the ground to reduce risk of seed predation. Traps are located randomly within plots (to represent different habitat types), or in a stratified random design at 4-13 m intervals on alternating sides of pre-existing trails. Specimens are collected weekly to bimonthly. All plant reproductive parts are identified to species, seed and fruits are counted and flowers recorded on a qualitative logarithmic scale. Details for trap construction and methods are available online (http://www.ctfs.si.edu/floss/page/methods/).

1.6. Seedling performance

To monitor the establishment, growth, and survival of seedlings, three 1-m^2 seedling plots are installed in association with each flower/seed trap (n≤1,008 seedling plots associated with ≤336 seed traps; n varies by site). Woody seedlings are identified, measured (height and number of leaves), and permanently tagged. They are monitored annually (quarterly at some sites) from germination until plants reach 1 cm DBH and enter the core census. Canopy photographs are taken over each seedling plot annually to assess light availability. The proximity of seed traps and seedling plots enables an evaluation of the seed-to-seedling transition through comparisons of seed inputs and seedling recruitment.

1.7. DNA barcoding of plants

DNA sequences are being captured at multiple genetic loci for all tree species in the CTFS-ForestGEO network, with nearly 3,000 plant species sequenced to date (http://www.ctfs.si.edu/group/Science+Initiatives/DNA+Barcoding). Collection of plant samples for DNA barcode data begins with proper taxonomic identification of individual species from which a reference voucher and tissue sample are collected (see Kress *et al.*, 2012 for workflow). Ideally, 4-5 individuals are sampled per species. Field collected samples consist of 0.1-0.5 grams of green leaf tissue that are placed in silica gel desiccant. Only 0.01 gram of tissue is used in DNA extraction for plants where PCR and sequencing follows Fazekas *et al.* (2012; see also http://ccdb.ca/resources.php). Sequence data are cleaned and aligned into a multi-gene sequence matrix using Geneious (version 7.0, Biomatters), and then used in maximum-likelihood based phylogentic reconstruction following Kress *et al.* (2009) to generate phylogenetic trees. Quantitative assessment of phylogenetic diversity metrics are conducted in R using the Picante package (see Swenson, 2012; picante.r-forge.r-project.org/). DNA barcode data are included in the BOLD database (e.g., Wabikon, USA: dx.doi.org/10.5883/DS-WABLK).

2. Animals

2.1. Arthropods

Multi-taxon censuses are being conducted at five tropical sites (Table S6-S7), focusing on a target set of assemblages chosen for their ecological relevance, taxonomic tractability and ease of sampling (Table S7; http://www.ctfs.si.edu/group/arthropod%20monitoring/).

2.1.1. Light traps

We use 10 W black light traps (automatic bucket-type model) fitted with intercept panes and a roof protecting catches from rain (Kitching *et al.*, 2001). Traps are filled with crumpled paper to provide surface to hold moths and other insects so that they do not loose most of their scales. Plastic, open egg trays separate larger insects from more fragile specimens. Insects are collected dry and killed by five strips of DDVP insecticide dispensed in the trap. The attraction range of one trap is < 50m (Baker & Sadovy, 1978).

2.1.2. Winkler

To concentrate and extract litter ants, mini-Winkler eclectors (Besuchet *et al.*, 1987; Agosti, 2000) are used from a 0.25 m^2 sample of leaf litter. The litter is picked up from within a 0.25m^2 frame, concentrated with a litter sifter and stored into a cloth bag. Each replicate (sample) is calibrated with a 400ml cylinder randomly scooped up and hung in a mini-Winkler. The extraction of material lasts for 72 hours. Ants are collected in ethanol and then processed as required.

2.1.3. McPhail traps

McPhail traps (International Atomic Energy Agency, 2003; model from Biobest, www.biobest.be), baited with methyleugenol and cuelure are used to attract tephritid flies. The traps are running for a week and are set up in the vegetation, not in direct sunlight, at 3-4 m height. Attraction range of baits is < 100-200m (Cunningham & Couey, 1986).

2.1.4. Butterfly transects

Walking transects of 500 m, timed to about 30 minutes (similar to Caldas & Robbins, 2003) are established to observe and catch butterflies. The observer restricts his/her attention to a 2 m wide strip across the transect and up to 5m height. For each transect, air temperature, relative humidity (%), and wind speed are also recorded. Cloudiness (%) is estimated visually. A full description of the protocol and how to implement it practically (establishment of local reference collection, etc.) is detailed in (Basset *et al.*, 2013).

2.1.5. Termite transects

Termite sampling transects are destructive (wood fragmentation, soil disturbance, etc.) and therefore are performed outside the permanent plots. Each year, we sample one transect of 400m, including 1 quadrat of $5m^2$ searched for 30 minutes by one person, every 10m (total 40 samples; Roisin *et al.*, 2006). This include 4 different operations: (a) inspection of all trunks and branches for termite galleries up to 2m in height; (b) breaking any dead logs and branches; (c) scooping 6 smaller soil samples of ca. 15x15x10 cm; and (d) stirring and inspecting most of litter within the quadrat.

2.1.6. Bee baits

Cineole baits are used to attract euglossine bees traps (Ackerman *et al.*, 1982; Roubik, 2001), dispensed in McPhail traps (see item 3). The traps are baited with 7ml cineole and 100ml of commercial ethyleneglycol (car coolant) and run for a week.

2.1.7. Interaction studies: seed predation

Non-rotting fruit and seeds from focal plant families are collected from inside and outside the plots. Fruits/seeds are processed as soon as possible after collection and placed in suitable rearing containers covered with black mesh and lined with tissue paper. Fruits of different species, tree individuals, collection sites, stage of maturity, size, and collection date are stored in separate rearing containers. Containers are checked a minimum of two times per week for emerging seed predators and parasitoids. Fruit/seeds are kept in a rearing shed for a period of three months. After this period, fruits/seeds are dissected before being discarded. In cases where developing larvae are encountered during dissection, fruits/seeds are returned to the rearing shed to allow for continued development of immature individuals. The protocol was adapted from (Janzen, 1980).

2.1.8. DNA barcoding of arthropods

Field arthropod samples are collected by placing a leg of each individual into vells of a microplate filled with 95% ethanol. The voucher specimen is dry mounted, pictured and preserved in a local reference collection. Vouchers are later transferred into collections of national importance in the host country. Sample preparation and DNA sequencing for arthropods are detailed in Wilson (2012; see also http://ccdb.ca/resources.php). Sequences and voucher pictures are gradually becoming all public at http://www.boldsystems.org/.

2.2. Vertebrates

The vertebrate program (http://www.ctfs.si.edu/group/vertebrates) is collecting data on vertebrates in selected sites across the ForestGEO network. To date, the focus is on ground-dwelling mammals, which are monitored using standardized camera trapping procedures.

2.2.1. Camera trapping: TEAM Protocol (P1)

Terrestrial mammals are monitored following the terrestrial vertebrate monitoring protocol implemented by the Tropical Ecology Assessment and Monitoring Network (TEAM Network, 2011; see also http://www.teamnetwork.org). This protocol uses digital camera traps (60-90 camera traps points) at a density of 1 camera every 2 km^2 to monitor the status of species and changes in the community. Photographs are processed with an application called DeskTEAM (Fegraus *et al.*, 2011). The data product is used to build annual occupancy and spatial occurrence models through sites. Protocols are available at http://www.teamnetwork.org/protocols/bio/terrestrial-vertebrate.

2.2.2. Camera trapping: CTFS-ForestGEO Protocol (P2)

Terrestrial mammals are monitored using camera traps deployed at points in a 1-km² grid centered on each plot at a density of 1 camera trap / 2 ha (one hundred times more dense than TEAM protocol). The rates at which species pass in front of the cameras and are photographed are used as proxy for their abundance and can be compared between survey years and across plots. Photographs are securely stored and processed with custom-made database and processing tools (Kays *et al.*, 2009). Protocols are at http://www.ctfs.si.edu/group/vertebrates.

3. Ecosystem and Environmental Variables

3.1. Aboveground biomass

3.1.1. Ground based estimates

Biomass is estimated from tree diameter, height, and wood density data (when available) using the best available allometric equations. In the tropics, calculations rely on standard allometric equations (e.g., Chave *et al.*, 2005). In the temperate and boreal regions, species- and even site-specific allometric equations are sometimes available (e.g., Yosemite; Lutz *et al.*, 2012), and generic allometries (e.g., Jenkins *et al.*, 2003) are used when these are not available.

Aboveground biomass (AGB) based on general allometric equations (currently Chave *et al.*, 2005) can be calculated using the CTFS R package available at http://ctfs.arnarb.harvard.edu/Public/CTFSRPackage/index.php/web/tutorials/biomass/index. This code will soon be updated to take advantage of the newest tropical forest allometries (Chave et al. 2014).

3.1.2. Airborne LiDAR estimates

Airborne LiDAR measurements have been made following a variety of protocols (e.g., Lefsky *et al.*, 1999; Parker *et al.*, 2004; Weishampel *et al.*, 2007; Mascaro *et al.*, 2011). There is not a specific CTFS-ForestGEO protocol.

3.2. Dead Wood/ Coarse Woody Debris (CWD)

Two alternative sets of protocols for measuring necromass have each been implemented at multiple CTFS-ForestGEO sites. The CTFS Forest Carbon Research Initiative methods include CWD long transect, and fallen and standing CWD dynamics (P1-P3 below). An alternative method that has been employed at several temperate sites involves comprehensive inventories of all woody debris within the plot perimeter (P4 below). These methods are described below.

3.2.1. CWD long transect (P1)

Dry mass of fallen woody debris per area is quantified using line-intersect surveys following Warren & Olsen (1964). An inventory of fallen coarse pieces (or CWD, >200 mm in diameter) is performed on the entire transect, and fine woody debris (or FWD, 20-200mm in diameter) on 10% of the transect (2 m of every 20 m). The diameter of each piece intersecting a transect is measured to enable estimation of the average volume of woody debris on the plot as a whole and its confidence limits. Where permitted, a sample is also taken from each piece to enable estimation of the dry mass of woody debris per unit area on the plot as a whole, with its confidence limits (Larjavaara & Muller-Landau, 2011). Where sampling on the plot is not allowed, other data on the wood density of woody debris are used instead. Hardness of coarse pieces is in all cases recorded using a penetrometer, and these values can be used as a basis for assigning wood densities (Larjavaara & Muller-Landau, 2010). The protocol is described in detail at http://www.ctfs.si.edu/group/Carbon/Protocol+Document.

3.2.2. Fallen CWD dynamics (P2)

Fallen coarse woody debris (CWD; >200 mm diameter) is quantified using a repeated inventory of line transects. Transects are 20-m long within typically one hundred 40 m x40 m subplots (same subplots used for the standing CWD and the stratified sample of dendrometers). More details can be found in the online protocol document (http://www.ctfs.si.edu/group/Carbon/Protocol+Documents).

