Above-Ground and Soil Carbon Sequestration Potential of Teak Plantations Under Varied Rainfall Regimes

.

ABSTRACT

Aims: Forest plantations are considered to be the most effective approach to reducing the atmosphere's rising carbon dioxide levels. The qualification of the key plantation species' capacity to sequester carbon and the heterogeneity across climatic regimes, however, are urgently needed.

Place and Methodology: Research was conducted on seven-year-old teak plantations in Karnataka, India, to determine the above-ground and soil carbon sequestration potential of teak plantations under various rainfall regimes.

Results: The teak plantations under high RFZ accumulated maximum above-ground biomass revealing the positive effect of rainfall the productivity.This was reflected in the total above-ground carbon sequestration of the plantations leading to maximum carbon storage under the high RFZ followed by medium and low RFZ. Further, the variation of the SOC along the soil depth was evident in the present study.

Conclusion: According to the findings, rainfall significantly impacted above-ground carbon sequestration and SOC, with high rainfall leading to the greatest sequestration. The climate sensitivity of carbon sequestration demands elaborate studies to improve carbon storage in the plantations in future climate change scenarios.

Keywords: Carbon, Teak, Soil organic carbon, Rainfall

1. INTRODUCTION

Since the Industrial Revolution, human-caused rapid increases in atmospheric CO_2 have drawn attention to the Earth's carbon stores and fluxes. There is a great deal of uncertainty over the quantity of carbon stored in and emitted from, terrestrial ecosystems, although many of the stocks and fluxes within the global carbon cycle are very well defined and understood [1]. Compared to soil carbon, global phyto mass carbon stocks and their distribution have been fairly thoroughly studied and measured [2]. Although soil and surface litter store two to three times as much carbon in organic form as the atmosphere globally, as defined by the Kyoto Protocol, soil carbon is expected to be of significant importance in addition to phyto-mass carbon. About two-thirds of global soil carbon is held as soil organic carbon (SOC), with the remaining one-third being inorganic carbon [3]. Despite extensive research, there is currently significant uncertainty regarding the size of global SOC stocks, their spatial distribution, and carbon emissions from soils, and these have received relatively little attention from decision-making bodies. For improved carbon management and climate change mitigation options, as well as to assist in parameterizing global circulation models used to inform climate policy, a better knowledge of SOC stocks and fluxes is crucial.

Through direct seeding and planting, plantation forestry, management or preservation of secondary or successional forests, and other methods, interest has been sparked among the common people to improve tree cover through afforestation and reforestation. For more accurate projections of the current and future implications of changes in land use and land cover on the global carbon cycle, it is imperative to comprehend the function of plantation forests as carbon reservoirs. Soils that were exhausted during intense farming can be replenished with nutrients and organic matter owing to plantations [4]. Plantation forests can provide a habitat for avian biodiversity in fragmented landscapes, as well as for secondary forest species in the understory[5]. Through better-forested management techniques, tree plantings may contribute to the objectives of restoring forest ecosystem services and providing residents with economic opportunities [6]. To maximize carbon sequestration and enhance our capacity to restore fertility to damaged soils, it is important to understand how soil carbon reacts to growing tree cover during forest development and planting. Accurate evaluations of carbon stocks in original and replacement biomass, as well as in soils, are a limitation of accounting models that quantify the impacts of deforestation and reforestation on the global carbon cycle [7]. It is even more crucial to pinpoint the variables that influence soil carbon content under various land-cover types to improve projections of the feedback effects between vegetation, land-use change, and climate change. One such significant plantation species that has become well-known around the world for the beauty and toughness of its wood is *Tectona grandis*. Teak can be used for a variety of purposes, including constructing, making furniture and cabinets, railway sleepers, ornamental veneer, joinery, building ships and automobiles, mining, and making reconstituted wood, among others [8]. Plantations have been established both inside and outside of their original nations as a result of market needs [8]. Therefore, the current study focuses on the teak plantations' capacity to store carbon under various rainfall regimes.

