Hindawi Publishing Corporation
International Journal of Forestry Research
Volume 2011, Article ID 212361, 10 pages
doi:10.1155/2011/212361

Letter to the Editor

Comment on "Carbon in Trees in Tasmanian State Forest"

Christopher Dean[1, 2]

[1] *Biological, Earth, and Environmental Sciences, University of New South Wales, High Street, Randwick, NSW 2052, Australia*
[2] *Biodiversity and Climate Institute, Department of Environment and Agriculture, Curtin University, Kent Street, Bentley, WA 6102, Australia*

Correspondence should be addressed to Christopher Dean, cdeanspace@gmail.com

Received 23 March 2011; Accepted 1 May 2011

Moroni et al. (2010) reported extant, spatially representative carbon stocks for Tasmania's State forest. Their disputation of earlier work, contextual setting, redefinition of carbon carrying capacity (CCC), methods, adoption of ecological concepts and consequent conclusions on carbon flux were investigated. Their reported data was very useful; however, the absence of sufficient context and fundamental equations was atypical of scientific publications; old-growth should have been differentiated from mature forests and wet-sclerophyll from mixed-forest, redefinition of CCC was unwarranted, and several of their arguments and conclusions appeared unwarranted. From their graphs and tables, I estimated that the carbon deficit in State forest biomass (the amount below CCC) due to commercial forestry was conservatively 29(±4) Tg (or 106(±13) Mtonnes CO_2-eq; with couped-production forests 29(±6)% below CCC) a greenhouse gas mitigation opportunity—indicating the usefulness of the existing definition of CCC. Also, using their data, earlier work on long-term fluxes accompanying conversion of wet-eucalypt forests to harvesting cycles was found to correspond to 0.56(±0.01) Mha (i.e., >1/3 of State forest), 76(±2)% of which is in the commercial production area—in contrast to their claim that earlier work referred to a small and atypical proportion.

1. Introduction

Moroni et al. [1] reported extant, spatially representative carbon stocks for the native forests and non-forest areas in Tasmania's public "State forest" of 1.5 Mha. They additionally disputed earlier work on carbon (C) dynamics, proposed a new definition of carbon carrying capacity (CCC) and advocated specific management options.

Tasmania is the State of Australia with the climate and soils most suitable to high-biomass forests (per hectare). It is the leading State exporter of wood products (mostly pulpwood for fine paper production [2, 3], and it has had multidecadal discord over forest usage, requiring repeated federal intervention and economic support. One recent controversy is accounting for the carbon footprint of the native forest industry. Correspondingly, the stated aims of the Moroni et al. article [1] were (1) to "improve understanding of forest C stocks at the landscape level" and (2) to "estimate the Carbon Carrying Capacity of Tasmanian State forest and explore the methods required to achieve and maintain Carbon Carrying Capacity".

The presentation of acreages and carbon densities of forest types in Moroni et al. was self-contained and would have fulfilled their first aim to a substantial degree. However, they added to that some arguments without supporting data, changed definitions, and lack of a historical context. They disputed earlier work on forest carbon dynamics and provided a subjective application of ecological concepts with consequent management options.

The C content and fluxes of forests, effects of anthropogenic activity, and climate change, are topics contributing to a relatively new field of science. They are crucial to climate change studies and to a basic understanding of ecology. In order to best progress the science, it is necessary to scrutinise, clarify, and correct several issues apparent in Moroni et al. These are summarised in Table 1 and engaged in the following sections.

2. Discussion

2.1. Context and Literature Survey. In the introduction and discussion in Moroni et al., the authors claim that earlier

Table 1: Summary of issues in Moroni et al. [1] addressed in this letter.

Issue	Clarification and adjustment provided
Insufficient context to display C flux science	Description of the state-of-the-science, including types of C stocks and fluxes needed to address the knowledge gaps in commercial forestry, applicable to [global] climate change science.
Earlier work contested and disputed	Logic and explanation to show context, validity and significance of earlier work.
Redefinition of CCC	Validity of the existing definition of CCC, its relevance to appropriately addressing the knowledge gap, and why their redefinition is inappropriate.
Methods and Results sections	Explanation of data standards and methods necessary for scientific reproducibility in this field, to promote more useful reporting and more usability of data.
Discussion and Conclusions sections	Ecological context allowing interpretation the C dynamics. Explanation of how their results do not support some of their discussion and conclusions.
Additional realisations	CCC and C deficit calculated [from their data] to meet the stated aim and for climate relevance. Quantified validation of contested earlier work.

work on carbon accounting in southeast Australia inappropriately:

(a) focused on high-biomass forests,

(b) did not include landscape-level effects such as fire or different stand ages,

(c) incorrectly interpreted and calculated CCC.

However, the reporting of the state-of-the-science by Moroni et al. missed key aspects such as the context of global climate change, the forest industry's historical context regarding C flux, what is required for climate change research, and the earlier spatiotemporal work such as age-related calculations, fire-impact modelling and landscape-level, and temporal forecasts.

2.1.1. Context of C Flux Research. Carbon accounting of extractive forestry activities is relevant to climate change science (as part of land-use and land-cover change) and to ecology (e.g., through biogeochemical cycles). With respect to climate change it helps quantify the degree attributable to anthropogenic greenhouse gas (GHG) emissions [4], with contributions from land use necessary for quantification of climate change positive feedback [5]; more generally, it can determine industry's carbon footprint. Moroni et al. began by stating that "Storing carbon (C) in forests" is the reason for C flux analysis of "forested landscapes". But that is only one aspect—namely, that pertaining to emission offsets—measuring young specimens and assuming a blank slate. A major part of the science (e.g., for calculation of current and future climate change) is calculating benefits from conservation of extant forest C stocks such as those in old-growth forests (in biomass, necromass, and soil), a field which entails analysis of industry-induced C fluxes (e.g., [6, 7]), assessment of long-term, pre-industry stocks, and thus determining the amount of emissions [to be "offset"], that is, the industry carbon footprint. As 25–50% of anthropogenic emissions remain in the atmosphere for 500–10,000 yrs [8–10], improved accounting for both historic and future emissions aids climate change modelling. Apart from direct reduction in forest biomass, other emissions from resource-extractive forestry, such as decomposition of wood products and changes in soil carbon are all strong contributors to anthropogenic GHG emissions and their quantification is currently poor [11]. From the 1960s in southeast Australia, wood production from native forests increased, and pulpwood export dominated [12], multiplying at least fourfold from 1970–1980 to ~2.2 Tg yr^{-1} (dry weight) and remaining near that level to 2000 [13]. Accounting for that period and for future activity relates directly to climate change and entails flux determination and historical and future CCC determination. This crucial setting explains the function of the earlier work disputed in Moroni et al.