3.2.3. Standing CWD dynamics (P3)

Standing dead trees are inventoried within 40 m x 40 m sub-plots. Standing CWD (>200 mm) are censused throughout the whole subplot, while standing FWD (20-199 mm) are censused only in the central area with a radius of 5 m. For each standing dead tree greater than 200 mm in diameter, dbh (or diameter above buttress), height, and hardness (using a penetrometer) are measured. In addition, the proportion of branches remaining is categorized. More details can be found in the online protocol document (http://www.ctfs.si.edu/group/Carbon/Protocol+Documents).

3.2.4. CWD comprehensive (P4)

This alternative method of inventorying woody debris includes all deadwood objects within a plot perimeter (at some sites, only trees >100 mm dbh are measured). All pieces are outlined as vectors on a site local map, which allows posterior calculation of length and orientation plus local coordinates. Objects are sorted by two binary classifications into a “standing/lying” and “whole/broken” class. According to their combination and height attributes six deadwood types are defined: whole dead standing tree, broken dead standing stem (snag), whole dead lying tree, base part of dead lying stem, further parts of dead lying stem, and stump. Volume is calculated using DBH allometric equations (truncated cones for stem parts). A decomposition class (hardwood, touchwood, and disintegrated) is assigned to each piece to track tree individuals until their final decomposition (Král *et al.*, 2014).

3.3. Soil Carbon and Fine Root Biomass

Soil samples are systematically taken from around the center 20 x 20 m quadrat in every hectare at each plot. Soil is sampled to 3 m in the center of the quadrat, with additional samples taken to 1 m (x4) and 10 cm (x9) around the quadrat. Roots are separated by hand into fine roots < 2 mm and coarse roots > 2 mm diameter, dried at 60°C, and weighed. The soils are air-dried, sieved (<2 mm) and a subsample ground for analysis. Soil carbon concentration is determined by combustion and gas chromatography using a Thermo Flash EA 1112 Elemental Analyzer (for details, http://www.ctfs.si.edu/group/Carbon/Protocol+Documents)

3.4. Soil Nutrients

3.4.1. Soil nutrient mapping (P1)

Soils are sampled using a regular grid of points every 50 m within sites. Each alternate grid point is paired with an additional sample point to capture variation in soil properties. 50 g of topsoil (0- to 10-cm depth) is collected at each sample point, and available cations and P are extracted using the Mehlich-3 extractant solution. N mineralization rates are measure on site using 3-inch diameter pipes 15 cm into the ground and incubated for 28 days (in-field incubation). Maps of estimated soil resource availability at the 10 x 10 m scale for each plot are then generated following John *et al.* (2007).

3.4.2. Soil nutrient mapping-Turner protocol (P2)

More recent nutrient mapping has used Bray-1 solution to determine available phosphorus and 0.1 M BaCl2 to determine exchangeable base cations and extractable Al and Mn. The latter is preferred to the Mehlich extraction because it yields measures of effective cation exchange capacity, base saturation, and the potential toxins Al and Mn. It does not, however, provide extractable micronutrient data. Soil pH is determined in deionized water, 0.01 M $CaCl_2$ and 0.1 M $BaCl_2$.

3.4.3. Soil nutrient mapping-Turner protocol (P3)

This method follows same steps as P2 above for cations but includes measurements of N mineralization (NH_4 and NO_3) using in-field resin bags. Briefly, mixed ion exchange resins are sealed in mesh bags and placed in the upper 10 cm of soil at the same sample locations as in P1 above. After three weeks, resin bags are removed, cleaned, and extracted in 0.5 M HCl. In addition to nitrogen, the extracts are also analyzed for P and base cations.

3.5. Litterfall

Litter production of the stand, including trees and lianas of all species combined, is monitored using a set of aboveground and ground litter traps (n=100 pairs). Traps are located systematically or randomly within plots. Each aboveground litter trap has a surface area of 0.5 m^2 and is elevated off the ground to reduce risk of seed predation. Ground traps are next to the aboveground trap and are used to monitor palm fronds and branchfalls of material that is too large to be captured in the aboveground traps. The traps are censused on a weekly to monthly basis. Trap contents are oven-dried at 65 C, then sorted into leaves, reproductive parts (flowers, seeds, fruits), fine woody material, and other. These fractions are weighed for each trap. Details of trap construction and methods are available online at http://www.ctfs.si.edu/group/Carbon/Protocol+Documents.

3.6. Bio-micrometeorology

At or adjacent to 15 sites, ecosystem-atmosphere gas exchange has been measured using the eddy-covariance technique (e.g., Barford *et al.*, 2001; Kume *et al.*, 2011; Thomas *et al.*, 2011; Kosugi *et al.*, 2012; Soderberg *et al.*, 2012; Wharton *et al.*, 2012; Zhang *et al.*, 2012). There is not a specific CTFS-ForestGEO protocol. While integration between flux measurements and core tree census data remains limited, these co-located measurements represent an important opportunity to link the growth and water use of individual trees to whole-ecosystem carbon cycling and evapotranspiration.

3.7. Micrometeorology

Meteorological stations vary by site. At sites with meteorological stations installed as part of the CTFS Carbon Program (BCI, SCBI, Huai Kha Khaeng, Khao Chong, and Pasoh), a standardized meteorological station installed within or adjacent to the plot. The stations include several sensors recorded automatically by a CR1000 datalogger (Campbell Scientific) at a 5-minute interval. These sensors include: 1) an aspirated and shield temperature and a relative humidity sensor plus an additional secondary temperature sensor (MetOne Instruments); 2) a 2-D sonic anemometer WS425 (Vaisala); 3) a tipping rain bucket TB4-L (Campbell Scientific); and 4) a solar radiometer CMSP2 (Kipp & Zonen), plus a secondary radiometer LI-290 (LiCOR biogeoscience).

In addition to meteorological data, some sites monitor soil temperature, moisture, and/or snow presence (e.g., Raleigh *et al.*, 2013).

Table S1. Geographic coordinates, elevation data, and references to site descriptions for all CTFS-ForestGEO sites.

#	Site	Latitude	Longitude	Elevation-min (m)	Elevation-max (m)	Topographic relief (m)	Site Description
1	Korup	5.07389	8.85472	150	240	90	Thomas *et al.*, 2003, 2015; Chuyong *et al.*, 2004
2	Ituri (Edoro and Lenda)[*]	1.4368	28.5826	700	850	150	Makana *et al.*, 2004
3	Rabi	-1.9246	9.88004	28	54	26	
4	Mpala	0.2918	36.8809	1660	1800	140	Georgiadis, 2011
5	Wanang	-5.25	145.267	90	190	100	
6	Kuala Belalong	4.5384	115.154	160	320	160	
7	Dinghushan	23.1695	112.511	230	470	240	Pei *et al.*, 2011
8	Heishiding	23.27	111.53	435	698	263	Yin & He, 2014
9	Hong Kong	22.4263	114.181	145	257	112	
10	Jianfengling	18.7308	108.905	866	1017	151	
11	Nonggang	22.4333	106.95	370	180	190	Wang *et al.*, 2014
12	Xishuangbanna	21.6117	101.574	709	869	160	Cao *et al.*, 2008
13	Mudumalai	11.5989	76.5338	980	1120	140	Sukumar *et al.*, 2004
14	Danum Valley	5.10189	117.688				
15	Lambir	4.1865	114.017	104	244	140	Lee *et al.*, 2003, 2004
16	Pasoh	2.982	102.313	70	90	20	Manokaran *et al.*, 2004
17	Palanan	17.0402	122.388	72	122	50	Co *et al.*, 2004
18	Bukit Timah	1.35	103.78	74	124	50	Lum *et al.*, 2004; LaFrankie *et al.*, 2005
19	Sinharaja	6.4023	80.4023	424	575	151	Gunatilleke *et al.*, 2004
20	Fushan	24.7614	121.555	600	733	133	Su *et al.*, 2007
21	Kenting	21.98	120.7969	250	300	50	Lin *et al.*, 2011; Wu *et al.*, 2011

#	Site	Latitude	Longitude	Elevation-min (m)	Elevation-max (m)	Topographic relief (m)	Site Description
22	Lienhuachih	23.9136	120.879	667	841	174	Lin *et al.*, 2011; Chang *et al.*, 2012
23	Nanjenshan	22.059	120.854	300	340	40	Sun & Hsieh, 2004
24	Zenlun	23.4247	120.5509				
25	Doi Inthanon	18.5833	98.4333	1630	1710	80	Kanzaki *et al.*, 2004
26	Huai Kha Khaeng	15.6324	99.217	549	638	89	Bunyavejchewin *et al.*, 2004, 2009
27	Khao Chong	7.54347	99.798	110	360	250	
28	Mo Singto	14.4333	101.35	725	815	90	Brockelman *et al.*, 2011; Chanthorn *et al.*, 2013
29	Haliburton	45.2901	-78.6377	412.5	454.4	41.9	
30	Scotty Creek	61.3	-121.3	258	274	16	Chasmer *et al.*, 2014
31	Harvard Forest	42.5388	-72.1755	340	368	28	Motzkin *et al.*, 1999
32	Lilly Dickey Woods	39.2359	-86.2181	230	303	73	
33	Santa Cruz	37.0124	-122.075	314	332	18	Gilbert *et al.*, 2010
34	SCBI	38.8935	-78.1454	273	338	65	Bourg *et al.*, 2013
35	SERC	38.8891	-76.5594	6	10	4	McMahon & Parker, 2014
36	Tyson Research Center	38.5178	-90.5575	172	233	61	
37	Wabikon	45.5546	-88.7945				
38	Wind River	45.8197	-121.9558	352.4	384.7	32.3	Lutz *et al.*, 2013
39	Yosemite National Park	37.7662	-119.819	1774.1	1911.3	137.2	Lutz *et al.*, 2012
40	Ilha do Cardoso	-25.0955	-47.9573	3	8	5	de Oliveira *et al.*, 2014
41	Manaus	-2.4417	-59.7858	40	80	40	Gomes *et al.*, 2013
42	Amacayacu	-3.8091	-70.2678				Arias Garcia *et al.*, 2009
43	La Planada	1.1558	-77.9935	1796	1840	44	Vallejo *et al.*, 2004

#	Site	Latitude	Longitude	Elevation-min (m)	Elevation-max (m)	Topographic relief (m)	Site Description
44	Yasuni	-0.6859	-76.397	215	245	30	Valencia *et al.*, 2004
45	Barro Colorado Island	9.1543	-79.8461	120	160	40	Hubbell, 1979; Condit, 1998; Leigh *et al.*, 2004
46	Cocoli	8.9877	-79.6166				Condit *et al.*, 2004
47	San Lorenzo/ Sherman	9.2815	-79.974				Condit *et al.*, 2004
48	Luquillo	18.3262	-65.816	333	428	95	Thompson *et al.*, 2002; Thompson *et al.*, 2004
49	Laupahoehoe	19.9301	-155.287	1150	1170	20	Ostertag *et al.*, 2014
50	Palamanui	19.7394	-155.994	255	275	20	Ostertag *et al.*, 2014
51	Badagongshan	29.46	110.52	1470	1369	101	Wang *et al.*, 2014
52	Baotianman	33.4956	111.9397			241	
53	Changbaishan	42.3833	128.083	792	810	18	Wang *et al.*, 2009
54	Donglingshan	39.9566	115.425	1290	1509	219	Liu *et al.*, 2011
55	Gutianshan	29.25	118.117	446	715	269	Lai *et al.*, 2009; Ma *et al.*, 2009; Lin *et al.*, 2012
56	Tiantongshan	29.8116	121.783	304	602	298	Yang *et al.*, 2011
57	Zofin	48.6638	14.7073	735	825	90	Král *et al.*, 2010; Šamonil *et al.*, 2011
58	Speulderbos	52.253	5.702	49	63	14	Wijdeven, 2003
59	Wytham Woods	51.7743	-1.3379	104	163	59	Butt *et al.*, 2009; Thomas *et al.*, 2011b

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[*] Ituri has four plots at two locations (Edoro and Lenda). Geographic coordinates are the midpoint value.