2. MATERIAL AND METHODS

The study was conducted on Seven-year-old plantations at different locations in Karnataka state, India (Fig 1). Based on the mean annual precipitation, the study sites were categorized into High (3000 mm Mean Annual precipitation; MAP), Medium (1500 mm average annual rainfall), and Low (1000 mm average annual rainfall) rainfall zones (Table 1). To assess the growth parameters of each species under contrasting environmental conditions, in each location, sample plots of 20 m × 20 m were randomly laid out. Observations on the following parameters were recorded and used for the carbon stock estimation. Estimation of the total carbon storage under varied rainfall regimes (above and below ground biomass) in each plot was estimated using the following formula [9]:

Total above-ground biomass (AGB) = Plot volume × Wood basic density × Biomass expansion factor (1.58).

Below ground biomass (BGB) = Above ground biomass × 0.26

Total biomass = AGB+ BGB

Total carbon stock =Total biomass × 0.47

2.1 Soil organic Carbon

To study the soil parameters three soil samples were taken at five different depths (0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm, and 80–100 cm) at each location. These soil samples were analyzed for soil organic carbon by placing 0.5 g of soil in a flask with 10 ml of potassium dichromate solution (K_2Cr_2O7), adding 20 ml of concentrated sulfuric acid (H_2SO_4), and mixing, the organic carbon content of the soil was ascertained. 200 cc of distilled water was gently added and well shaken after about 30 minutes. One milliliter of ferroin indicator was added just before titration. 0.5 N ferrous ammonium sulfates were used to titrate the excess $K_2Cr_2O_7$ till the color eventually changed to brownish red at the endpoint [10]. The organic carbon concentration in the soil was converted to total SOC pool as per [11] as follows:

$$Total\ SOC\ Pool = \frac{\%\ of\ SOC}{100} \times BD \times 2000$$

where total SOC pool is the weight of soil organic carbon (Mg ha^{-1}), SOC is soil organic carbon (%), BD is soil bulk density and 2000 is the volume of 1 ha furrow slice (0.20 m) (m^3). The Total Carbon Stock (TCS) was obtained by summing the quantities of carbon stored in the biomass and in the soil.

2.2 Statistical analysis

Observations recorded were analyzed as per the standard statistical procedure.The data were subjected to a one-way analysis of variance (ANOVA) using Origin Pro.