Moroni et al. suggest that the early work on southeast Australia, by looking at the more-carbon-dense forests and older-age classes, was misplaced. However, the Tasmanian old-growth and mature, wet-eucalypt forests have been and continue to be, a prime source of high-quality sawlogs and export pulpwood [14–16]. (Wet-eucalypt forests consist of wet-sclerophyll forest and mixed-forest (high-biomass, wet-eucalypt forest with a rainforest understorey, which can form an ecotone and a seral stage between wet-sclerophyll and rainforest stands—all three being related by fire regime [17, 18])). Much of that resource extraction from the 1960s onward involved clearfelling, intense burning (with high emission from logging slash) and then either reseeding with native seed [19] or plantation development. Presently, the annual area felled of dry eucalypt, (with lower C density per unit area than wet-eucalypt), outnumbers that of wet-eucalypt, but extraction from the dryer forests began later and was at a slower rate [20]. Also, the more-mature rainforest (e.g., >200 yrs) on more fertile soils and the older mixed-forests have already been sourced for the higher-priced, deep-red myrtle sawlogs [21]. Addressing such major influences on biomass, necromass, and soil by the forest industry inherently requires study of the high-biomass and older forests.

The mathematical reason for analysing older forests and larger trees is to facilitate calculation of an ample expanse of any growth curve [22], these being necessary for: (1) forecasting carbon trajectories under different management and wildfire scenarios (e.g., [23, 24]), (2) for determining how the extant soil carbon stocks were acquired (a result of the long half-lives of some soil pools), (3) for calibrating biogeochemical models, and (4) for modelling various ecological processes. Most work to date on forest mass has been attuned to timber production, with less attention to elemental or compound fluxes (e.g., C, N and H_2O) and little to environmental consequences of the timber trade. Mass and volume research has focussed on forecasting timber outputs, especially where investment was highest, such as in silvicultured stands. For example, in the comprehensive review of biomass allometrics for southeast Australia [25], of 78 formulae, 53 were for plantations, and 25 were for native forests. Of those for native forests, the minimum and maximum DBH were 0.16(0.10) and 0.64(0.55) metres respectively (SD in brackets) ($N = 24$) and the maximum stand age was 67(66) yrs ($N = 21$), these being far below dimensions of mature and old-growth specimens (e.g., [26]). Thus, allometrics prior to 2000 had included comparatively few mature stands although mature and old-growth native forests are from where most native forest wood products in southeast Australia have been obtained and are consequently from where high C fluxes are expected to arise. New research must attend to knowledge gaps in the existing science. Indeed, from a Commonwealth government project to implement Australia's National Carbon Accounting System, it was found that more data were needed for high-biomass forests [27]. It was in that vein that the work of Keith et al. [25], Keith et al. [28], Keith et al. [29], Dean et al. [30], Dean [22], and Roxburgh et al. [24] began as part of the Cooperative Research Centre for Greenhouse Accounting, and it attempted to identify and start filling the knowledge gap. It was a founding step in advancing the science, and its contestation by Moroni et al. neglected the scientific and public-relevance contexts.

2.1.2. Spatiotemporal Aspects Disputed in the Literature Critique in Moroni et al. Regarding temporal representativeness, in the series of papers looking at Tasmanian harvesting [23, 30–32], the long-term averages of prelogging C stocks (which included all growth stages, from seedling to senescence), and the long-term, harvest-cycle-average stocks (including wood products) were used to calculate logging effects (namely, relative change in carbon stocks per unit area for conversion of native forest to harvesting cycles). Thus, they were temporally representative for that forest type. Time-based average is a method recommended by the IPCC for accounting for change in soil carbon: "best estimated over several rotations or disturbance cycles" [33], and it is equitable to also apply it to the biomass and necromass pools over the same accounting period in native forests.

Additionally, Dean and Wardell-Johnson [31] showed that such difference in long-term stocks [due to logging] were unaltered if the first logging of the native forest was prior to maturity (e.g., at 60 yrs) or when it had become old growth—a consequence of using long-term averages—and thus, the results were to some degree also representative of that forest type across the forest estate. Therefore, the statement of Moroni et al. [1]: "estimates of Carbon Carrying Capacity in the above studies are demonstrated as the difference between current forest carbon stocks and those anticipated for an area when supporting solely mature, carbon-saturated forests", is incorrect, and misleading.

As a first attempt to represent State-wide fluxes associated with extractive forestry in Tasmanian wet-eucalypt forests, Dean and Wardell-Johnson [32] modelled E1 and E+3 forest types (the latter an uneven-aged, mixed-species, low-biomass forest, once subject to light selective logging but recovered sufficiently to old-growth status)—finding approximately the same relative emissions for both forest types upon conversion to harvesting cycles. With regard to estate-wide representation of forest growth stages and detailed forest-typing—Forestry Tasmania (the affiliation of Moroni et al.) are the custodians of that data and it is not publicly available in electronic form—some printed maps are available, but they require scanning and digitising before use in a GIS. For C flux research in the absence of the regional, digital data, approximations must be made.

Also, although Moroni et al. cited Dean et al. [30] and Dean and Wardell-Johnson [32], they did not acknowledge the corresponding landscape-level and spatiotemporal work of Dean et al. [34] and Dean and Roxburgh [23] (although the latter is referenced on a research website administered by Forestry Tasmania). Those two papers included modelling of catchment-level C forecasts, including all growth stages, showing model sensitivities to gaps in the ecological knowledge, and they presented modelling of different fire management scenarios at the catchment-scale. The landscape-level work [23, 34] did not attempt to measure CCC but, nevertheless, included both natural and unnatural disturbance by including forest regrowth from the 1800 and 1939 fires, the latter being anthropogenic in origin [35]. Thus it was spatiotemporally representative. Therefore, Moroni et al.'s statement "discussions of forest C in Australia to date either lack a landscape view or have derived a landscape view from sites representing a small and atypical proportion of the forest landscape" is incorrect, and from the issue outlined above regarding major, industrial C fluxes, their statement neglects the fundamental reason for "discussions of forest C".