Table S2. Climate data for all CTFS-ForestGEO sites: average for 1980-2012 from CGIAR-CSI climate data. Additional climate data are available online (www.ctfs.si.edu/Data). *Note:* These values do not correspond exactly to values in Table 2 (most of which come from local weather stations measured over a range of time frames) or Figure 2 (which come from the WorldClim database). For high precipitation-sites within the CTFS-ForestGEO network, values from the CRU-TS v3.10.01 Historic Climate Database tend to underestimate MAP, dramatically so at some sites (e.g., Korup, Kuala Belalong, Sinharaja, Fushan, La Planada; see Appendix S1).

#	Site	Annual temperature (°C)	January temperature (°C)	July temperature (°C)	Frost days (days/yr)	Annual PET (mm/yr)	MAP (mm/yr)	Months with PPT<PET	Precipitation Seasonality (CV; %)	Precipitation days (days/yr)	Cloud Cover (%)
1	Korup	26.4	26.2	25.0	0.0	1050	2440	4.0	77	172	84
2	Ituri (Edoro and Lenda)	24.2	24.1	23.2	0.0	1168	1430	4.2	43	137	69
3	Rabi	26.1	27.3	23.6	0.0	956	1943	4.3	85	139	90
4	Mpala	17.7	16.4	16.9	2.3	1280	773	10.0	71	116	69
5	Wanang	26.5	26.8	25.8	0.0	1183	3366	0.6	44	278	75
6	Kuala Belalong	26.6	26.2	26.6	0.0	1164	3757	0.8	47	276	69
7	Dinghushan	22.0	13.4	28.8	0.5	1065	1870	4.2	86	148	70
8	Heishiding	21.5	12.6	28.4	1.5	1022	1719	4.4	83	155	72
9	Hong Kong	23.0	15.7	28.6	0.0	-	2334	-	99	158	66
10	Jianfengling	24.9	19.7	28.5	0.0	1197	2102	4.9	89	110	69
11	Nonggang	22.5	14.2	28.5	0.2	1066	1345	6.0	86	156	73
12	Xishuangbanna	21.1	16.2	24.0	0.2	1054	1423	5.9	91	203	63
13	Mudumalai	24.3	22.6	23.6	0.0	1498	1079	7.6	89	60	51
14	Danum Valley	25.6	25.3	25.4	0.0	1104	2724	1.2	49	253	70
15	Lambir	26.3	25.7	26.5	0.0	1114	3249	1.0	50	284	71
16	Pasoh	26.3	25.7	26.4	0.0	1120	1896	2.5	47	240	74
17	Palanan	25.1	22.5	26.6	0.0	1238	2724	3.2	73	172	65
18	Bukit Timah	27.5	26.6	27.7	0.0	1172	2301	2.5	52	264	74
19	Sinharaja	26.9	26.2	27.0	0.0	1384	2533	3.3	64	130	65

#	Site	Annual temperature (°C)	January temperature (°C)	July temperature (°C)	Frost days (days/yr)	Annual PET (mm/yr)	MAP (mm/yr)	Months with PPT<PET	Precipitation Seasonality (CV; %)	Precipitation days (days/yr)	Cloud Cover (%)
20	Fushan	21.4	15.3	27.3	0.0	1085	2121	2.8	66	205	73
21	Kenting	23.5	18.4	27.7	0.0	-	2207	-	85	175	68
22	Lienhuachih	16.7	11.8	21.2	3.1	908	1958	3.6	84	187	71
23	Nanjenshan	23.3	18.7	26.8	0.0	1255	2157	5.4	99	144	67
24	Zenlun	17.4	12.8	21.5	1.6	943	2031	3.8	88	179	71
25	Doi Inthanon	23.1	19.4	23.8	0.0	1135	1201	6.3	97	159	55
26	Huai Kha Khaeng	25.1	22.6	25.6	0.0	1202	1448	5.9	92	154	58
27	Khao Chong	27.1	26.3	27.2	0.0	1208	2331	3.4	67	174	72
28	Mo Singto	27.4	25.6	27.8	0.0	1300	1672	5.9	94	141	62
29	Haliburton	4.8	-11.2	18.8	186.2	653	1176	2.7	34	172	63
30	Scotty Creek	-2.7	-23.5	16.8	231.0	511	380	6.0	72	100	61
31	Harvard Forest	8.8	-5.0	21.6	157.0	910	1150	4.4	47	135	66
32	Lilly Dickey Woods	11.9	-1.8	24.4	115.3	981	1130	4.9	52	126	66
33	Santa Cruz	14.6	10.3	18.1	9.6	1084	664	8.2	134	42	48
34	SCBI	12.8	1.0	24.3	110.1	1003	1029	5.9	52	133	66
35	SERC	14.1	1.8	26.1	82.3	1111	1128	5.8	52	119	61
36	Tyson Research Center	13.6	-0.5	26.6	99.6	1138	992	7.3	59	117	61
37	Wabikon	4.2	-11.4	18.4	199.2	684	748	5.4	64	130	68
38	Wind River	8.3	0.6	17.9	141.9	770	1893	4.3	86	129	71
39	Yosemite National Park	10.8	2.6	21.3	154.3	1293	960	7.5	120	44	49
40	Ilha do Cardoso	21.2	24.8	17.3	0.0	-	2265	-	60	227	65
41	Manaus	27.3	26.8	27.0	0.0	1166	2177	3.3	58	249	82
42	Amacayacu	25.8	25.8	25.3	0.0	1010	2623	0.8	41	337	82
43	La Planada	16.1	15.8	16.1	0.0	920	1612	3.5	59	197	81
44	Yasuni	25.9	26.3	24.8	0.0	1380	3270	1.0	42	300	83
45	Barro Colorado Island	26.3	25.7	26.9	0.0	1311	3025	4.0	76	218	58

#	Site	Annual temperature (°C)	January temperature (°C)	July temperature (°C)	Frost days (days/yr)	Annual PET (mm/yr)	MAP (mm/yr)	Months with PPT<PET	Precipitation Seasonality (CV; %)	Precipitation days (days/yr)	Cloud Cover (%)
46	Cocoli	26.6	26.2	27.2	0.0	1385	1709	4.6	75	217	56
47	San Lorenzo/ Sherman	26.3	25.7	26.9	0.0	1311	3025	4.0	76	218	58
48	Luquillo	25.6	23.4	27.0	0.0	1219	2363	2.8	61	201	61
49	Laupahoehoe	18.8	17.1	20.3	0.0	1091	2041	3.3	64	246	69
50	Palamanui	17.6	15.9	19.1	0.0	1052	1587	4.3	56	246	68
51	Badagongshan	14.0	2.8	24.3	55.0	821	1250	3.9	67	177	75
52	Baotianman	14.3	1.6	25.8	82.0	959	781	8.6	88	93	63
53	Changbaishan	1.3	-18.6	17.8	215.9	762	877	7.8	112	109	53
54	Donglingshan	8.1	-8.7	22.7	160.3	1057	461	10.8	117	69	44
55	Gutianshan	15.9	4.0	26.8	48.3	934	1637	3.3	66	153	66
56	Tiantongshan	16.8	5.9	27.9	28.3	906	1430	3.1	63	163	68
57	Zofin	8.5	-1.5	18.3	123.1	704	726	5.3	57	166	66
58	Speulderbos	10.0	2.8	17.6	78.4	619	802	4.7	50	192	77
59	Wytham Woods	10.3	4.5	17.2	64.7	637	681	5.3	52	156	77

Table S3. Recent climate change at CTFS-ForestGEO sites (difference between 2008-2012 and 1951-1980 average) calculated from CGIAR-CSI climate data.

Additional climate data are available online (www.ctfs.si.edu/Data). *Note:* For high precipitation-sites, values from the CRU-TS v3.10.01 Historic Climate Database tend to underestimate MAP, dramatically so at some sites (e.g., Korup, Kuala Belalong, Sinharaja, Fushan, La Planada; see Appendix S1).

#	Site	Δ MAT(°C)	Δ January T (°C)	Δ July T (°C)	Δ Frost days (days/yr)	Δ Annual PET (%)	Δ MAP (%)	Δ Months PPT<PET (months/yr)	Δ Precipitation Seasonality (%)	Δ Precipitation days (days/yr)	Δ Cloud Cover (%)
1	Korup	0.74	0.50	0.66	0.0	1.56	-6.7	0.7	7.2	-2.1	0.4
2	Ituri (Edoro and Lenda)	1.28	1.26	1.29	0.0	3.20	3.5	-0.9	-22.1	4.7	-1.2
3	Rabi	0.31	0.08	0.31	0.0	0.55	3.3	-0.2	-11.5	4.0	0.1
4	Mpala	1.01	1.08	1.03	-2.1	3.75	-5.3	0.9	-27.9	-31.5	-1.3
5	Wanang	0.19	0.20	0.20	0.0	0.63	4.4	-0.8	-15.6	10.9	1.2
6	Kuala Belalong	0.28	0.27	-0.04	0.0	-1.80	21.8	-0.3	5.9	23.2	1.5
7	Dinghushan	0.27	-1.19	0.58	-0.1	8.15	7.6	-0.5	-3.4	3.1	-2.3
8	Heishiding	0.05	-1.39	0.36	0.5	6.93	3.1	-0.7	-9.5	3.0	-2.4
9	Hong Kong	-0.10	-0.73	-0.42	0.0		-5.2		-8.3	-3.0	-1.0
10	Jianfengling	0.27	-0.38	0.22	0.0	4.05	24.5	-1.4	-17.9	0.2	1.7
11	Nonggang	0.13	-1.31	0.25	0.1	5.89	-1.1	-0.2	-12.7	-11.5	-2.7
12	Xishuangbanna	1.23	1.43	1.00	-1.6	7.73	6.5	-0.3	-6.2	-4.9	-6.2
13	Mudumalai	0.90	1.24	0.80	0.0	0.80	-1.0	-0.6	-14.9	6.3	3.8
14	Danum Valley	0.60	0.77	0.36	0.0	-0.87	22.2	-0.5	-1.4	16.3	0.9
15	Lambir	0.08	-0.05	-0.24	0.0	-3.08	18.9	-0.2	18.7	20.4	1.9
16	Pasoh	1.18	0.92	1.30	0.0	2.02	5.3	-1.7	-33.5	13.2	0.5
17	Palanan	0.52	0.34	0.18	0.0	2.06	16.9	-0.6	7.5	-10.9	-0.9
18	Bukit Timah	0.95	0.63	1.20	0.0	2.04	12.0	-0.2	-0.9	8.9	-0.2
19	Sinharaja	0.66	0.58	0.72	0.0	0.22	-10.5	-0.6	-9.0	14.2	1.9

