Supporting Information

Fang et al. 10.1073/pnas.1402333111

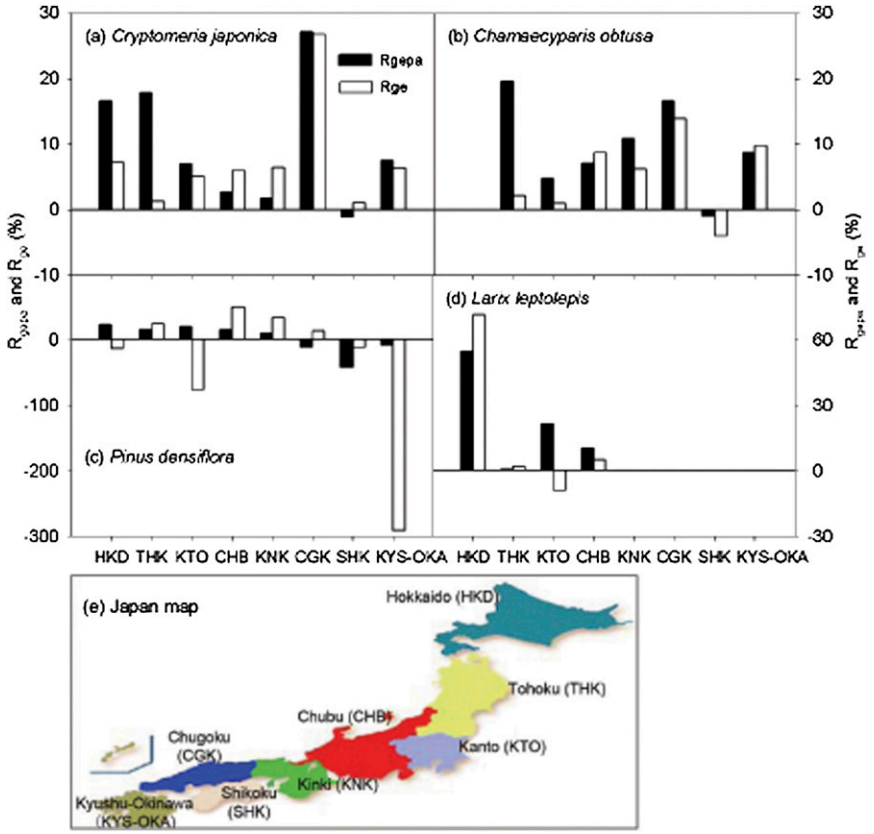

Fig. S1. Regional distribution of the effects of environmental changes on tree growth of various planted forest types in Japan. The effects of environmental changes on tree growth were described as growth enhancement per area (R_{gepa}) or the ratio of total growth enhancement to net biomass increase (R_{ge}). (*A*) Japanese cedar, (*B*) Japanese cypress, (*C*) Japanese red pine, (*D*) Japanese larch plantations, and (*E*) map of Japan showing regional divisions used in this study. Following Japanese inventories, the country was divided into eight regions: Hokkaido (HKD), Tohoku (THK), Kanto (KTO), Chubu (CHB), Kinki (KNK), Chugoku (CGK), Shikoku (SHK), and Kyushu-Okinawa (KYS-OKA).

Table S1. Parameters used for estimation of biomass expansion factor

Forest type	*n*	*a*, Mg·m^{-3}	*b*, Mg·ha^{-1}	r^2
Cryptomeria japonica	212	0.4878	19.4830	0.98
Chamaecyparis obtusa	149	0.5580	33.9560	0.96
Pinus densiflora	106	0.5687	15.3300	0.92
Larix leptolepis	36	0.5968	16.7000	0.95

Parameters obtained from Fang et al. (1). Biomass expansion factor (BEF) is expressed as a function of stand stem volume per hectare (x), $BEF = a + b/x$, where a and b are constants for each forest type, respectively.

1. Fang JY, Oikawa T, Kato T, Mo WH, Wang ZH (2005) Biomass carbon accumulation by Japan's forests from 1947-1995. *Global Biogeochem Cycles* 19:GB2004, 10.1029/2004GB002253.