2.1.3. Actual Issues in Earlier Work. There were, however, errors in some of the papers which Moroni et al. [1] disputed (although not identified in their critique), and it is relevant to summarise them: (a) in Dean et al. [30], the loss of soil carbon with each disturbance event was an overestimate when considering the full soil profile and harvesting area—corrected in Dean and Wardell-Johnson [32], (b) Mackey et al. [36] similarly misplaced soil carbon emissions that might accompany long-term commercial forestry activities, as short-term emissions—noted by Roxburgh [37], and (c) in Table 1 in Dean and Wardell-Johnson [32], the forest-type potential carbon in biomass from FullCAM [27] should be halved, as they were in terms of C and not dry biomass—values then concur with Keith et al. [28] who noted that the FullCAM layer underestimates potential of wet-eucalypt C by approximately half. However, none of those errors in earlier work impacted on the calculated emissions from biomass and necromass (including decomposing wood products) accompanying commercial forestry. Note that there is a slight discrepancy between the area of tall open-forest for Australia nationwide, and the area of wet-eucalypt forests in Tasmania, owing to the minimum height for the two forest types being 30 and 34 m, respectively, but that would make a negligible difference to C accounting, at the current state-of-the-science.

2.1.4. The Redefinition of CCC. Moroni et al. [1] suggested that the basic concept of CCC was inapplicable to the forest estate; they suggested that it was incorrectly calculated by Roxburgh et al. [24], Mackey et al. [36], and Keith et al. [28] and that CCC needs redefining as a theoretical estate-wide maximum, independent of natural disturbance, but that can never be achieved. Moroni et al. incorrectly cite Nabuurs et al. [38] when they say: "Such calculations estimate the theoretical biological maximum forest carbon stocks achievable or Theoretical C Saturation [11]." The statement to which they refer in Nabuurs et al. [38] was: "The theoretical maximum carbon storage (saturation) in a forested landscape is attained when all stands are in old-growth state, but this rarely occurs as natural or human disturbances maintain stands of various ages within the forest." Moroni et al. neglect that the forests measured in Roxburgh et al. [24] and in Keith et al. [29] showed fire impacts, for example, the various fire types mentioned in Roxburgh et al. [24] and the uneven-aged stands of the [fire] obligate seeder (*Eucalyptus regnans* F. von Muell.)—being the highest biomass stands measured; how the wildfire effects and a range of stand ages were included in those earlier CCC calculations was amply explained in a CSIRO review of sequestration and GHG mitigation opportunities [37]. The CCC work of Keith et al. [29] was an initial estimate, and therefore, future work requires more spatially and temporarily representative measurements of CCC—an area of ongoing research (personal communication, Brendan Mackey, 2011). It is possible that the work of Keith et al. [29] required data on both higher- and lower-biomass stages of southeast Australian forests, but that is insufficient reason to redefine CCC. The situation was best summarised by Roxburgh [37] in his analysis of the Keith et al. series of papers on CCC: "...it requires knowledge of the actual spatiotemporal variation in natural disturbance history of the forest estate, the spatiotemporal variation in other attributes relating to site quality, and the site histories from where the data were collected."

The landscape saturation that Moroni et al. refer to was not used for landscape-level calculations nor for industry carbon footprint calculations in the Dean et al. series, Roxburgh et al. [24] and the Keith et al. series, as suggested by Moroni et al. It was only used for unit area (point or site) calculations at specific points in time, which is appropriate. CCC, although not named as such, has been applied to the USA forest estate and incorporates natural disturbance and reveals the opportunity for sequestration due to the deficit created by timber harvesting (e.g., [39–41]).

Moroni et al., after rejecting and redefining CCC, calculated and used theoretical estate-wide C saturation and stated that it was an impossible scenario. From their data, they did not present a calculation of CCC or an industry C footprint, nor did they discuss relevance of their data or results to either climate change mitigation or adaptation. The relevance of their findings to climate science was not stated.

It must also be noted that it is not possible in southeast Australia to measure the highest-biomass forests possible at the regional level, because after European colonisation, they were either sourced for large, merchantable specimens or cleared (prior to carbon accounting) and often replaced by agriculture or their remnants in the latter half of the 20th century were replaced by plantations or eucalypt regeneration [30, 42]. For example, the amount of Tasmanian rainforest burnt anthropogenically was much higher in the 20th century than in the previous two centuries and has included much attrition of old-growth stands [42]. Also, current firewood extraction from Australian native eucalypt forests is $\sim 7\,\mathrm{Tg\,yr^{-1}}$ of biomass [43]. Consequently, wherever CCC is derived from an observation of the upper limit of present-day stocks, it could well be an underestimate. Therefore, it is possible that a landscape-level CCC calculated from extant stocks, but without representative inclusion of very young regenerating stands, could offset the absence of the missing high-biomass stands, and thereby inadvertently result in a reasonably accurate estimate of CCC.

In their Discussion section, Moroni et al. unnecessarily segregated two concepts: CCC and wildfire. After their redefinition of CCC as "theoretical carbon saturation" in the introduction, they suggest in the discussion that earlier calculation of CCC was invalid, because wildfire reduces landscape-level C stocks from the level of C saturation and they imply that human-induced fires are natural. (However, wildfire may not always reduce C stocks in biomass in the short-term if it is not of stand-replacing severity, as evidenced by the high biomass of uneven-aged stands of fire-sensitive species). The standard definition of CCC, which they quoted in the introduction, includes: "...and natural disturbance regimes, but excluding anthropogenic disturbance", and therefore it already provides sufficient distinction of events. In Kyoto Protocol obligations, forest emissions from arson are classified as "natural" (e.g., [44]), however, for scientific purposes (such as in climate change modelling) the distinction must be made between "natural" and "anthropogenic". Around 50% of Australian forest fires are ignited by arson but it can be as high as 75% [45, 46]. There are also fuel-load reduction burns, specifically in forests, to prevent arson (State Forests NSW, personal communication, 2009). Moroni et al. suggest that because of wildfire (in which they include anthropogenic fire) then their redefined CCC is an impossible concept, with the implication that a measure of CCC is impossible. However, wildfire is intrinsic to both the standard definition of CCC and to the time-based average method of determining carbon budgets for forest activities.