#	Site	Δ MAT(°C)	Δ January T (°C)	Δ July T (°C)	Δ Frost days (days/yr)	Δ Annual PET (%)	Δ MAP (%)	Δ Months PPT<PET (months/yr)	Δ Precipitation Seasonality (%)	Δ Precipitation days (days/yr)	Δ Cloud Cover (%)
20	Fushan	0.58	0.41	0.40	0.0	10.73	12.4	-0.3	-20.0	7.4	3.6
21	Kenting	0.46	0.26	0.25	0.0		-2.7		-25.4	-0.7	3.5
22	Lienhuachih	0.65	0.46	0.53	-2.7	12.17	7.2	-1.3	-19.0	5.7	5.6
23	Nanjenshan	0.53	0.35	0.34	0.0	6.14	-0.3	-1.0	-8.0	0.8	4.2
24	Zenlun	0.63	0.41	0.50	-1.6	11.26	5.7	-1.1	-11.8	4.4	5.1
25	Doi Inthanon	0.85	1.99	0.37	-0.3	2.74	-6.3	0.2	-1.2	-0.5	-2.6
26	Huai Kha Khaeng	0.22	0.56	-0.14	0.0	-2.48	17.7	-0.3	-1.1	5.7	3.2
27	Khao Chong	0.69	0.90	0.60	0.0	-0.79	13.0	-0.5	-12.5	0.7	4.8
28	Mo Singto	0.52	0.87	0.19	0.0	-2.05	22.2	-1.3	-4.2	1.6	5.4
29	Haliburton	1.22	1.31	0.90	-11.3	1.02	7.4	-0.7	-22.7	7.9	3.3
30	Scotty Creek	0.99	2.83	1.04	-7.3	6.12	9.2	0.3	-25.2	-25.5	0.4
31	Harvard Forest	1.23	0.76	1.05	-14.5	7.33	19.9	-0.2	8.4	6.8	4.4
32	Lilly Dickey Woods	1.25	0.27	1.55	-21.1	9.29	15.4	-0.7	14.3	5.7	6.6
33	Santa Cruz	0.58	1.15	0.20	-8.7	-2.16	-0.7	-0.1	5.0	1.0	8.7
34	SCBI	0.28	-0.06	0.52	-8.0	1.67	2.7	-0.9	-22.4	8.5	5.5
35	SERC	0.90	0.35	1.29	-11.4	10.14	6.8	-0.1	-3.5	8.0	4.8
36	Tyson Research Center	1.29	1.42	1.39	-14.5	8.07	26.3	-0.8	4.4	18.0	5.4
37	Wabikon	0.55	0.17	0.70	-6.4	-5.30	-0.9	0.4	5.4	-5.8	6.6
38	Wind River	-0.06	1.20	0.17	-5.5	-3.69	1.8	-1.1	-15.0	8.2	3.5
39	Yosemite National Park	1.58	1.97	2.05	-39.0	0.75	-18.7	0.1	10.6	-0.5	18.7
40	Ilha do Cardoso	1.09	0.65	1.16	0.0		29.5		-4.7	15.5	-0.5
41	Manaus	0.77	0.32	0.84	0.0	2.46	9.5	-0.2	5.2	-10.7	-0.4
42	Amacayacu	0.25	-0.05	0.44	0.0	-1.57	-7.8	0.4	14.2	-8.1	0.3
43	La Planada	-0.01	-0.27	0.22	0.0	-12.70	2.4	-0.3	10.2	3.0	5.8
44	Yasuni	-0.02	-0.30	0.35	0.0	-7.30	8.4	0.2	25.8	5.2	4.8

#	Site	Δ MAT(°C)	Δ January T (°C)	Δ July T (°C)	Δ Frost days (days/yr)	Δ Annual PET (%)	Δ MAP (%)	Δ Months PPT<PET (months/yr)	Δ Precipitation Seasonality (%)	Δ Precipitation days (days/yr)	Δ Cloud Cover (%)
45	Barro Colorado Island	0.36	0.46	0.44	0.0	-3.31	17.9	0.1	9.2	13.3	2.7
46	Cocoli	0.33	0.41	0.41	0.0	-3.01	11.2	-0.5	3.9	11.2	1.8
47	San Lorenzo/ Sherman	0.36	0.46	0.44	0.0	-3.31	17.9	0.1	9.2	13.3	2.7
48	Luquillo	0.34	0.08	0.60	0.0	-0.16	29.0	-0.6	2.9	11.4	1.2
49	Laupahoehoe	-0.04	0.03	0.01	0.0	-7.27	-20.7	1.3	18.2	4.7	2.6
50	Palamanui	0.07	0.13	0.11	0.0	-7.21	-28.4	2.8	-4.2	-3.4	3.0
51	Badagongshan	0.29	-0.79	0.13	-5.6	0.67	-5.6	1.2	-6.8	-3.1	6.8
52	Baotianman	0.90	0.10	0.55	-15.0	4.55	-1.7	0.4	-3.9	-1.6	5.8
53	Changbaishan	0.71	0.87	0.02	-9.7	4.67	0.2	-0.3	2.7	-9.9	-6.0
54	Donglingshan	1.51	0.80	1.73	-16.8	11.70	2.8	0.3	-10.7	0.5	-2.1
55	Gutianshan	0.25	-0.87	0.17	0.1	10.96	3.0	0.2	-15.7	2.0	-0.8
56	Tiantongshan	0.29	-0.58	0.35	-2.5	3.91	10.6	-0.4	-2.7	6.0	1.7
57	Zofin	1.32	1.82	1.26	-17.4	9.01	4.8	0.0	-4.1	1.2	-5.6
58	Speulderbos	0.99	0.95	1.30	-14.7	16.24	6.7	0.3	6.1	3.3	-4.0
59	Wytham Woods	0.75	0.65	0.61	-15.1	6.51	3.3	1.1	-12.1	-17.2	2.8

Table S4. Climate Change Projections for CTFS-ForestGEO sites.
Recent climate ('R'; 1950-2000 average; source: WorldClim) and future- HADGEM2-ES model Climate Change Projections for 2050 (2041-2060 average) under two emissions scenarios: RCP 2.6 (IPCC's most optimistic scenario, with emissions going to zero by 2070) and RCP 8.5 (IPCC's most pessimistic emissions scenario). Full data on climate change projections are available online (www.ctfs.si.edu/Data). *Note:* These values do not correspond exactly to values in Table 2 (most of which come from local weather stations measured over a range of time frames). For high precipitation-sites within the CTFS-ForestGEO network, values from the WorldClim Database tend to underestimate MAP, dramatically so at some sites (e.g., Korup, Kuala Belalong, Sinharaja, Fushan, La Planada; see Appendix S1).

		Mean Annual Temperature (°C)			**Max T of warmest month (°C)**			**Min T of coldest month (°C)**			**Mean Annual Precipitation (mm yr^{-1})**			**Precipitation of wettest month (mm mo^{-1})**			**Precipitation of driest month (mm mo^{-1})**		
#	**Site**	**R**	**RCP 2.6**	**RCP 8.5**	**R**	**RCP 2.6**	**RCP 8.5**	**R**	**RCP 2.6**	**RCP 8.5**	**R**	**RCP 2.6**	**RCP 8.5**	**R**	**RCP 2.6**	**RCP 8.5**	**R**	**RCP 2.6**	**RCP 8.5**
1	Korup	26.6	28.3	29.3	32.5	34.1	35	22	23.9	24.9	2680	2763	2762	411	426	408	29	32	31
2	Ituri (Edoro and Lenda)	24.3	26.3	27.5	31.3	33.1	34.6	17.9	20	21.2	1750	1775	1818	198	198	200	67	84	77
3	Rabi	25.6	27.3	28.2	32.3	33.9	34.9	18.5	20.6	22	1970	2026	2002	371	398	423	2	2	3
4	Mpala	17.9	20	21.1	28	29.7	30.8	8.1	10.7	12.1	709	648	662	133	125	142	21	17	17
5	Wanang	26.2	27.8	28.6	30.9	32.5	33.4	21.4	23	24	3764	4006	4074	430	516	539	180	143	134
6	Kuala Belalong	26.5	27.9	28.8	30.4	31.9	33	23	24.5	25.3	3767	3890	4061	370	391	441	247	252	248
7	Dinghushan	19.7	21.8	22.7	30.1	31.8	32.8	7.1	9.8	10.8	1735	1829	1847	283	318	339	33	31	30
8	Heishiding	22	24.2	25.1	33.5	35.3	36.2	8.9	11.5	12.4	1440	1507	1506	245	254	263	33	34	33
9	Hong Kong	21.9	24	24.8	30.5	32.1	33	11.3	13.9	14.6	2286	2312	2280	415	451	452	28	26	25
10	Jianfengling	20.4	22.1	22.8	27.4	28.9	30	10.9	13	13.6	1657	1569	1355	318	310	349	17	18	17
11	Nonggang	22.5	24.8	25.8	32.6	34.8	36.3	10.2	12.6	13.5	1376	1356	1343	240	228	246	24	29	24
12	Xishuangbanna	21.3	23.1	24.4	30.4	32.9	34.5	9	10.6	12.2	1611	1641	1579	290	289	288	21	25	22
13	Mudumalai	22.3	24	25	30.1	31.9	32.8	14.9	16.4	17.6	1480	1658	1582	409	410	392	2	1	1
14	Danum Valley	25.9	27.3	28.2	30.5	32.1	33.1	21.8	23.3	24.2	2466	2412	2525	275	261	294	147	130	111
15	Lambir	26.5	27.8	28.6	30.8	32.1	33	22.5	24	24.7	2929	3076	3234	347	350	395	170	170	173
16	Pasoh	26.4	28	28.9	32.1	33.9	34.9	21	22.6	23.5	1975	1861	1975	254	209	239	103	112	101
17	Palanan	26.5	27.9	28.6	33.4	35.1	36	19.5	20.7	21.3	2644	2724	2707	558	573	594	79	70	65
18	Bukit Timah	26.9	28.1	28.9	31.5	32.9	33.6	22.1	23.4	24	2371	2374	2367	301	284	287	153	162	158