Table S2. Forest area, biomass density, and stock over age sequence in Japan's *C. japonica* plantation during the period 1980–2005

	Area, 10^4 ha						Biomass carbon density, Mg C/ha						Biomass carbon stock, Tg C					
	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005
Total	426.5	443.7	450.7	448.6	442.9	437.3	42.0	51.4	59.0	67.0	80.3	89.5	179.1	228.3	265.7	300.5	355.5	391.5
Age, y																		
5	31.7	21.3	14.4	9.6	3.7	2.1	9.8	9.8	9.8	9.8	9.8	9.8	3.1	2.1	1.4	0.9	0.4	0.2
10	47.0	33.3	25.4	14.3	7.2	5.0	10.9	11.0	11.1	11.4	11.2	11.0	5.1	3.7	2.8	1.6	0.8	0.6
15	71.1	46.5	35.0	25.5	11.3	7.2	21.5	21.8	21.8	22.6	22.4	23.2	15.3	10.2	7.6	5.8	2.5	1.7
20	81.0	70.1	50.6	35.1	21.3	11.4	34.2	34.0	33.9	34.1	34.1	34.2	27.7	23.8	17.1	12.0	7.3	3.9
25	75.7	78.7	72.3	50.2	33.0	21.6	47.4	48.3	47.0	47.1	46.9	47.1	35.9	38.0	34.0	23.6	15.5	10.2
30	50.5	74.8	78.8	72.1	43.8	33.0	60.2	61.5	61.3	61.1	60.2	60.2	30.4	46.0	48.4	44.1	26.3	19.8
35	19.9	49.7	69.3	77.9	66.1	43.6	74.5	73.0	74.0	73.5	73.2	72.5	14.8	36.3	51.3	57.2	48.4	31.6
40	13.9	19.5	41.9	68.1	76.3	65.0	83.8	84.8	84.8	83.0	85.1	84.6	11.6	16.5	35.6	56.6	64.9	55.0
45	12.1	13.6	16.0	39.8	72.0	75.1	90.9	94.3	95.7	92.1	95.8	95.5	11.0	12.8	15.3	36.6	69.0	71.7
50	9.9	11.1	12.6	15.5	49.2	71.5	96.4	100.1	102.1	101.0	103.5	105.6	9.6	11.1	12.8	15.6	50.9	75.5
55	7.8	9.0	9.9	11.8	20.2	48.3	103.0	104.3	107.0	107.0	110.2	114.0	8.0	9.4	10.6	12.7	22.3	55.1
60	6.1	6.9	7.8	9.2	12.0	20.0	108.8	109.8	111.6	111.9	117.4	118.0	6.6	7.6	8.7	10.2	14.0	23.6
65		5.5	5.9	6.8	9.4	11.8		114.0	117.4	115.7	120.7	123.8		6.3	7.0	7.9	11.3	14.6
70		3.8	4.6	5.6	7.3	9.2		120.0	120.7	120.0	123.8	127.6		4.6	5.5	6.7	9.1	11.7
75			3.7	4.1	5.6	7.2			125.3	122.8	126.6	129.7			4.7	5.0	7.1	9.3
80			2.4	3.2	4.4	5.2			124.4	125.6	129.9	131.9			3.0	4.0	5.7	6.9

Table S3. Forest area, biomass density, and stock over age sequence in Japan's *C. obtusa* plantation during the period 1980–2005