Additionally, in their discussion, Moroni et al. state that their redefined CCC cannot be reached, because some locations have low fertility or water availability. However, the earlier work that they contested inherently included such environmentally variability in site potential through avenues such as remote sensing, growth adjusted for site index, and a range of study sites (e.g., [28, 34]). This further negates the need for their redefinition of CCC and disputation of the earlier work.

2.2. The Methods and Results Sections. Three major detractions from an appropriate-level of reporting appear in the Methods and Results sections in Moroni et al. [1]:

(a) the definition of mature forests did not suit calculations for CCC nor for spatiotemporal-specific carbon calculations,

(b) neither sufficient methods nor data were provided for the standard reproducibility of a scientific paper,

(c) error margins were not presented for some forest types and for the penultimate calculations.

Moroni et al. defined the upper limit of biomass, as stands at ≥110 yrs. That would underrepresent any specific-site's potential biomass and regional CCC, because mixing of biomass values for all the ages ≥110 yrs would produce a low value compared with potential. The age of 110 yrs may well represent "maturity" for timber harvesting purposes, but it does not represent ecological or C maturity—the latter being crucial to such accounting studies.

For example, from CAR4D [23], the estimated total C in biomass of an *E. regnans* mixed-forest, type E1.M+ (one of the types targeted for pulpwood and sawlogs), at 110, 200, 300, and 400 yrs (including losses from senescence) is 402, 594, 768, and 864 Mg ha^{-1}, respectively. The time-based averages of C in biomass for that forest type from 110–200 yrs and 200–400 yrs are 506 and 754 Mg ha^{-1}, respectively, that is, 50% higher for old-growth than for mature to early old-growth. (Such mixed forests can still have high biomass in their eucalypt component when they are beyond 500 years of age [47]). Similarly old-growth stands of ~250 years of age in the Carpathian mountains had 50% more biomass than mature stands of 100–150 yrs [48]. However, the average-aged wet-eucalypt C in biomass in Moroni et al. was 222 Mg ha^{-1}—only 4% lower than their "mature" value of 232 Mg ha^{-1} and indistinguishable within error margins.

The spatiotemporal representativeness of old-growth in the stands of ≥110 yrs in Moroni et al. was not stated. Together with the extant landscape-level stocks being below CCC values due to extensive logging of high-biomass forests and individual trees in Tasmania (Section 2.1), then a regular grid array of sampling points would not measure representative old-growth stands. Representative old-growth stands may not have been included in the analysis of Moroni et al., which would result in their potential biomass value for forests of ≥110 yrs being unrepresentative for several of the forest types they measured and, in turn, unrepresentative of landscape-level potential, that is, of CCC. Nevertheless, their values for some specific sites appear to have included old-growth forests, and their values for some forest types appear to be within expected values.

Reproducibility is the core of the scientific method, "it enables scientists to evaluate the validity of each other's hypotheses and provides the basis for establishing known truths" [49]. For example, the International Union of Crystallography has a long-standing requirement that observed and calculated structure factors are deposited with publication of structures—thus enabling alternative structure refinements. There are two main methods for biomass calculation in temperate forests: stem volume estimation and destructive sampling. Moroni et al. apparently used the stem volume method via "a variety of protocols" (plus biomass expansion factors) and a third method of "expert opinion". Allometrics relating readily measureable physical attributes of the tree to stem volume can be achieved from taper formulas, remote sensing, or mill measurements. Moroni et al. did not present the allometrics they used to show how stem volume was achieved from DBH and height data and therefore their methods are not reproducible.

Expert opinion may be satisfactory for a qualitative paper but not for a quantitative one, especially one where conclusions are based on quantitative data such as Moroni et al. and where the underlying reason for the research is to provide numeric input to another field, namely climate science. Steps used in the "expert opinion" and "various protocols" in such a report must be presented, at least as supplementary material. Additionally, Forestry Tasmania (to which Moroni et al. are affiliated) has unique access to the data and to the forests, and therefore, has the responsibility of disclosure to the scientific community. The reason for retention of that information may be that it is commercial-in-confidence. However, much of that information was probably acquired prior to commercialisation of the government department. Also, as mentioned in Moroni et al., Forestry Tasmania is the legislated administrator of the State forests' resources, and therefore, has no business competition. Sufficient formulae were provided in the Dean et al. series of papers, Roxburgh et al. [24], and in the Keith et al. series.

The penultimate values presented for total extant C stock in biomass were not assigned error margins. This may have been because the rainforest components (classes 85 and 86) did not have error margins assigned. Error margins could have been calculated in part from their Table 2 and separately for the "expert opinion" estimates. Without error margins then their conclusions, based on comparisons between forest types, have reduced weight.

2.3. Ecological Concepts and Consequences in the Discussion and Conclusion Sections. In their Results section, Moroni et al. [1] calculated a comparison of wet-eucalypt forest with rainforest, namely, their classes 4 and 5 compared with classes 85 and 86. But the reason and validity for that comparison were not stated and the error margins associated with their rainforest biomass were not stated (although they were for other forest classes)—obscuring the validity of the comparison. In their Discussion section, that change of forest types (to rainforest) was extended to cover all wet-eucalypt forests being converted to rainforest. However, in their Methods section, regarding non-eucalypt forest, they stated: "...standing-tree volumes are derived from expert opinion because little tree measurement data is available", and "little to no data was available for non-eucalypt dominated forests or non-merchantable biomass components of eucalypts. These data gaps require further study...". However, a significant portion of their Discussion and Conclusion was based

Table 2: Carbon deficit and CCC for State forests based on data in Moroni et al. [1], accounting for wet eucalypt only. Values were rounded to 3 sig. fig. not during calculations but for presentation. [a]: "110wawr" = age≥110 yrs, with and without regrowth.