19	Sinharaja	23.6	25	25.8	29.1	30.8	31.7	18.7	19.8	20.6	3442	3716	3556	434	607	529	162	115	119
20	Fushan	19.3	21.1	21.7	28.1	29.8	30.3	10.1	12	12.8	3189	3018	3139	461	482	513	125	107	106
21	Kenting	24.4	25.8	26.3	30.6	32	32.6	16.6	18.2	18.6	2470	2401	2468	565	568	551	30	25	25
22	Lienhuachih	19.3	21.1	21.7	27	28.7	29.2	10.3	12.1	12.9	2345	2313	2437	488	602	551	25	19	18
23	Nanjenshan	22.9	24.3	24.8	29.1	30.5	31.1	15.1	16.6	17.1	3034	2901	2986	703	662	696	54	45	45
24	Zenlun	22.7	24.3	24.9	30.9	32.5	33	12.9	14.7	15.4	2620	2591	2780	613	600	655	16	12	12
25	Doi Inthanon	19.7	21.7	22.9	30.6	32.5	33.4	7.1	9.5	11	1057	1080	992	195	220	202	10	11	12
26	Huai Kha Khaeng	24.8	26.7	27.8	34.3	35.9	36.9	14.3	16.6	17.9	1347	1327	1224	257	254	257	3	4	4
27	Khao Chong	26.9	28.2	29.1	34	35.8	36.8	21	22.4	23.2	2114	2243	2211	324	342	372	38	43	33
28	Mo Singto	23.5	25.6	26.8	31.6	33.8	35.1	13.2	15.9	17.2	1098	1083	975	236	226	229	6	6	8
29	Haliburton	4.2	7.3	8.6	24.5	27.3	29.6	-16.9	-13.1	-12.3	962	1064	1048	94	110	115	62	69	67
30	Scotty Creek	-3.5	0.1	2.2	23	25.4	26.8	-30.5	-26.3	-22.7	372	411	418	59	64	60	18	20	20
31	Harvard Forest	6.7	9.6	10.7	26	28.7	30.4	-12.8	-8.8	-8.4	1151	1267	1288	106	122	126	82	90	82
32	Lilly Dickey Woods	11.4	14.1	15.5	29.7	33.4	36.9	-7.1	-4.7	-3.3	1088	1158	1087	120	133	120	69	61	61
33	Santa Cruz	13.2	15.1	16	24.7	26.6	27.7	3.4	5.3	5.9	899	1006	1007	193	230	239	2	2	2
34	SCBI	11.2	13.8	15	29.2	32	34.9	-7.1	-4.6	-3.7	1011	1055	1033	102	108	101	64	64	60
35	SERC	13.2	15.8	16.9	30.4	33	35.5	-3.8	-1.2	-0.4	1068	1135	1093	112	117	114	71	71	74
36	Tyson Research Center	12.4	15.1	16.4	31.5	35.3	37.7	-7.7	-5.3	-3.8	999	1048	1014	107	122	120	51	61	64
37	Wabikon	4.2	7.3	8.6	25.4	28.5	29.9	-17.9	-13.9	-12	803	799	826	106	99	101	24	28	27
38	Wind River	9.4	11.9	13	25.3	28.6	30.5	-1.6	0.3	1.2	2565	2602	2447	458	487	490	22	22	22
39	Yosemite National Park	7.4	9.7	10.8	25.1	27.6	28.9	-5.1	-3.4	-2.5	1034	1081	1076	184	210	214	7	7	7
40	Ilha do Cardoso	22.5	23.7	24.4	30.9	32.3	33	13.8	14.8	15.6	2479	2549	2605	377	332	359	85	90	96
41	Manaus	26.7	28.8	30.2	32.3	34.4	36.1	22	23.7	24.9	2404	2213	2122	314	320	313	110	100	102
42	Amacayacu	25.9	27.7	28.9	31.2	33.2	34.5	20.2	22.2	23.3	2790	2635	2758	317	321	332	150	140	148
43	La Planada	17.8	19.4	20.4	23.7	25.4	26.5	12.3	13.9	14.9	1716	1872	1765	214	270	252	40	42	42
44	Yasuni	25.1	26.8	27.9	30.9	32.6	33.6	19.7	21.4	22.4	3115	3208	3236	329	351	364	197	210	208
45	Barro Colorado Island	25.9	27.5	28.3	30.8	32.2	33.1	21.6	23.4	24.2	2635	2999	3006	386	446	463	26	35	32
46	Cocoli	26.6	28.2	29.1	32.2	33.5	34.5	21.9	23.7	24.5	2018	2211	2242	317	306	328	11	15	14
47	San Lorenzo/ Sherman	26.2	27.8	28.6	30.4	31.9	32.7	22.3	23.8	24.6	3188	3723	3702	501	575	591	48	61	49
48	Luquillo	22.6	24.1	24.7	28.6	30	30.7	16	17.6	18.3	3015	3019	2686	336	434	384	129	145	132

49	Laupahoehoe	16.2	18	18.7	22.7	24.8	25.5	10.1	11.8	12.5	1937	1890	1921	255	334	334	43	42	48
50	Palamanui	22.2	24.1	24.8	28	30.2	31	16.3	18	18.7	1177	1246	1303	124	176	172	71	57	40
51	Badagongshan	15.9	18.1	19.1	31.2	33.4	34.9	0.8	3.3	4.3	1410	1678	1566	229	291	252	33	36	36
52	Baotianman	8.1	10.3	11.4	23.9	25.9	27.2	-9.4	-7.1	-6.3	950	1067	1013	192	219	224	15	18	18
53	Changbaishan	2.3	4.7	5.8	24.5	26.5	27.3	-24.3	-20.7	-19.4	693	769	788	163	194	193	7	9	11
54	Donglingshan	4.7	6.9	8.1	24.6	26.3	27.3	-18.3	-15.2	-13.7	519	616	614	148	191	182	4	4	4
55	Gutianshan	15.4	17.9	18.8	30.6	33.6	34.6	-0.3	2.3	3.3	1860	1917	1934	317	343	332	51	51	53
56	Tiantongshan	14.4	16.8	17.6	28.5	31.2	31.8	0.1	2.6	3.5	1480	1476	1514	204	222	223	52	48	49
57	Zofin	5.7	8.7	9.9	20.7	25.4	28.2	-7.2	-3.9	-2.6	949	931	912	122	118	104	55	55	63
58	Speulderbos	9	11.3	12.2	21	24.5	26	-1	0.7	2	803	794	764	78	84	88	49	51	42
59	Wytham Woods	9.3	11.5	12.4	20.7	24.7	26.6	0	1.3	2.3	657	656	626	65	68	73	39	43	30

Table S5. Atmospheric deposition; forest degradation, loss, and fragmentation; and local anthropogenic disturbances at CTFS-ForestGEO sites.
Atmospheric deposition data in year 2000 estimated from Dentener *et al.* (2006). Statistics on tree cover, recent forest loss, forest fragmentation, and forest degradation calculated from the data of Hansen *et al.* (2013) as described in Appendix S1. Note that in this analysis, "forest" can include agroforestry areas. Local anthropogenic disturbances refer to perturbations within the plots. Complete data are available online (www.ctfs.si.edu/Data).

#	Site	*NOy deposition* (g N m^{-2} yr^{-1})	*NHx deposition* (g N m^{-2} yr^{-1})	*SOx deposition* (g S m^{-2} yr^{-1})	*Tree cover in originally forested land area relative to tree cover in plot (%)*				*Percent of 2000 forest area lost by 2012*				*Forest fragmentation index (edge km / area km2) in 2012*				*Degradation Index*	*Anthropogenic Disturbance-Past*[†]	*Anthropogenic Disturbance-Ongoing*[*]
					<1 km	1-5 km	5-25 km	25-50 km	<1 km	1-5 km	5-25 km	25-50 km	<1 km	1-5 km	5-25 km	25-50 km			
1	Korup	0.45	0.54	0.17	99	101	99	90	0.1	0.1	0.7	1.1	0.2	0.2	0.5	0.8	2	f, e, h	-
2	Ituri (Edoro and Lenda)[‡]	0.46	0.48	0.14	100	100	99	99	0.0	0.0	1.1	0.9	0.0	0.0	0.4	0.4	1	-	h
3	Rabi	0.31	0.20	0.11	99	95	99	98	0.2	0.9	0.7	0.7	0.3	1.2	0.5	0.5	1	W	w
4	Mpala[§]	0.16	0.39	0.08	>100	>100	>100	>100	0.0	0.0	0.0	0.4	-	-	-	-	0	P, A, W,E,H	P, A, I
5	Wanang	0.06	0.11	0.79	129	136	142	141	6.5	3.2	2.9	2.8	5.8	3.5	2.5	2.6	2	H	H
6	Kuala Belalong	0.18	0.19	0.18	100	99	91	83	0.0	0.9	3.6	6.0	0.0	0.6	3.2	4.2	5	h	-
7	Dinghushan	0.67	2.16	1.85	92	76	46	39	0.0	8.3	8.8	13.0	3.0	6.6	13.5	20.3	22		
8	Heishiding	0.63	2.25	1.60	35	17	63	73	14.2	30.0	16.9	14.8	33.4	47.1	19.9	16.2	36		
9	Hong Kong	0.65	1.18	1.79	93	51	40	22	0.3	0.4	1.1	8.1	1.0	8.1	11.9	17.6	25	F, W, B, H, E	e
10	Jianfengling	0.35	0.79	0.71	102	93	51	39	0.1	0.5	6.0	8.8	0.1	2.2	7.7	12.8	16		
11	Nonggang	0.45	2.00	0.81	99	110	62	59	0.3	1.2	1.9	5.2	4.6	3.8	12.5	13.1	11	-	-
12	Xishuangbanna	0.39	1.26	0.43	79	74	76	75	1.1	5.4	4.2	6.1	5.3	6.5	5.5	5.9	14	H	
13	Mudumalai	0.38	0.95	0.79	106	95	66	54	0.0	0.0	0.7	0.8	0.2	2.0	7.1	9.0	11	W, H	h
14	Danum Valley	0.14	0.13	0.17	102	103	90	79	0.2	0.5	6.8	13.9	0.3	0.6	4.4	6.8	7		
15	Lambir	0.18	0.16	0.18	97	82	45	57	1.2	7.1	44.0	31.7	0.7	5.2	14.1	9.6	25	H, e	H
16	Pasoh	0.32	0.41	0.41	99	53	52	61	0.1	44.0	32.9	24.1	0.1	5.2	12.8	10.0	30		h, e
17	Palanan	0.15	0.30	0.35	99	67	94	71	0.8	2.6	1.2	3.8	0.8	6.9	2.0	6.2	10	H, w, e	-