	Area, 10^4 ha						Biomass carbon density, Mg C/ha						Biomass carbon stock, Tg C					
	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005
Total	203.8	228.7	242.2	249.5	250.9	251.0	40.1	46.4	52.0	59.0	69.5	77.2	81.7	106.1	125.9	147.1	174.3	193.8
Age, y																		
5	26.9	20.5	16.3	11.5	4.4	2.0	17.0	17.0	17.0	17.0	17.0	17.0	4.6	3.5	2.8	2.0	0.7	0.3
10	33.4	28.0	23.9	15.4	9.3	6.4	18.2	18.3	18.3	18.3	18.2	18.0	6.1	5.1	4.4	2.8	1.7	1.2
15	35.6	34.7	29.4	23.3	13.9	9.4	27.4	28.5	28.3	29.6	28.8	29.1	9.8	9.9	8.3	6.9	4.0	2.7
20	31.7	36.9	36.8	28.6	20.6	13.9	36.8	38.2	38.8	39.9	39.4	39.1	11.7	14.1	14.3	11.4	8.1	5.4
25	28.0	31.9	35.3	36.0	28.7	20.6	47.2	49.3	50.0	51.8	51.6	50.9	13.2	15.7	17.6	18.6	14.8	10.5
30	16.8	28.7	31.6	35.7	33.6	28.5	56.8	59.3	61.4	62.6	63.5	63.3	9.5	17.0	19.4	22.4	21.3	18.1
35	6.2	16.6	25.7	32.0	38.0	33.0	68.9	68.2	71.3	73.5	74.9	75.1	4.2	11.3	18.3	23.5	28.4	24.8
40	5.3	5.9	13.5	26.2	32.1	37.5	78.7	79.4	80.0	78.9	83.7	85.5	4.1	4.7	10.8	20.7	26.9	32.1
45	5.8	5.1	5.0	13.6	28.1	31.6	84.9	87.8	90.6	86.2	90.5	92.4	4.9	4.5	4.5	11.7	25.4	29.1
50	5.4	5.2	4.9	5.2	17.1	28.7	90.5	92.8	95.9	91.9	95.1	97.5	4.9	4.8	4.7	4.8	16.3	28.0
55	4.8	4.8	4.6	4.9	6.5	17.3	96.3	96.5	99.4	97.5	99.9	101.4	4.6	4.7	4.6	4.8	6.5	17.5
60	4.1	4.0	4.0	4.5	4.4	6.7	100.2	100.8	102.8	100.0	105.8	104.5	4.1	4.1	4.2	4.5	4.6	7.0
65		3.6	3.6	3.9	4.2	4.3		104.2	106.6	101.6	107.3	109.1		3.7	3.8	4.0	4.5	4.7
70		2.9	3.1	3.5	3.9	4.2		105.8	108.3	104.0	108.5	110.7		3.1	3.3	3.7	4.2	4.7
75			2.6	2.8	3.3	3.8			111.0	105.5	109.8	111.1			2.9	3.0	3.6	4.2
80			1.8	2.3	2.9	3.2			106.7	105.8	111.3	111.3			1.9	2.4	3.2	3.6

Table S4. Forest area, biomass density, and stock over age sequence in Japan's *P. densiflora* plantation during the period 1980–2005

	Area, 10^4 ha						Biomass carbon density, Mg C/ha						Biomass carbon stock, Tg C					
	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005
Total	117.6	107.5	101.9	97.1	88.9	86.2	29.2	37.2	44.0	50.4	62.0	67.6	34.4	40.0	44.8	48.9	55.1	58.3
Age, y																		
5	5.5	1.6	0.7	0.3	0.1	0.1	7.7	7.7	7.7	7.9	7.7	8.6	0.4	0.1	0.1	0.0	0.0	0.0
10	12.9	5.4	2.5	0.9	0.2	0.1	9.2	9.7	10.0	10.0	8.7	8.5	1.2	0.5	0.2	0.1	0.0	0.0
15	24.2	11.9	6.0	2.9	0.5	0.2	18.4	19.3	19.3	20.3	19.1	15.7	4.5	2.3	1.2	0.6	0.1	0.0
20	29.1	21.6	12.6	6.7	1.6	0.5	27.3	28.7	29.0	29.7	29.9	27.8	8.0	6.2	3.7	2.0	0.5	0.1
25	19.9	26.2	21.8	13.0	4.4	1.7	35.8	38.0	38.1	39.2	42.2	41.0	7.1	9.9	8.3	5.1	1.9	0.7
30	10.9	17.8	24.8	21.3	8.9	4.6	43.9	45.9	48.4	47.2	51.1	51.3	4.8	8.2	12.0	10.0	4.5	2.4
35	4.9	9.6	14.9	22.6	17.4	9.2	48.6	49.9	53.9	56.2	58.4	59.2	2.4	4.8	8.0	12.7	10.2	5.5
40	2.9	4.2	7.6	13.6	22.0	17.4	54.5	53.3	56.3	59.3	64.1	65.1	1.6	2.2	4.3	8.0	14.1	11.3
45	2.4	2.6	3.1	6.5	16.8	21.3	57.9	58.8	59.4	62.2	70.1	70.4	1.4	1.5	1.8	4.0	11.8	15.0
50	2.1	2.0	2.1	2.6	8.0	15.5	59.8	60.1	62.5	64.2	71.6	75.6	1.3	1.2	1.3	1.7	5.7	11.8
55	1.6	1.8	1.6	1.9	3.2	7.5	64.6	61.1	65.8	67.2	71.0	75.9	1.0	1.1	1.1	1.3	2.3	5.7
60	1.2	1.2	1.4	1.5	1.7	3.1	67.9	65.6	66.2	64.4	71.3	72.9	0.8	0.8	0.9	1.0	1.2	2.2
65		0.9	0.9	1.3	1.4	1.7		69.6	71.7	67.3	70.4	72.8		0.6	0.6	0.9	1.0	1.2
70		0.8	0.7	0.9	1.3	1.3		66.7	73.6	70.9	67.9	70.4		0.5	0.5	0.6	0.9	0.9
75			0.8	0.7	0.8	1.3			69.9	68.9	70.6	68.5			0.5	0.5	0.6	0.9
80			0.4	0.6	0.7	0.8			73.6	66.3	70.2	68.7			0.3	0.4	0.5	0.6