#	Carbon pool	Source	C density or stock	Area (Mha)
A	Potential, E1or2, 110wawr[a]	Figure 3	303(±28.7) Mg ha^{-1}	
B	Potential, E+3orX, 110wawr	Figure 3	188(±17.3) Mg ha^{-1}	
C	Extant, E1or2 even-aged regrowth	Figure 3	7.39(±0.813) Tg	0.0950
D	Extant, E+3orX even-aged regrowth	Figure 3	2.22(±0.245) Tg	0.0520
E	Extant, native State-forests	Figure 3	164(±2) Tg	1.38
F	Potential, E1or2 even-aged regrowth, 110wawr	Area (C) × A	28.8(±2.87) Tg	0.0950
G	Potential, E+3orX even-aged regrowth, 110wawr	Area (D) × B	9.78(±0.948) Tg	0.0520
H	Deficit, E1or2 plus E+3orX	F+G-(C+D)	29.0(±4) Tg	0.147
	CCC, native State-forests	E+H	193(±23) Tg	1.38

on the transition of wet-eucalypt forest to rainforest, which requires going through the intermediate stage of mixed-forest, the old-growth stage of which has a significant portion of rainforest species biomass, for which they had "little to no data". With that lack of data for myrtle beech (*Nothofagus cunninghamii* f. Hook.) and sassafras (*Atherosperma moschatum* Labill.) (a major component of M+ rainforest biomass), their quantitative and qualitative conclusions of lower biomass for rainforest than for wet-eucalypt forest—for instance, "rainforest C density is expected to be much lower"—appear unwarranted.

Dean and Wardell-Johnson [32] showed that at the landscape-level, modelled data for both the biomass and soil carbon are higher in the rainforests of Tasmania than in its wet-eucalypt forests. That estimate for biomass was based on the FullCAM layer [27] which used productivity, soils, climate, and remote-sensing data. Thus it was more geographical than temporal, and it did not necessarily represent differences in biomass from catchment-scale forest succession. Nevertheless, it remains as a possible guide to relative biomass. The remote-sensing data from which the FullCAM layer was derived, was two-dimensional and, therefore, did not differentiate biomass between different stem heights (e.g., with eucalypts being taller than rainforest trees). Alternatively, rainforest species, being more shade tolerant, can have higher stand densities and thus possibly acquire more biomass below a shorter canopy than can eucalypts. Until more data is revealed, the conclusion of a net drop in biomass through the seral succession of wet-sclerophyll to mixed-forest to rainforest cannot be made. Also, the soil carbon pool contributes to total carbon for each forest type and that would also have to be included in a C comparison of forest types.

Mention of biomass estimates of mixed-forest specifically, are absent from the paper of Moroni et al. although they are most likely included within some of the "mature" wet-eucalypt categories, E1, E2, and E+3. They are however delineated in State forest mapping by Forestry Tasmania [50]. The mixed-forests are the successional stage between the wet-eucalypt forests of <100 years old and the rainforests, or comprise the ecotone between rainforests and the eucalypt forests with more frequent fire [17, 51]. Development of mature rainforest components in mixed-forests (e.g., myrtle beech, a common component of M+ type mixed-forest) requires a fire-free period of about 200 yrs [19, 52]. The biomass of old-growth mixed-forests, being a superposition of two forest types, is likely to be higher than that of each component separately, unless pure rainforests can exceed the eucalypt biomass in mixed-forest. A variety of C trajectories for related scenarios are portrayed in the Dean et al. series of papers. More precisely, change in biomass with forest succession for a wide range of forest types in New Zealand is detailed in Hall and Hollinger [53]: most often the early-seral stage (the pioneer stage) has higher biomass, although not always, which is in contrast with the claim of Moroni et al. that reduced biomass is "atypical ecology". In the absence of fire in the eastern USA mixed-hardwood forests (*Acer* spp., *Quercus* spp, and *Liriodendron tulipifera* L.) can be replaced by the more shade-tolerant Eastern Hemlock (*Tsuga canadensis* (L.) Carr.), with increasing C density. There will be a range of such succession possibilities in Tasmania. The different rainforest types and eucalypt habitat may be linked to interactions between fire frequency and soil chemistry [54]. The spatial representativeness of the different eucalypt types and associated rainforest types in the mixed-forests would need to be assessed before concluding on one carbon trajectory State-wide, as in Moroni et al.

Commercial forestry, through its conversion of mature and old-growth wet-eucalypt forests, together with some rainforests (Section 2.1), to eucalypt forests with an average harvesting cycle well below 200 yrs, has increased the proportional coverage of rainforest-free eucalypt stands—thereby decreasing the likelihood of occurrence of both mixed-forest and rainforest. That situation is likely to continue with the planned forestry activities in Tasmania over the next two to three decades. Thus there is little danger of a significant loss of biomass by conversion of wet-eucalypt to rainforest over the next century or two, even if the rainforest and mixed-forest had lower biomass than the rainforest-free wet-eucalypt forests.

Moroni et al. implied that without anthropogenic intervention a significant portion of wet-eucalypt forest would become rainforest, but there is no evidence for that scenario. If it was indeed probable, then there would be little mixed-forest or wet-sclerophyll forest present today. With climate change the forests of Tasmania are forecast to change to dryer forest types [32] which implies rainforest succeeded by mixed-forest then by wet-sclerophyll and so forth. The concept of "drought-free areas" in Tasmania raised in Moroni et al. is unrealised, as average annual precipitation, whatever level, does not preclude drought. Fire severity and frequency is expected to increase with climate change [55, 56] and direct anthropogenic fire in Tasmania is not expected to decline, but it increases logarithmically with population [57]. Thus, there is no evidence to suggest a reasonable likelihood for the concluding scenario portrayed in Moroni et al. of conversion to rainforest with accompanying loss in State-wide C stocks. Instead, their data could have been used to assess effects of commercial forestry, to date and into the future, or the effects of climate change.

3. Additional Realisations

A rough estimate for CCC for State forest in Tasmania can be derived from the data presented in Figure 3 of Moroni et al. [1]. As an initial and conservative estimate, one can assume that the only C deficit exists in the wet-eucalypt forests (as they have been the most targeted to date) and only in the areas of even-aged silvicultural regeneration (i.e., for E1 or 2 and E+3orX, ≤1959-to-2000s; within classes 50-to-74). Other deficits across the production area of State forest are: (1) non-clearfell logging (of eucalypt and rainforest); (2) the 83800 ha of State plantation [58]; (3) anthropogenic fire and firewood collection; (4) the deficit in E3-, E4, and E5 type (dry-eucalypt) production forests; and (5) the logging roads.