18	Bukit Timah	0.32	0.25	0.49	70	37	22	50	0.3	2.3	17.2	28.0	7.3	17.4	24.3	13.9	34	F, CC	
19	Sinharaja	0.20	0.47	0.36	98	93	82	68	0.1	0.5	1.2	1.9	0.1	1.1	4.1	8.4	8		e
20	Fushan	0.52	0.54	1.47	102	101	81	69	0.0	0.0	0.3	0.7	0.0	0.1	3.0	5.0	6		h
21	Kenting	0.35	0.34	0.81	84	68	79	90	1.7	1.7	2.0	3.1	4.2	8.0	5.4	4.2	11	F, e	e
22	Lienhuachih	0.49	0.92	1.21	94	84	71	61	0.8	1.4	1.1	0.6	2.5	4.7	5.9	4.9	12	H, F	h
23	Nanjenshan	0.44	0.63	1.07	97	80	70	75	1.3	1.6	2.3	3.4	1.1	5.0	4.9	5.0	11	-	-
24	Zenlun	0.49	0.92	1.21	114	95	82	88	8.0	4.5	1.3	1.6	11.4	10.0	5.5	5.8	6	W	W
25	Doi Inthanon	0.46	0.92	0.36	97	85	61	51	0.0	0.6	3.9	3.3	0.4	6.0	5.8	7.8	14	-	-
26	Huai Kha Khaeng	0.45	0.65	0.43	96	98	83	64	0.1	0.0	0.3	0.5	0.1	0.0	1.0	2.5	7	-	h
27	Khao Chong	0.23	0.28	0.27	98	92	57	47	0.0	2.1	12.0	14.2	0.3	2.4	12.8	15.5	17		
28	Mo Singto	0.49	0.63	0.54	102	97	68	24	0.1	0.1	0.8	1.5	0.1	1.0	5.5	16.7	14		
29	Haliburton Forest	0.51	0.31	0.87	100	98	97	95	0.1	0.6	0.4	0.6	0.4	1.1	1.4	1.9	1		
30	Scotty Creek Forest Dynamics Plot**	0.03	0.02	0.74	138	139	184	177	0.0	0.0	0.1	0.3	-	-	-	-	0		
31	Harvard Forest	0.94	0.27	1.16	98	92	88	78	3.7	1.7	2.0	2.2	1.1	3.3	4.2	6.3	7	P, W,I	I
32	Lilly Dickey Woods	0.99	0.59	1.73	99	82	67	29	0.1	0.2	0.4	0.5	0.4	4.4	6.1	13.3	15	W, b, h	b, h, i
33	Santa Cruz	0.27	0.13	0.15	84	71	77	31	0.9	1.1	3.0	1.6	5.0	6.5	4.0	13.6	18	w	I
34	SCBI	0.99	0.38	1.60	87	69	57	51	0.0	1.9	1.3	2.0	2.1	7.3	8.3	9.9	18	P, I	I
35	SERC	1.07	0.32	1.51	78	53	49	37	4.3	1.3	2.3	3.7	7.0	13.9	13.5	16.4	24		
36	Tyson Research Center	0.84	0.65	1.36	87	69	43	33	0.0	2.1	1.8	1.6	2.4	6.8	13.5	14.8	22	H, W, p, i	i, h
37	Wabikon Lake Forest	0.40	0.34	0.59	95	93	83	81	1.5	0.8	2.8	3.4	0.6	1.8	4.3	3.9	7	W, h	h
38	Wind River	0.18	0.19	0.21	81	93	89	71	0.0	1.3	2.1	8.8	2.9	1.6	1.9	5.7	10	I	I
39	Yosemite National Park	0.26	0.10	0.14	92	85	56	32	4.0	7.6	6.0	5.8	2.7	5.0	6.9	12.0	20	I	I
40	Ilha do Cardoso	0.29	0.44	0.26	100	95	92	88	0.4	0.0	0.3	1.4	0.4	1.6	2.2	3.2	3		
41	Manaus	0.24	0.22	0.11	100	100	98	96	0.0	0.1	0.9	2.1	0.0	0.0	0.6	1.4	1		
42	Amacayacu	0.20	0.10	0.09	100	95	95	96	0.0	1.4	1.7	2.1	0.0	1.8	1.3	1.0	2		
43	La Planada	0.20	0.35	0.49	99	93	88	74	0.0	1.1	1.3	2.3	0.0	1.6	2.2	5.3	7	P	E
44	Yasuni	0.19	0.28	0.30	99	98	99	97	0.0	0.2	0.1	1.8	0.1	0.7	0.2	0.8	1	cc	e, h
45	Barro Colorado Island	0.20	0.20	0.23	101	100	69	63	0.1	0.1	4.3	6.7	0.1	0.4	8.4	11.4	10	w, f	-
46	Cocoli	0.21	0.22	0.25	87	72	55	60	4.9	4.4	3.9	4.4	3.8	7.1	10.2	9.8	18		

47	San Lorenzo/ Sherman	0.20	0.20	0.23	101	99	79	65	0.3	0.7	4.8	7.5	0.4	1.2	7.2	11.3	9		
48	Luquillo	0.09	0.07	0.13	99	83	49	54	0.3	1.4	2.8	2.3	0.5	5.7	15.3	12.6	15	CC, F	
49	Laupahoehoe	0.04	0.04	0.12	100	95	42	33	0.0	0.1	0.5	0.9	0.0	0.7	6.7	8.4	16	I, A	I, H
50	Palamanui	0.04	0.04	0.12	105	68	68	64	6.9	2.2	0.9	0.5	20.0	16.2	15.6	13.3	14	I, A	I
51	Badagongshan	0.73	3.05	2.34	104	103	103	95	0.3	0.1	0.4	0.8	9.4	9.8	9.2	11.3	1	e	
52	Baotianman	0.83	1.84	2.83	94	91	74	46	0.6	0.3	0.6	0.9	1.1	1.4	5.5	8.9	12		
53	Changbaishan	0.38	0.74	0.84	101	95	95	87	0.0	0.6	0.9	1.0	0.2	2.2	3.0	4.7	3	w	-
54	Donglingshan	0.64	0.81	2.18	78	35	28	18	0.0	0.2	0.2	0.5	6.3	19.9	22.5	26.5	30	CC	
55	Gutianshan	0.94	2.02	2.93	95	87	74	71	0.1	0.2	4.1	3.2	0.3	2.4	6.3	5.8	10	w, b, H	-
56	Tiantongshan	0.81	1.13	3.14	104	86	30	37	0.0	0.4	0.7	0.9	1.7	4.9	12.0	13.0	19		
57	Zofin	0.76	1.09	1.08	90	80	50	45	8.8	11.3	4.6	5.0	7.1	9.5	13.2	13.7	21	w, h	-
58	Speulderbos	0.82	1.48	1.00	80	61	38	20	1.2	3.0	5.1	2.8	4.9	9.3	17.1	29.0	27		
59	Wytham Woods	0.73	0.97	0.96	60	7	5	8	0.0	0.7	2.0	1.7	7.2	48.3	47.1	40.2	40	P, W, h, I	I

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† Codes are as follows: F-farming; P-pasture; W-wood harvesting; CC-clear cut/ complete clearing; B-burn; H-hunting; E-extraction of NTFP (non-timber forest products); I-invasive species; '-' no significant disturbances. Capital letters denote strong pressure; lowercase denote mild pressure.

‡ Forest cover/ loss/ fragmentation/ degradation are average values for four plots.

§ Tree cover at this savanna site falls below the 10% tree cover threshold used to classify forest. Therefore, calculations were not limited to areas originally classified as forest. Forest fragmentation index was unreliable due to low-density tree cover and therefore is not reported.

** Forest fragmentation index was unreliable due to low-density tree cover and therefore is not reported.

Table S6. Record of supplementary measurements made at CTFS-ForestGEO sites.
Coded as follows: P(#): measured using standardized CTFS-ForestGEO protocol outlined in Appendix S2 (numbers differentiate multiple protocols in the same category); 'N'- Will be measured by NEON (see NEON, 2011); '+' measured (any protocol); '-' not measured or no information; * in progress; (f)-planned for near future, with funding. Other codes explained in footnotes.

#	Site	N tree censuses[‡‡]	Lianas	Functional Traits[§§]	Dendrometer Bands	Flower & Seed Production	Seedling Performance	DNA barcoding[***]	Arthropods[†††]	Vertebrates	Airborne LiDAR	Dead Wood/ CWD	Fine Roots	Soil C	Soil Nutrients	Litterfall	Eddy Covariance[‡‡‡]	Weather station[§§§]
1	Korup	3	P	L; SM; H; WD	-	-	-	P(p)*	-	P1	-	-	-	P	P1	-	-	A
2	Ituri (Edoro and Lenda)	3	P	+	-	-	-	-	-	+	-	-	-	-	+	-	-	
3	Rabi	1	-	-	-	-	-	P(p)*	-	-	-	-	-	-	-	-	-	A
4	Mpala	1*	-	+	-	-	-	P(p)*	-	+	-	-	-	-	+; P2(f)	-	+	A
5	Wanang	1	-	+	-	-	-	P(a)	P	-	-	-	-	-	P3	-	-	
6	Kuala Belalong	1*	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	
7	Dinghushan	2	-	L; SM; H; WD	P1	P	P	P(p)	-	P2	-	-	-	-	+	P	-	+
8	Heishiding	1	P	L; SM; H; WD	-	+	+	-	-	-	-	-	-	-	-	-	-	
9	Hong Kong	1*	-	-	-	-	-	P(p)*	P*	-	-	-	-	-	-	-	-	A, C
10	Jianfengling	1	-	L; SM; H; WD	*	P	P	P(p)	-	-	-	-	-	+	+	P	+	A
11	Nonggang	1*	-	L; SM; H; WD	-	-	-	-	-	P2	-	-	-	-	-	-	-	B
12	Xishuangbanna	1	+	L; SM; H; WD	P1	P	P	P(p)	-	P2	-	-	-	-	+	-	-	-
13	Mudumalai	4	-	L; SM; H; WD	P1	-	-	-	-	+	-	P1	-	-	-	P	-	A
14	Danum Valley	1*	-	SM	-	-	-	P(p)*	-	+	-	-	-	+	P1	-	-	A
15	Lambir	4	-	L; SM; H; WD	P1	-	-	-	-	+	-	P1	P*	P*	+	P	+	A
16	Pasoh	6	+	L; SM; H; WD	P1	P	P	-	-	P1	-	P1; P2; P3	P	P	+; P1	P	+	A