Table S5. Forest area, biomass density, and stock over age sequence in Japan's *L. leptolepis* plantation during the period 1980–2005

	Area, 10^4 ha						Biomass carbon density (Mg C/ha)						Biomass carbon stock, Tg C					
	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005	1980	1985	1990	1995	2000	2005
Total	110.2	108.5	107.9	106.7	104.0	101.0	34.2	43.9	50.0	56.4	64.9	69.9	37.7	47.7	54.0	60.2	67.5	70.6
Age, y																		
5	5.3	3.3	2.5	1.8	1.2	1.4	8.4	8.4	8.4	8.4	8.4	8.4	0.4	0.3	0.2	0.1	0.1	0.1
10	13.3	5.4	3.7	2.5	1.5	1.2	8.6	8.8	9.0	9.4	10.1	9.5	1.1	0.5	0.3	0.2	0.1	0.1
15	21.3	12.1	6.1	3.7	2.2	1.4	26.2	29.0	26.4	25.5	29.9	36.3	5.6	3.5	1.6	1.0	0.7	0.5
20	25.2	19.9	13.9	6.1	3.1	2.2	35.1	38.9	42.0	40.2	39.2	48.9	8.9	7.7	5.8	2.5	1.2	1.1
25	24.2	23.2	20.3	13.9	5.1	3.2	42.3	45.2	48.7	54.5	49.7	52.2	10.2	10.5	9.9	7.6	2.5	1.7
30	13.8	23.9	23.7	19.9	9.6	5.1	49.7	50.9	52.5	58.3	62.4	60.4	6.9	12.1	12.4	11.6	6.0	3.1
35	3.0	13.9	21.1	23.7	17.8	9.5	57.6	58.4	58.3	59.8	68.7	71.2	1.7	8.1	12.3	14.2	12.2	6.8
40	1.7	2.8	10.9	20.3	20.4	17.7	66.0	66.1	64.5	62.4	66.6	74.9	1.1	1.8	7.0	12.7	13.6	13.2
45	0.9	1.5	1.9	9.8	22.4	20.2	69.4	72.9	72.5	67.2	68.2	71.3	0.6	1.1	1.4	6.6	15.3	14.4
50	0.6	0.8	1.3	1.7	13.7	21.4	69.6	74.9	76.0	75.4	73.5	72.5	0.4	0.6	1.0	1.3	10.1	15.5
55	0.6	0.5	0.6	1.2	3.7	12.2	74.9	76.5	79.6	76.1	78.8	77.5	0.4	0.4	0.5	0.9	2.9	9.4
60	0.5	0.5	0.5	0.6	1.3	2.9	70.5	76.8	78.0	75.1	83.9	83.0	0.4	0.4	0.4	0.5	1.1	2.4
65		0.5	0.4	0.5	0.8	1.1		74.0	81.2	74.9	82.8	90.8		0.3	0.4	0.4	0.7	1.0
70		0.4	0.4	0.4	0.5	0.7		77.3	73.1	78.0	80.7	87.7		0.3	0.3	0.3	0.4	0.6
75			0.3	0.4	0.4	0.4			77.3	75.4	81.4	82.6			0.2	0.3	0.3	0.4
80			0.2	0.3	0.4	0.4			78.2	75.0	78.4	81.2			0.2	0.2	0.3	0.3

Table S6. Contribution of growth enhancement to biomass carbon accumulation for four major plantations by region during 1980–2005