Data I extracted from Figure 3 had a procedural error margin of approximately plus or minus one line width, that is, $\pm 1.2\,\mathrm{Mg\,ha^{-1}}$ for C densities and ±200 ha for the areas: that is, a maximum of ~0.5%. Empirical error margins in C density were reported in Table 2 in Moroni et al. The potential C densities for regenerating, wet-eucalypt forests were calculated from the area-weighted C densities of forests types E1, E2, and E+3, at age ≥110 yrs, with and without regrowth (i.e., amongst forest classes 1-to-17): 348(±40), 259(±20) and 188(±17) $\mathrm{Mg\,ha^{-1}}$, respectively. Inclusion of the forests containing regrowth (which were of lower C density than without regrowth) and the lower-aged mature forests (≥110 yrs), rather than using data for old-growth alone, made the estimated potential more conservative and represented temporal variability; that is, it corresponded more to a time-based average. The potential (time-based average) stock for the wet-eucalypt, silvicultural regeneration forests is then simply their areas multiplied by the potential C densities. The C deficit is then the difference between those potential stocks and the extant stocks: 29(±4) Tg (Table 2). The CCC, at the estate-wide level (across all native forests on State-owned land, including those in reserve) is the extant stock for native forests plus the C deficit: 193(±23) Tg. The areas of regeneration would not all achieve maximum C stock simultaneously; nevertheless, as the potentials were not derived from old-growth data alone but from data for "age ≥110 yrs, with and without regrowth" forests, then the deficit and CCC are spatiotemporally representative.

An independent estimate for the C deficit, with which to compare the value of 29(±4) Tg, can be calculated from the MBAC report [58], commissioned by Forestry Tasmania to provide a carbon budget for 2007–2057. If native forest logging had ceased in 2007 and the commercial estate could sequester C at the same rate as the non-commercial estate, then from Figure 8 in MBAC [58], the State forest biomass would sequester an additional 30(±2) Tg of C by 2057 (after discounting the ~6 Tg of C for changes in soil, debris, and wood products pools associated with logging). This would suggest that the C deficit value of 29(±4) Tg calculated above from data presented in Moroni et al. is of the expected order of magnitude and is likely to be conservative (as the sequestration modelled [58] would most likely continue beyond 2057). (Note that these figures do not incorporate impacts on future growth due to climate change effects.)

From Figure 5 in Moroni et al., the area of production forest was 0.871(±0.009) Mha, and that of couped-production forest was 0.570(±0.006) Mha. The total C in production forest and couped-production forest from Figure 5 was 93(±2) and 71(±2) Tg, respectively. With the 29(±4) Tg deficit calculated above for even-aged regeneration of E1, E2, and E+3 type forests, the production and couped-production forests in Tasmania are 24(±5)% and 29(±6)%, respectively below their CCC—that is, where management has most opportunity for sequestration ventures. (Note: (1) these percentages ignore the other deficits, as mentioned above, and (2) they do not assume State-wide C saturation, but they do assume that all the commercial forestry has been in the couped-production forests.)

The area referred to in the calculations in Dean and Wardell-Johnson [31, 32], as the area subject to 50% emissions of carbon stocks in the long-term, upon conversion to harvesting cycles, is that which contains forest types E1, E2, and E+3 (i.e., wet-eucalypt forests). From Figure 3 in Moroni et al., the area of those forest types was 0.56(±0.01) Mha; from their Figure 5 this is equivalent to 38(±1)% of the whole State forest area, and combining that acreage with their partitioning in their Table 3 indicates 76(±2)% of that forest type is in the production area and 9(±1)% is in formal reserve. Those representations of 38(±1)% and 76(±2)% indicate that the statement in Moroni et al. suggesting that areas "capable of growing such very tall eucalypt forests… comprise only a small proportion of total forest area" is thus unwarranted. Additionally, major emissions with commercial forestry are relative to the differences in long-term, time-based-average C densities [31] and therefore both area and C density are of relevance to climate science, not just area alone.

4. Concluding Remarks

The numbers presented in Moroni et al. [1] on C densities and acreages for forest types are very useful to science and carbon accounting. The portrayal of the state-of-the-science of forest C dynamics by Moroni et al. missed major aspects, such as the context, and was potentially misleading. The absences of sufficient context and of fundamental equations were atypical of scientific publications. Much of the discourse in Moroni et al. was a product of their unnecessary redefinition of CCC and their use of C saturation at a landscape-scale rather than its usual usage over a specific duration for a specific forest stand, similarly for their postulation of State-wide conversion of wet-eucalypt to rainforest. The reason for their train of arguments was not stated in their paper although one possible (albeit unstated) implication is that if the current trends in commercial forestry were discontinued then that would not aid climate change mitigation. From their graphs and tables, the estimated C deficit in Tasmanian State forests (the amount below its CCC) due to commercial forestry is currently 29(±4) Tg (or 106(±13) Mtonnes CO_2-eq), with the couped-production forests 29(±6)% below CCC. That amount can be sequestered for climate change mitigation, but it was not mentioned in Moroni et al., and the deficit shows the usefulness of the existing definition of CCC. Earlier work on long-term fluxes accompanying conversion of wet-eucalypt forests to harvesting cycles was found to correspond to 0.56(±0.01) Mha, (i.e., over a third of the forest estate), 76(±2)% of which is in the commercial production area—in contrast to their claim that earlier work referred to "a small and atypical proportion of the forest landscape".

Acknowledgments

The author is indebted to discussions with Stephen Roxburgh, Nick Fitzgerald, Steve Read, Martin Moroni, Brendan Mackey, David Lindenmayer and Jamie Kirkpatrick. The author would also like to thank the reviewers for their valuable suggestions which improved the quality of the paper.

References

[1] M. T. Moroni, T. H. Kelley, and M. L. McLarin, "Carbon in trees in Tasmanian State forest," *International Journal of Forestry Research*, vol. 2010, Article ID 690462, 13 pages, 2010.

[2] P. M. Attiwill and M. A. Adams, "Harnessing forest ecological sciences in the service of stewardship and sustainability: a perspective from 'down-under'," *Forest Ecology and Management*, vol. 256, no. 10, pp. 1636–1645, 2008.

[3] ABARE and BRS, "Australian forest and wood product statistics, March and June quarters 2010," Australian Bureau of Agricultural and Resource Economics & Bureau of Rural Sciences, Canberra, Australia, 2010.