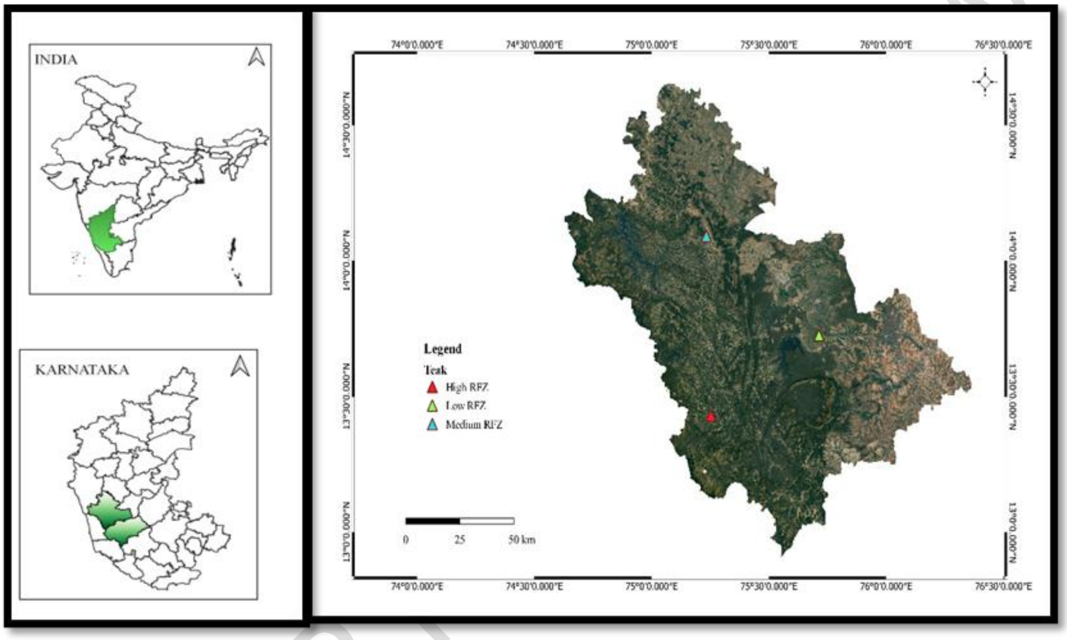

Fig. 1: Overview of the Study Locations

Table 1. Geo coordinates and weather parameters of the study locations

Rainfall Zone	Latitude	Longitude	Altitude (MSL)	MAP (mm)	Max temp (°C)	Min Temp (°C)	Max RH (%)	Min RH (%)
High RFZ	13° 25′ 49.80″ N	75° 15′ 10.44″ E	725 m	3500	31.42	18.98	95.90	55.62
Medium RFZ	14° 5′ 30.66″ N	75° 13′ 59.59″ E	663 m	1500	30.86	19.25	98.66	57.58
Low RFZ	13° 43′ 33.24″ N	75° 42′ 49.78″ E	660 m	1000	30.81	19.26	95.88	56.32

3. RESULTS AND DISCUSSION

The carbon (C) stored in forest ecosystems serves as a key indicator of the global C balance. C is mostly stored in soils and living biomass, with some amount being present in coarse woody detritus [12]. While forest soils are supposed to possess roughly 73 percent of the world's SOC stock, standing biomass C stock makes for 82–86 percent of the aboveground C stock [13]. Following the absorption of atmospheric CO_2 by forests through photosynthesis, plant debris (litter and roots) decomposes to contribute carbon to the soil's carbon pool [14]. Changes in land use have a substantial effect on the global carbon cycle by altering the rate of soil carbon accumulation and fine root turnover [15]. Thus, the distribution of vegetative biomass and carbon stores may change [16]. Due to deforestation and the breakdown of soil organic matter, a shift in land use typically results in higher CO_2 emissions [17]. Furthermore, because the majority of carbon in semiarid and arid ecosystems is found underground [18], fluctuations in soil CO_2 brought on by infrequent precipitation events may have significant effects on soil carbon stocks. Therefore, it is crucial to precisely measure soil CO_2 in connection to rainfall events to comprehend the dynamics of the carbon balance in these ecosystems that are primarily underground. Rainfall surges may become even more significant in the near future since precipitation frequency and intensity are expected to rise [19]. The interannual fluctuation in the terrestrial carbon sink is determined by semiarid habitats, which are now known to be significantly more significant in the global terrestrial carbon balance than previously believed [20]. Hence, an attempt to understand the variations in carbon storage under teak plantations was made in the study and the results depicted in Table 2 revealed that, the significant influence of rainfall on above-ground and below-ground biomass. The teak plantations under high RFZ accumulated maximum above-ground biomass revealing the positive effect of rainfall the productivity. Teak is a long rotation crop (50 to 80 years). However, the rotation period may be reduced by suitable silvicultural practices [21]. The productivity of short rotation teak is high with a mean annual increment range of 10-20 m^3 ha^{-1} yr^{-1} [22]. Further, this was reflected in the total above-ground carbon sequestration of the plantations leading to maximum carbon storage under the high RFZ followed by medium and low RFZ. In the recent past decade, the country has become the net importer of teak wood to meet its requirements [23]. To reduce the import duty of teak there is great enthusiasm among farmers to grow teak outside the forest area which is also appropriately supported by different government programmes. In the present study, however, the productivity was much lower than the values reported by the literature. Further, the carbon sequestration of the trees under high RFZ was higher than that of low RFZ. The research by [24] on the above-ground biomass of teak plantations on farmlands showed substantial differences concerning agro-climatic zones and age, which supported these findings. At all three age gradations, teak plantations grown on farmlands in the Northern Transition Zone had considerably higher above-ground biomass than those in the Northern Dry Zone and Hilly Zone. As a result, the amount of total above-ground carbon sequestered in the Northern Transition Zone's teak plantations was much higher than in the Northern Hilly Zone and Northern Dry Zone. The authors hypothesize that changes in soil fertility, rainfall, temperature, and other environmental variables may be to blame for the discrepancies in above-ground biomass and carbon sequestration capability between the various agro-climatic zones.