Forest type	Region	NBIPA, Mg C·ha^{-1}	*GEPA*, Mg C·ha^{-1}	R_{gepa}, %	NBI, Tg C	TGE, Tg C	R_{ge}, %
Japanese cedar (*C. japonica*)	Hokkaido	35.9	5.9	16.6	1.2	0.1	7.2
	Tohoku	39.8	7.1	17.8	53.0	0.7	1.2
	Kanto	48.2	3.3	6.9	15.9	0.8	5.0
	Chubu	44.5	1.2	2.6	36.7	2.2	6.0
	Kinki	46.5	0.8	1.7	18.9	1.2	6.4
	Chugoku	64.5	17.5	27.0	20.9	5.6	26.7
	Shikoku	49.2	−0.5	−1.1	18.5	0.2	1.1
	Kyushu-Okinawa	56.5	4.3	7.6	47.3	3.0	6.4
	Country total	47.5	4.0	8.4	212.3	8.7	4.1
Japanese cypress (*C. obtusa*)	Hokkaido	—	—	—	—	—	—
	Tohoku	17.5	3.4	19.6	1.3	0.0	2.2
	Kanto	29.1	1.4	4.7	5.9	0.1	1.0
	Chubu	29.7	2.1	7.1	22.7	2.0	8.7
	Kinki	38.5	4.2	10.9	16.8	1.0	6.2
	Chugoku	40.4	6.7	16.5	21.9	3.0	13.9
	Shikoku	34.7	−0.3	−0.9	15.8	−0.6	−4.0
	Kyushu-Okinawa	49.3	4.3	8.7	27.5	2.7	9.8
	Country total	37.1	4.1	11.0	112.0	11.6	10.4
Red pine (*P. densiflora*)	Hokkaido	18.9	4.4	23.3	−0.5	0.1	−13.0
	Tohoku	42.2	6.8	16.1	14.5	3.5	24.0
	Kanto	37.4	7.4	19.9	−1.0	0.8	−75.4
	Chubu	30.9	4.9	15.7	3.8	1.9	49.7
	Kinki	37.6	3.9	10.3	1.1	0.4	33.6
	Chugoku	43.5	−4.8	−11.0	5.5	0.7	13.4
	Shikoku	36.2	−15.0	−41.3	0.5	−0.1	−11.8
	Kyushu-Okinawa	40.6	−3.3	−8.0	−0.1	0.2	−290.8
	Country total	38.3	4.8	12.6	23.9	8.5	35.5
Japanese larch (*L. leptolepis*)	Hokkaido	38.1	20.8	54.5	13.8	9.9	71.4
	Tohoku	29.8	0.2	0.7	6.3	0.1	1.9
	Kanto	37.9	8.1	21.3	2.0	−0.2	−8.9
	Chubu	36.1	3.7	10.4	10.8	0.5	4.8
	Kinki	—	—	—	—	—	—
	Chugoku	—	—	—	—	—	—
	Shikoku	—	—	—	—	—	—
	Kyushu-Okinawa	—	—	—	—	—	—
	Country total	35.7	7.7	21.6	32.9	11.4	34.7

For location of regions, see Fig. 3*E*. *GEPA*, growth enhancement per area; NBI, net biomass increase; NBIPA, net biomass increase per area; R_{ge}, ratio of TGE to NBI; R_{gepa}, ratio of *GEPA* to NBIPA;TGE, total growth enhancement.

Table S7. Overall mean biomass density of young-age (e.g., 5-y-old) stands in Japan for different inventory periods

	Biomass density, Mg C·ha^{-1}					
Species	1980	1985	1990	1995	2000	2005
C. japonica	9.82	9.83	9.83	9.80	9.83	9.83
C. obtusa	16.99	16.99	16.98	16.99	16.99	16.99
P. densiflora	7.69	7.67	7.67	7.89	7.67	8.61
L. leptolepis	8.35	8.35	8.35	8.35	8.35	8.35

The similar initial standing biomass over time suggests similar silvicultural treatments at early stages of plantations over the study periods. Data are from Forest Inventory of Japan (1–6).

1. Japan Agency of Forestry (1982) *Forest Resources of Japan 1980* (Japan Agency of Forestry, Tokyo).
2. Japan Agency of Forestry (1987) *Forest Resources of Japan 1985* (Japan Agency of Forestry, Tokyo).
3. Japan Agency of Forestry (1992) *Forest Resources of Japan 1990* (Japan Agency of Forestry, Tokyo).
4. Japan Agency of Forestry (2000) *Forest Resources of Japan 1995* (Japan Agency of Forestry, Tokyo).
5. Japan Agency of Forestry (2003) *Forest Resources of Japan 2000* (Japan Agency of Forestry, Tokyo).
6. Japan Agency of Forestry (2008) *Forest Resources of Japan 2005* (Japan Agency of Forestry, Tokyo).