[4] P. Meir, P. Cox, and J. Grace, "The influence of terrestrial ecosystems on climate," *Trends in Ecology and Evolution*, vol. 21, no. 5, pp. 254–260, 2006.

[5] M. Gloor, J. L. Sarmiento, and N. Gruber, "What can be learned about carbon cycle climate feedbacks from CO_2 airborne fraction?" *Atmospheric Chemistry and Physics Discussions*, vol. 10, no. 16, pp. 7739–7751, 2010.

[6] M. E. Harmon, W. K. Ferrel, and J. F. Franklin, "Effects on carbon storage of conversion of old-growth forests to young forests," *Science*, vol. 247, no. 4943, pp. 699–702, 1990.

[7] M. E. Harmon, J. M. Harmon, W. K. Ferrel, and D. Brooks, "Modeling carbon stores in Oregon and Washington forest products: 1900–1992," *Climatic Change*, vol. 33, no. 4, pp. 521–550, 1996.

[8] J. T. Houghton, L. G. Meira Filho, J. Bruce et al., *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the 1992 IPCC IS92 Emissions Scenario*, Cambridge University Press, Cambridge, UK, 1994.

[9] D. Archer, M. Eby, V. Brovkin et al., "Atmospheric lifetime of fossil fuel carbon dioxide," *Annual Review of Earth and Planetary Sciences*, vol. 37, pp. 117–134, 2009.

[10] M. Eby, K. Zickfeld, A. Montenegro, D. Archer, K. J. Meissner, and A. J. Weaver, "Lifetime of anthropogenic climate change: millennial time scales of potential CO_2 and surface temperature perturbations," *Journal of Climate*, vol. 22, no. 10, pp. 2501–2511, 2009.

[11] R. A. Houghton, "Carbon flux to the atmosphere from land-use changes: 1850–2005," in *TRENDS: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn, USA, 2008, http://cdiac.ornl.gov/trends/landuse/houghton/houghton.html.

[12] R. G. Florence, "Forestry in transition in Australia: from the primacy of wood production to ecologically sustainable development," *Commonwealth Forestry Review*, vol. 72, no. 4, pp. 321–337, 1993.

[13] Tasmanian Government, *State of the Environment Tasmania. Woodchip Production Data Native Forest*, Tasmanian Government, Hobart, Australia, 2006, http://soer.justice.tas.gov.au/2003/table/332/index.php.

[14] A. D. Helms, "A giant eucalypt (*Eucalyptus regnans*) Nichols Spur, Junee, Derwent Valley, Tasmania," *Australian Forestry*, vol. 9, pp. 24–28, 1945.

[15] B. Felmingham, M. Farley, G. Lancaster, and C. Farley, "Impact of the Policy to Cease Clearfelling of Old growth Forests in 2010: An Overview of Productivity, Financial & Employment Aspects. A report prepared for the Tasmanian Forest & Timber Industries," Symetrics Business Intelligence, 2004, http://www.nafi.com.au/userfiles/publication/Felmingham%20Report.pdf.

[16] H. J. Elliot, K. C. Felton, S. J. Jarman, and M. G. Stone, *A History of Innovation: Eighty-five Years of Research and Development at Forestry Tasmania*, Forestry Tasmania, Hobart, Australia, 2008, http://www.forestrytas.com.au/publications/a-history-of-innovation.

[17] J. M. Gilbert, "Forest succession in the Florentine Valley, Tasmania," *Papers and Proceedings of the Royal Society of Tasmania*, vol. 93, pp. 129–151, 1959.

[18] D. H. Ashton and P. M. Attiwill, "Tall open-forests," in *Australian Vegetation*, R. H. Groves, Ed., pp. 157–196, Cambridge University Press, Cambridge, UK, 1994.

[19] J. Hickey, "A floristic comparison of vascular species in Tasmanian oldgrowth mixed forest with regeneration resulting from logging and wildfire," *Australian Journal of Botany*, vol. 42, no. 4, pp. 383–404, 1994.

[20] N. McCormick and J. Cunningham, "Uneven-aged forest management in Tasmania's dry-sclerophyll forests," *Tasforests*, vol. 1, pp. 5–12, 1989.

[21] TWFF, *Tasmania's Specialty Timber Industry. A Blueprint for Future Sustainability*, Timber Workers for Forests, Kingston, Australia, 2004, http://www.twff.com.au/documents/research/spectimbfinal.pdf.

[22] C. Dean, "Calculation of wood volume and stem taper using terrestrial single-image close-range photogrammetry and contemporary software tools," *Silva Fennica*, vol. 37, no. 3, pp. 359–380, 2003.

[23] C. Dean and S. H. Roxburgh, "Improving visualisation of mature, high-carbon-sequestering forests," *Forest Biometry, Modelling and Information Sciences*, vol. 1, pp. 48–69, 2006.

[24] S. H. Roxburgh, S. W. Wood, B. G. Mackey, G. Woldendorp, and P. Gibbons, "Assessing the carbon sequestration potential of managed forests: a case study from temperate Australia," *Journal of Applied Ecology*, vol. 43, no. 6, pp. 1149–1159, 2006.

[25] H. Keith, D. Barrett, and R. Keenan, "Review of allometric relationships for estimating woody biomass for New South Wales, the Australian Capital Territory, Victoria, Tasmania and South Australia," NCAS Technical Report 5b, Australian Greenhouse Office, 2000, http://pandora.nla.gov.au/pan/23-322/20020220-0000/www.greenhouse.gov.au/ncas/files/pdfs/tr05bfinal.pdf.

[26] J. H. Maiden, *The Forest Flora of New South Wales*, vol. 4, part 31, Forest Department of New South Wales, Sydney, Australia, 1908.

[27] G. P. Richards and C. Brack, "A continental biomass stock and stock change estimation approach for Australia," *Australian Forestry*, vol. 67, no. 4, pp. 284–288, 2004.

[28] H. Keith, G. Mackey, S. L. Berry et al., "Estimating carbon carrying capacity in natural forest ecosystems across heterogeneous landscapes: addressing sources of error," *Global Change Biology*, vol. 16, no. 11, pp. 2971–2989, 2010.

[29] H. Keith, B. G. Mackey, and D. B. Lindenmayer, "Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 106, no. 28, pp. 11635–11640, 2009.