#	Site	N tree censuses[‡‡]	Lianas	Functional Traits[§§]	Dendrometer Bands	Flower & Seed Production	Seedling Performance	DNA barcoding[***]	Arthropods[†††]	Vertebrates	Airborne LiDAR	Dead Wood/ CWD	Fine Roots	Soil C	Soil Nutrients	Litterfall	Eddy Covariance[‡‡‡]	Weather station[§§§]
17	Palanan	3.5	-	L; H(f)	-	*	*	P(p)	+	+	-	-	-	-	-	*	-	(f)
18	Bukit Timah	6	-	-	P1	-	-	P(p)	-	-	-	P1; P3; P4	P	P	P2	P	-	A
19	Sinharaja	3	-	-	-	+	-	-	-	+	-	-	-	-	+; P1	-	-	
20	Fushan	3	-	H; L; WD	P1	P	P	P(p)	+	+	+	P1; P2; P3	-	-	+	P	-	A
21	Kenting	3	-	H; C; L; SM	P1	P	P	P(p)	-	+	-	-	-	-	-	-	-	C
22	Lienhuachih	1	-	L; SM; H; WD	P1	P	P	P(p)	-	-	-	P1; P2; P3	-	-	+	P	-	A
23	Nanjenshan	3	-	L	-	-	+	P(p)	-	-	-	P1; P2; P3	-	-	-	-	-	A
24	Zenlun	2	-	-	-	P	P	-	+	+	-	-	-	-	-	-	-	A
25	Doi Inthanon	4	-	WD; H	-	-	-	+	-	-	-	-	-	-	-	-	-	C
26	HKK	4	-	-	P1	+	-	-	-	+	-	P1; P2	P(f)	P(f)	+; P	P	-	A
27	Khao Chong	3	-	-	P1	+	+	P(a)	P	-	-	P1	P(f)	P(f)	+*; P1; P3	P	-	A
28	Mo Singto	2.5	P	-	P1	-	-	-	-	+	-	P1; P2	-	-	-	P	-	
29	Haliburton Forest	1*(3)	-	L; SM; H; C; WD; O	-	P	-	P(p)	-	+	+	+	-	P	P2	P	+	A, B
30	Scotty Creek	1	n/a	C; WD	P1	-	-	P(a)	-	-	+	-	P(f)	P(f)	-	P(f)	+	A
31	Harvard Forest	1	-	N	P1; P2	-	-	-	N	N	+; N	N	N	N	N	+; N	+; N	A; N
32	Lilly Dickey	1	-	-	P1	-	-	-	-	-	-	-	-	P*	+; P2*	-	-	A
33	Santa Cruz	2	+	H; C; L; WD(f)	-	P	-	P(p)	-	+	+	-	-	-	+	-	-	A
34	SCBI	2	+	L; H; C; O	P1; P2	P	P	P(p)	+; N	+; P2; N	+; N	P1; P3; P4; N	P; N	P; N	+; P2; N	P; N	N	A, N
35	SERC	1	P	N	P1; P2	+	+	P(p)	N	+; P2*; N	+; N	P4; N	P; N	P; N	+; P3; N	N	+; N	A, N
36	Tyson	1(4)	-	L; WD; O	*	+	*	-	-	*	-	P4	-	-	+; P2	+	-	A

#	Site	N tree censuses‡‡	Lianas	Functional Traits§§	Dendrometer Bands	Flower & Seed Production	Seedling Performance	DNA barcoding***	Arthropods†††	Vertebrates	Airborne LiDAR	Dead Wood/ CWD	Fine Roots	Soil C	Soil Nutrients	Litterfall	Eddy Covariance‡‡‡	Weather station§§§
37	Wabikon Lake Forest	2	-	-	P1	+	+	P(p)	-	+	-	-	-	-	-	-	-	
38	Wind River	1(2)	n/a	N	P1	+	-	-	N	N	+; N	+; N	N	N	P2(f); N	N	+; N	A; N
39	Yosemite	2*	n/a	-	P1	-	-	-	-	-	+	+	-	-	-	-	-	A
40	Ilha do Cardoso	1	-	+	-	P	-	-	-	-	-	-	-	-	P1/ P2/ +	-	-	
41	Manaus	1	P	-	-	-	-	P(p)	-	P1	-	-	-	-	-	-	-	+
42	Amacayacu	1	-	L; SM; H; WD	P1	-	-	-	-	-	-	P1; P2; P3	P	P	P2	P	+(f)	
43	La Planada	2	-	-	-	-	-	-	-	-	-	-	-	-	P1	-	-	
44	Yasuni	3	+	L; SM; H; WD	P1	P	P	-	P	P1	+	P1; P2; P3	P	P	P1; P2	P	-	A
45	BCI	7	P; +	L; SM; H; C; WD; O	P1	P	P	P(p); P(a)	P	+; P1; P2	+	P1; P2; P3	P	P	P1	P	+	A
46	Cocoli	3	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C
47	San Lorenzo	1	+	L; SM; H; WD	P1	P	P	-	-	-	+	-	-	P	P2	-	-	C
48	Luquillo	5	+	L; SM; H; WD, C	P1	P	P	P(p)	+	+	-	+; P	P	P	P2	P	-	A
49	Laupahoehoe	1	-	-	-	P	P	P(p)*	-	-	+	-	-	-	-	+	-	A
50	Palamanui	2*	-	-	-	P	P	P(p)*	-	-	-	-	-	-	-	+	-	A
51	Badagongshan	1*	-	-	P1	P	P	-	-	P2	-	-	-	-	-	P	-	
52	Baotianman	1	-	-	-	P	P	-	-	P2	-	-	-	-	-	-	-	
53	Changbaishan	2	-	L; SM; H; WD	P1	P	P	P(p)	-	P1; P2	-	-	-	-	+	P	-	+
54	Donglingshan	1*	-	L; SM; H; WD	-	P	P	-	-	-	-	P1; P2; P3; P4	-	-	-	-	-	
55	Gutianshan	2	-	L; SM; H; WD	P1	P	P	P(p)	-	+	-	P1; P2; P3	-	-	+	P	-	B
56	Tiantongshan	1	-	L; SM; H; WD	-	P	P	-	-	-	-	-	-	-	-	-	-	

#	Site	N tree censuses[‡‡]	Lianas	Functional Traits[§§]	Dendrometer Bands	Flower & Seed Production	Seedling Performance	DNA barcoding[***]	Arthropods[†††]	Vertebrates	Airborne LiDAR	Dead Wood/ CWD	Fine Roots	Soil C	Soil Nutrients	Litterfall	Eddy Covariance[‡‡‡]	Weather station[§§§]
57	Zofin	1(4)	-	+	-	-	+	P(p)*	-	-	+	P4	-	+	+	-	-	A
58	Speulderbos	1	n/a	-	+	-	-	-	-	P2*	-	-	-	-	-	-	-	B
59	Wytham Woods	2	-	+	+	-	+	-	-	+	+	P1; P2; P3	+	+	+	+	+	A

[‡‡] Number of censuses as of May 2014. Numbers in parentheses indicate total number of censuses including those prior to the sites adoption of the CTFS-ForestGEO core tree census protocol (i.e., censuses with any DBH cutoff and/or smaller plots). These include any in-progress survey.

[§§] H: tree height; C: crown dimensions; L: leaf traits; SM: seed mass; WD: wood density; O: other

[***] p- plants; a- arthropods

[†††] Arthropod measurements made using standardized CTFS-ForestGEO protocol are detailed in Table S7.

[‡‡‡] Measured onsite or at a similar site within 10 km.

[§§§] A- onsite or a similar site within 10 km that is believed to have similar climate; B- nearby (within 50km), believed to have similar climate (e.g., similar elevation, distance from coast); C- nearby (within 50km), believed to have dissimilar climate (e.g., dissimilar elevation, distance from coast); '-' no known weather station within 50km; N-NEON (future). P denotes CTFS-ForestGEO protocols described in Appendix S2.

Table S7. Record of arthropod sampling at CTFS-ForestGEO sites.
Entries below are no. of individuals/no. of species / no. of DNA sequences / taxonomic knowledge (coded as follows: 1 = work needed; 2 = reasonable; 3 = checklist complete or nearly so) as of November 2013.

Protocol	Target taxa (order)	Guild	BCI	Khao Chong	Wanang	Yasuni	Hong Kong
Light traps	Passalidae (Coleoptera)	Wood eaters	510 / 13 / 51 / 3	-	-	-	-
	Platypodinae (Coleoptera)	Wood eaters	662 / 19 / 56 / 2	959 / 24 / 0 / 1	-	-	-
	Dynastinae (Coleoptera)	Scavengers	1,556 / 24 / 52 / 2	-	-	-	-
	Isoptera	Scavengers	14,289 / 30 / 62** / 2	4,896 / 4 / 0 / 1	-	-	-
	Flatidae (Hemiptera)	Sap-suckers	1,855 / 28 / 97 / 3	311 / 20 / 0 / 1	-	-	-
	Reduviidae (Hemiptera)	Predators	971 / 51 / 65 / 1	100 / 6 / 0 / 1	-	-	-
	Saturniidae (Lepidoptera)	Chewers (leaves)	34 / 714 / 168 / 3	-	-	-	-
	Geometridae (Lepidoptera)	Chewers (leaves)	6,673 / 229 / 961 / 2	6,220 / 396 / 409 / 2	-	-	Planned starting 2014
	Arctiinae (Lepidoptera)	Chewers (leaves)	8,875 / 160 / 812 / 2	4,394 / 174 / 34 / 1	-	-	Planned starting 2014
	Pyraloidea (Lepidoptera)	Chewers (leaves)	11,253 / 339 / 832 / 1	7,412 / 445 / 103 / 1	-	-	Planned starting 2014
	Ecitoninae - alates (Hymenoptera)	Predators	4,416 / 16 / 67 / 1	-	-	-	-
	Apidae + Halictidae - nocturnal (Hymenoptera)	Pollinators	2,904 / 23 / x / 2	140 / 5 / 0 / 2	-	-	-
Winkler	Formicidae - litter (Hymenoptera)	Varia	11,945 / 133 / 957 / 3	10,929 / 134 / 0 / 1	Planned starting 2014	2,500/100/0/ 1	-
McPhail traps	Tephritidae (Diptera)	Chewers (fruits)	-	17,945 / 83 / 93 / 2	Planned starting 2014	-	-
Butterfly transects	Papilonoidea+Hesper	Chewers	8,772 / 350 /	3,567 / 280 /	3,371 / 134 /	-	73 / 28 / 0 / 1

	iidae (Lepidoptera)	(leaves)	1,282 / 3	404 / 2	651 / 2		
Termite transects	Isoptera	Scavengers	2,598 / 13 / 62** / 2	2,268 / 35 / 0 / 2	Planned starting 2014	Planned starting 2015?	Planned starting 2015?
Bee baits	Apidae Euglossini (Hymenoptera)	Pollinators	19,020 / 26 / 96 / 3	-	-	-	-
Seed predation	Various in Lepidoptera, Coleoptera and Hymenoptera	Seed predators	24,000 / ? / 1,148 / 1	1,373 / 90 / 0 / 1	4,626 / 23 / 0 / 1	-	-

** Total number of sequences for all Isoptera

Table S8. Site-specific acknowledgments for selected CTFS-ForestGEO sites.