Soil organic matter (SOM) is one of the largest and most dynamic reservoirs of carbon (C) in the global C cycle. The amount of C stored in SOM is about twice that stored in the biosphere and atmosphere combined [25]. Hence an assessment of SOC revealed the nonexistence of significant differences among the locations of SOC. This might be due to the early age of the teak plantations which had resulted in the too little leaf fall to have significant variations among the locations. [26] stated that the level of plant material incorporated into the soil improves soil mineral status and opined that organic carbon content in soil accounted for the rate of the quantity of litterfall and the rate of their decomposition. Variations in organic carbon content in soils under various tree sp. are attributed to the age of the plantation and the amount of litterfall, their biochemical composition, and the rate of their decomposition. Further, [27] also observed that the OC under the teak plantation will be higher due to the relatively high amount of organic materials that might have resulted from litter falling from the trees in the teak plantation. [28] recorded an increase in soil organic matter in afforested areas under Teak. The data on the Total ecosystem carbon echoed the same trend as that of the total above-ground carbon revealing the maximum potential of plantations under high RFZ to sequester carbon compared to other rainfall zones. However, significant variations in the SOC along the soil depth under varied rainfall regimes were observed (Fig 2). The data reveals that, the higher amount of SOC in the upper 0-20 cm layer and at the 60-80 cm layer irrespective of the locations. This may be due to deeper root activities of trees which can add to the SOC. When deeper soil profiles were examined, soil C variations between rainfall classes increased even more because rainfall can impact the vertical distribution of roots and the stability of C in deep mineral layers [29]. In general, moister and cooler areas retained more soil carbon than drier and hotter sites (Table 2). Variations in oxygen levels can cause microbial metabolism in tropical forests with heavy rainfall to switch to less productive pathways [30], which slows microbial breakdown rates and increases soil carbon storage. The highest SOC levels in these soil layers were found in areas with high RFZ. The research [31], which found that rainfall and temperature were the two most crucial factors affecting soil C stores at all depths, validated this. Interactions between climate, other environmental factors, and historical circumstances become significant over the whole temperature gradient when deeper soil profiles are taken into consideration.

Table 2: Above-ground and SOC sequestration of Teak plantation under varied rainfall regimes

	AGB (Mg/ha)	**BGB (Mg/ha)**	**TB (Mg/ha)**	**TBC (Mg C/ha)**	**SOC (Mg C/ha)**	**TCS (Mg C/ha)**
High RFZ	35.84	9.31	45.16	21.22	170.19	188.48
Medium RFZ	30.89	8.03	38.92	18.29	110.61	131.83
Low RFZ	20.33	5.28	25.62	12.04	120.83	132.87
p value	0.014	0.013	0.013	0.014	NS	<0.001