Site	Acknowledgements
Amacayacu	We thank the Staff of the National Natural Park of Amacayacu and the National System of Protected Areas of Colombia.
Badagongshan	Work at Badagongshan was supported by the National Natural Science Foundation of China (31270562) and the Chinese Forest Biodiversity Monitoring Network (29200931131101919).
Baotianman	The 25 ha Baotianman forest dynamics plot was funded by National Science and Technology Support Plan (2008BAC39B02), State Key Laboratory of Vegetation and Environmental Change (LVEC2011zyts01), the Natural Science Foundation of China (31070554, 31270642, 31370586), and Biodiversity Committee, Chinese Academy of Sciences. Thanks to hundreds of college students, graduate students, local workers, and researchers for their hard works. Thanks to State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, the Chinese Academy of Sciences, Chinese Forest Biodiversity Monitoring Network, Henan Agricultural University, Nanyang Normal University, China University of Mining & Technology (Beijing), Pingdingshan University, and Baotianman National Nature Reserve for their cooperation and kind support.
Barro Colorado Island	The BCI forest dynamics research project was founded by S.P. Hubbell and R.B. Foster and is now managed by R. Condit, S. Lao, and R. Perez under the Center for Tropical Forest Science and the Smithsonian Tropical Research Institute in Panama. Numerous organizations have provided funding, principally the U.S. National Science Foundation, and hundreds of field workers have contributed.
Danum	The Danum plot is a core project of the Southeast Asia Rain Forest Research Programme (SEARRP). We thank SEARRP partners especially Yayasan Sabah for their support, and HSBC Malaysia and the University of Zurich for funding. We are grateful to the research assistants who are conducting the census, in particular the team leader Alex Karolus, and to Mike Bernados and Bill McDonald for species identifications. We thank Stuart Davies and Shameema Esufali for advice and training.
Harvard Forest	Funding for the Harvard ForestGEO Forest Dynamics plot was provided by the Center for Tropical Forest Science and Smithsonian Institute's Forest Global Earth Observatory (CTFS-ForestGEO), the National Science Foundation's LTER program (DEB 06-20443 and DEB 12-37491) and Harvard University. Thanks to many field technicians who helped census the plot. Jason Aylward was instrumental as a field supervisor and with data screening and database management. Thanks to John Wisnewski and the woods crew at HF for providing materials, supplies, and invaluable field assistance with plot logistics. Joel Botti and Frank Schiappa provided survey expertise to establish the 35-ha plot. Special thanks to Stuart Davies and Rick Condit for field training, database assistance, and plot advice. Sean McMahon and Suzanne Lao were extremely helpful with field planning, data questions, and many plot logistics. Thanks to Jeannette Bowlen for administrative assistance and

Site	Acknowledgements
	to Emery Boose and Paul Siqueira for help with plot coordinates. Thanks also to David Foster for his support and assistance with plot design, location, and integration with other long-term studies at HF.
Hong Kong	We thank the Hongkong Bank Foundation.
Huai Kha Khaeng and Khao Chong	We thank many people helped to create the permanent research plots in Huai Kha Khaeng and Khao Chong. The administrative staff of Huai Kha Khaeng Wildlife Sanctuary and Khao Chong Botanical Garden helped with logistic problems of the plots in many occasions. Over the past two decades the Huai Kha Khaeng 50-hectare plot and the Khao Chong 24-hectare plot projects have been financially and administratively supported by many institutions and agencies. Direct financial support for the plot has been provided by the people of Thailand through the Royal Forest Department (1991-2003) and the National Parks Wildlife and Plant Conservation Department since 2003, the Arnold Arboretum of Harvard University, the Smithsonian Tropical Research Institute, and the National Institute for Environmental Studies, Japan, as well as grants from the US National Science Foundation (grant #DEB-0075334 to P.S. Ashton and S.J. Davies), US-AID (with the administrative assistance of WWF-USA), and the Rockefeller Foundation. Administrative support has been provided by the Arnold Arboretum, the Harvard Institute for International Development, the Royal Forest Department, and the National Parks Wildlife and Plant Conservation Department. In addition, general support for the CTFS program has come from the Arnold Arboretum of Harvard University, the Smithsonian Tropical Research Institute, the John D. and Catherine T. MacArthur Foundation, Conservation, Food and Health, Inc., and the Merck Foundation. All of these organizations are gratefully acknowledged for their support.
Jianfengling	Jianfengling Forest Plot was supported by National Nonprofit Institute Research Grant of CAF (CAFYBB2011004, RITFYWZX200902, RITFYWZX201204), National Natural Science Foundation of China (31290223, 41201192), State Forestry Administration of China (201104057). It was also supported by the Jianfengling National Key Field Research Station for Tropical Forest Ecosystem.
Kuala Belalong	Funding for the 25 ha HOB Forest Dynamics Research Plot was provided by HSBC-Brunei Darussalam, Smithsonian's Centre for Tropical Forest Science and Universiti Brunei Darussalam. We also acknowlege the support from Heart of Borneo (HOB)-Brunei Darussalam, Brunei Forestry Department and the Kuala Belalong Field Studies Centre.
Khao Chong	See above: Huai Kha Khaeng and Khao Chong.
Laupahoehoe and Palamanui	The Hawai‘i Permanent Plot Network thanks the USFS Institute of Pacific Islands Forestry (IPIF) and the Hawai‘i Division of Forestry and Wildlife/Department of Land and Natural Resources for permission to conduct research within the Hawai‘i Experimental Tropical Forest; the Palāmanui Group, especially Roger Harris, for access to the lowland dry forest site. We thank the Smithsonian Tropical Research Institute Center for Tropical Forest Science, the University of California, Los Angeles, the Pacific Southwest Research Station of the USFS,

Site	Acknowledgements
	the University of Hawai‘i, and NSF EPSCoR Grants No. 0554657 and No. 0903833 for support.
Lilly Dickey	Funding for the Lilly Dickey Woods Forest Dynamics Plot was provided by the Indiana Academy of Sciences and the Smithsonian Institution's Center for Tropical Forest Science.
Luquillo	This research was supported by grants BSR-8811902, DEB 9411973, DEB 0080538, DEB 0218039, DEB 0620910 and DEB 0963447 from NSF to the Institute for Tropical Ecosystem Studies, University of Puerto Rico, and to the International Institute of Tropical Forestry USDA Forest Service, as part of the Luquillo Long-Term Ecological Research Program. Funds were contributed for the 2000 census by the Andrew Mellon foundation and by CTFS for the 2011 census. The U.S. Forest Service (Dept. of Agriculture) and the University of Puerto Rico gave additional support. We also thank the many volunteers and interns who have contributed to the Luquillo forest censuses.
Nonggang	We appreciate the researchers from the Guangxi Institute of Botany, Chinese Academy of Sciences, for their contributions to the establishment and census of the 15-ha Nonggang karst forest plot. They are Wusheng Xiang, Bin Wang, Tao Ding, Shuhua Lu, Fuzhao Huang, Wenheng Han, Lanjun He, Qingbai Lu, Dongxing Li, respectively.We also thank many volunteersin the field work from the College of Life Science, Guangxi Normal University. We acknowledge the support from the Administration Bureau of the Nonggang National Nature Reserve.
Mudumalai	We thank the Ministry of Environment and Forests (Government of India), for funding research Tamilnadu Forest Department, for permissions to conduct long-term research
Palamanui	See above: Laupahoehoe and Palamanui
Rabi	We thank the Center for Conservation Education and Sustainable (CCES), Center for Tropical Forest Science (CTFS) and Shell Gabon.
Santa Cruz	The UCSC Forest Ecology Research Plot was made possible by National Science Foundation grants to Gregory S. Gilbert (DEB-0515520 and DEB-084259), by the Pepper-Giberson Chair Fund, the University of California Santa Cruz, the UCSC Natural Reserve, and the hard work of dozens of UCSC students.
SCBI	Funding for the establishment of the SCBI ForestGEO Large Forest Dynamics Plot was provided by the Smithsonian Global Earth Observatory initiative, the Smithsonian Institution, National Zoological Park and the HSBC Climate Partnership. We especially thank the numerous technicians, interns and volunteers of the Conservation Ecology Center at the SCBI who were essential in assisting with plot establishment and data collection. Support for the original exclosure fence installation was provided by the Friends of the National Zoo and Earthwatch Foundation.
Tyson	We thank the International Center for Advanced Renewable Energy and Sustainability (I-CARES) at Washington University in St. Louis, the Center for Tropical Forest Science and Forest Global Earth Observatories (CTFS-

Site	Acknowledgements
	ForestGEO) Grants Program, and the Tyson Research Center for financial support.
Wanang	We wish to acknowledge financial support from the National Science Foundation (DEB-0816749), Swire & Sons Ltd., Darwin Initiative for the Survival of Species (19-008), the Grant Agency of the Czech Republic (14-36098G), and the Christensen Foundation.
Wind River	We acknowledge Ken Bible, Todd Wilson, the Gifford Pinchot National Forest, the USDA Forest Service Pacific Northwest Research Station, Utah State University, University of Washington, University of Montana, Washington State University, and the volunteers listed at http://www.wfdp.org.
Wytham Woods	Plot establishment and subsequent data collection was funded by HSBC/Smithsonian Institution. Thanks to Research and Field Assistant: Gordon Campbell; for practical site support to: Michele Taylor, Nigel Fisher, Terhi Riutta; and to fieldworkers (in addition to N. Butt & G. Campbell): Sam Armenta Butt, Luke Sherlock, Youshey Zakiuddin, Dan Gurdak, Arthur Downing, Dominic Jones, Jay Varney, Leo Armenta Butt, Jeremy Palmer, Daniel Goldhill.
Yasuni	We gratefully acknowledge the professional help of numerous biologists and field collaborators of the Yasuni forest dynamics plot, particularly Álvaro Pérez, Pablo Alvia and Milton Zambrano, who provided invaluable expertise on plant taxonomy. Consuelo Hernández organized the data and improved its quality. P. Universidad Católica del Ecuador (PUCE) and STRI co-financed the first two censuses of the plot. The third census was financed with funds of the Government of Ecuador and PUCE. Seed traps and seedling plots are monitored for over 10 years thanks to STRI and two awards from the NSF program LTREB (DBI 0614525 and 1122634). STRI also sponsored the Carbon Dynamics Initiative. This study was endorsed by the Ministerio de Ambiente del Ecuador permits MAE: No 004-2012-IC-FLO-MAE-DPO, 09-FLO-MA-DPO-PNY and 06-2011-FAU-DPAP.
Yosemite	We acknowledge Joe Meyer, Yosemite National Park, Utah State University, University of Washington, University of Montana, Washington State University, and the students and volunteers listed at http://www.yfdp.org.
Zofin	The research was supported by Czech Ministry of Education, Youth and Sports, project No. LH12038

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