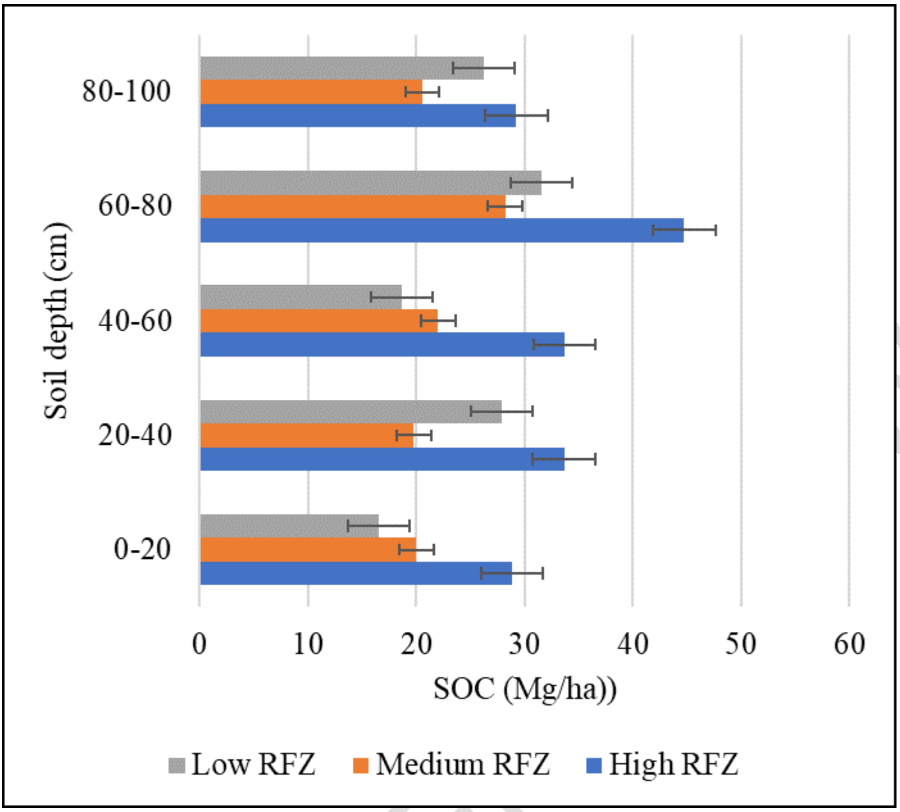

Fig. 2: Variation in SOC under varied RFZ and soil depths

4. CONCLUSION

The influence of rainfall and temperature on the above-ground and soil carbon stocks was evident in the present study. Although the study was conducted at the early ages of Teak plantations, it's imperative to understand the carbon sequestration potential of teak plantations owing to their long rotation and deciduous nature. Variations in the SOC along the soil depth were interesting and need to be explored more with the fine root activities and microbial abundance. The climatic controls suggest the sensitivity of soil C stocks in plantation forests to future climate change.

REFERENCES

[1] Menon S. Denman KL. Brasseur G. Chidthaisong A. Ciais P. Cox PM. et al. *Couplings between Changes in the Climate System and Biogeochemistry* (No. LBNL-464E). Lawrence Berkeley National Laboratory(LBNL). Berkeley, CA (United States). 2007

[2] Harris NL. Brown S. Hagen SC. Baccini A. and Houghton R.. Progress toward a consensus on carbon emissions from tropical deforestation. Winrock International and Woods Hole Research Center (Washington, DC and Woods Hole, MA.) 2012;77-9.

[3] Gianelle D. Oechel W. Miglietta F. Rodeghiero M. Sottocornola M. Cataloguing soil carbon stocks. *Science*. 2010;330(6010):1476-1477. doi:10.1126/science.330.6010.1476-c.

[4] Paul KI. Polglase PJ. Nyakuengama JG. Khanna PK. Change in soil carbon following afforestation. Forest Ecol Manag.2002;168(1-3):241-257. doi:10.1016/S0378-1127(01)00740-X.

[5] Ranganathan J, Daniels RJ, Chandran MD, Ehrlich PR, Daily GC (2008). Sustaining biodiversity in ancient tropical countryside. *Proc Natl Acad Sci U S A*;105(46):17852-17854. doi:10.1073/pnas.0808874105.

[6] Berthrong ST. Jobbágy EG. Jackson RB. A global meta-analysis of soil exchangeable cations, pH, carbon, and nitrogen with afforestation. *Ecol Appl*; 2009;19(8):2228-2241. doi:10.1890/08-1730.1.

[7] Ramankutty N. Gibbs HK. Achard F. DeFries R. Foley JA. Houghton RA. Challenges to estimating carbonemissions from tropical deforestation. Glob Change Biol.2007;13(1):51-66. doi:10.1111/j.1365-2486.2006.01272.x.

[8] Bhat KM. Timber quality of teak from managed tropical plantations with special reference to Indian plantations. Bois et Foreˆts des Tropiques. 2000;263(1):6-15.

[9] IPCC. *Land Use, Land–Use Change and Forestry; – A Special Report of the Intergovernmental Panel on Climate Change (IPCC) Cambridge University Press*. The Edinburgh Building, UK. 2000:388.

[10] Walkley A. Black IA. An examination method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci.1934;37(1):29-38. doi:10.1097/00010694-193401000-00003.

[11] Kukal SS. Rehanarasool. Benbi DK. Soil organic carbon sequestration in relation to organic and inorganic fertilization in rice–wheat and maize–wheat systems. Soil Till Res.2009;102(1):87-92. doi:10.1016/j.still.2008.07.017.

[12] Sierra CA. del Valle JI. Orrego SA. Moreno FH. Harmon ME. Zapata M. Colorado GJ. et al. Total carbon stocks in a tropical forest landscape of the Porce region, Colombia. Forest Ecology and Management. 2007; *243*(2-3):299-309.

[13] Li D. Niu S. Luo Y. Global patterns of the dynamics of soil carbon and nitrogen stocks following afforestation: a meta-analysis. New Phytol.2012;195(1):pp.172-181. doi:10.1111/j.1469-8137.2012.04150.x.

[14] Sartori F. Lal R. Ebinger MH. Eaton JA. Changes in soil carbon and nutrient pools along a chronosequence of poplar plantations in the Columbia Plateau, Oregon, USA. Agric Ecosyst Environ. 2007;122(3):325-339. doi:10.1016/j.agee.2007.01.026.

[15] Zeng X. Zhang W. Cao J. Liu X. Shen H. Zhao X.. Changes in soil organic carbon, nitrogen, phosphorus, and bulk density after afforestation of the “Beijing–Tianjin Sandstorm Source Control” program in China. CATENA.2014;118:186-194. doi:10.1016/j.catena.2014.01.005.

[16] Martens DA. Reedy TE. Lewis DT. Soil organic carbon content and composition of 130-year crop, pasture and forest land-use managements. Glob Change Biol.2004;10(1):65-78. doi:10.1046/j.1529-8817.2003.00722.x.

[17] de Blécourt M. Brumme R. Xu J. Corre MD. Veldkamp E.. Soil carbon stocks decrease following conversion of secondary forests to rubber (*Hevea brasiliensis*) plantations. *PLOS ONE*.201;38(7):69357. doi:10.1371/journal.pone.0069357.

[18] Burke IC. Mosier AR. Hook PB. Soil organic matter and nutrient dynamics of shortgrass steppe ecosystems. In: Lauenroth WK, Burke IC, eds. *Ecology of the Shortgrass Steppe*. Oxford University Press, New York: 2008.

[19] IPCC. *Climate Change* The physical science basis summary for policymakers. *Clim Change*. Intergovernmental Panel on Climate Change, Geneva, Switzerland. 2013

[20] Ahlström A. Raupach MR. Schurgers G. The dominant role of semi-arid ecosystems in the trend and variability of the land CO_2 sink. Science. 2015;22:895-899.

[21] Buvaneswaran C. George M. Saravanan S.. Teak as a short rotation crop under agroforestry systems to full fill rural needs-experiences in Tamil Nadu. In: Short Rotation Forestry for Industrial and Rural Development. Proceedings of the IUFRO-ISTS-UHF International Conference on World Perspective on Short Rotation Forestry for Industrial and Rural Development, Nauni, Solan, India, 2006.

[22] Sasidharan S. Teak plantations and wood production. In: The Teak Genome. Springer. 2021;13-25.

[23] Kollert W. Kleine M. *The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources*. IUFRO World Series. 2017; 36.

[24] Reddy MC. Priya RM. Madiwalar SL. Carbon sequestration potential of Teak plantations of different agro-climatic zones and age gradations of Southern India. Curr World Environ.2014;9(3):785-788. doi:10.12944/CWE.9.3.27.

[25] Schlesinger WH. Carbon balance in terrestrial detritus. Annu Rev Ecol Syst. 1977;8(1):51-81. doi:10.1146/annurev.es.08.110177.000411.

[26] Jones RB. Wendt JW. Bunderson WT. Itimu OA. Leucaena+ maize alley cropping in Malawi. Part 1: Effects of N, P, and leaf application on maize yields and soil properties. Agrofor Syst.1996;33(3):281-294. doi:10.1007/BF00055428.

[27] Imoro ZA. Tom-Dery D. Arnold KK. Assessment of soil quality improvement under Teak and Albizia. J Soil Sci Environ Manag. 2012;3(4):91-96.

[28] Dinakaran J. Krishnayya NSR.. Variations in soil organic carbon and litter decomposition across different tropical vegetal covers. Curr Sci. 2010;99(8):1051-1060.

[29] Jobbágy EG. Jackson RB. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecol Appl.2000;10(2):423-436. doi:10.1890/1051-0761(2000)010[0423:TVDOSO]2.0.CO;2.

[30] Teh YA. Silver WL. Conrad ME. Oxygen effects on methane production and oxidation in humid tropical forest soils. Glob Change Biol.2005;11(8):1283-1297. doi:10.1111/j.1365-2486.2005.00983.x.

[31] Marín-Spiotta E. Sharma S. Carbon storage in successional and plantation forest soils: a tropical analysis. Glob EcolBiogeogr. 2013;22(1):105-117. doi:10.1111/j.1466-8238.2012.00788.x.