[30] C. Dean, S. H. Roxburgh, and B. G. Mackey, "Growth modelling of *Eucalyptus regnans* for carbon accounting at the landscape scale," in *Modelling Forest Systems*, A. Amaro, D. Reed, and P. Soares, Eds., pp. 27–39, CABI, Oxford, UK, 2003.

[31] C. Dean and G. Wardell-Johnson, "Effective carbon management of forests requires recognition of major pools and timelines," in *Proceedings of the Adapting Forest Management to Maintain the Environmental Services: Carbon Sequestration, Biodiversity and Water*, Koli National Park, Finland, September 2009, http://www.metla.fi/tapahtumat/2009/koli/Dean.pdf.

[32] C. Dean and G. Wardell-Johnson, "Old-growth forests, carbon and climate change: functions and management for tall open-forests in two hotspots of temperate Australia," *Plant Biosystems*, vol. 144, no. 1, pp. 180–193, 2010.

[33] IPCC, "Good practice guidance for land use, land-use change and forestry," National Greenhouse Gas Inventories Programme Technical Support Unit, Institute for Global Environmental Strategies, Kanagawa, Japan, 2003, http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_contents.htm.

[34] C. Dean, S. H. Roxburgh, and B. G. Mackey, "Forecasting landscape-level carbon sequestration using gridded, spatially adjusted tree growth," *Forest Ecology and Management*, vol. 194, no. 1–3, pp. 109–129, 2004.

[35] L. E. B. Stretton, "Report of the Royal Commission to inquire into the forest fires of January 1939, in the State of Victoria and the means to be taken to prevent bush fires in the future. A summary with extracts," *The Empire Forestry Journal*, vol. 18, no. 2, pp. 269–281, 1939.

[36] B. G. Mackey, H. Keith, S. L. Berry, and D. B. Lindenmayer, *Green Carbon. The Role of Natural Forests in Carbon Storage. Part 1: A Green Carbon Account of Australia's South-eastern Eucalypt Forests, and Policy Implications*, Australian National University E Press, Canberra, Australia, 2008.

[37] S. H. Roxburgh, "Increase in carbon stocks in pre-1990 eucalypt forests," in *An Analysis of Greenhouse Gas Mitigation and Carbon Biosequestration Opportunities from Rural Land Use*, S. Eady, M. Grundy, M. Battaglia, and B. Keating, Eds., pp. 90–100, CSIRO, St. Lucia, Australia, 2009, http://www.csiro.au/files/files/prdz.pdf.

[38] G. J. Nabuurs, O. Masera, K. Andrasko et al., "Forestry," in *Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, B. Metz et al., Ed., pp. 543–584, Cambridge University Press, Cambridge, UK, 2007.

[39] S. Brown, P. Schroeder, and R. Birdsey, "Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development," *Forest Ecology and Management*, vol. 96, no. 1-2, pp. 37–47, 1997.

[40] M. Albani, D. Medvigy, G. C. Hurtt, and P. R. Moorcroft, "The contributions of land-use change, CO_2 fertilization, and climate variability to the Eastern US carbon sink," *Global Change Biology*, vol. 12, no. 12, pp. 2370–2390, 2006.

[41] C. Potter, P. Gross, S. Klooster, M. Fladeland, and V. Genovese, "Storage of carbon in U.S. forests predicted from satellite data, ecosystem modeling, and inventory summaries," *Climatic Change*, vol. 90, no. 3, pp. 269–282, 2008.

[42] J. B. Kirkpatrick, *A Continent Transformed. Human Impact on the Natural Vegetation of Australia*, Oxford University Press, Melbourne, Australia, 1994.

[43] D. Driscoll, G. Milkovits, and D. Freudenberger, "Impact and use of Firewood in Australia," CSIRO Sustainable Ecosystems report to Environment Australia, CSIRO, Canberra, Australia, 2000, http://www.environment.gov.au/land/publications/pubs/firewood-impacts.pdf.

[44] DCC, "Carbon Pollution Reduction Scheme Stakeholder Consultation," Department of Climate Change, Commonwealth of Australia, Canberra, Australia, 2009, http://www.climatechange.gov.au/government/initiatives/cprs/who-affected/~/media/publications/cprs/Reforestation%20-%20STAKEHOLDER%20CONSULTATION%20PAPER%20OCT%2009.ashx.

[45] Forestry Tasmania, *2000 Annual Report*, Forestry Tasmania, Hobart, Australia, 2001.

[46] C. Bryant, "Understanding bushfire trends in deliberately lit vegetation fires in Australia," Technical and Background Paper 27, Australian Institute of Criminology, Australian Government, Canberra, Australia, 2008.

[47] S. W. Wood, Q. Hua, K. J. Allen, and D. M. J. S. Bowman, "Age and growth of a fire prone Tasmanian temperate old-growth forest stand dominated by *Eucalyptus regnans*, the world's tallest angiosperm," *Forest Ecology and Management*, vol. 260, no. 4, pp. 438–447, 2010.

[48] W. S. Keeton, M. Chernyavskyy, G. Gratzer, M. Main-Knorn, M. Shpylchak, and Y. Bihun, "Structural characteristics and aboveground biomass of old-growth spruce-fir stands in the eastern Carpathian Mountains, Ukraine," *Plant Biosystems*, vol. 144, no. 1, pp. 148–159, 2010.

[49] Y. Gil, E. Deelman, M. Ellisman et al., "Examining the challenges of scientific workflows," *Computer*, vol. 40, no. 12, pp. 24–32, 2007.

[50] M. G. Stone, "Forest-type mapping by photointerpretation: a multi-purpose base for Tasmania's forest management," *Tasforests*, vol. 10, pp. 15–32, 1998.

[51] K. W. Cremer, "Eucalypts in rain forest," *Australian Forestry*, vol. 24, no. 2, pp. 120–126, 1960.

[52] J. Tabor, C. McElhinny, J. Hickey, and J. Wood, "Colonisation of clearfelled coupes by rainforest tree species from mature

mixed forest edges, Tasmania, Australia," *Forest Ecology and Management*, vol. 240, no. 1–3, pp. 13–23, 2007.

[53] G. M. J. Hall and D. Y. Hollinger, "Simulating New Zealand forest dynamics with a generalized temperate forest gap model," *Ecological Applications*, vol. 10, no. 1, pp. 115–130, 2000.

[54] J. Read, "Soil and rainforest composition in Tasmania: correlations of soil characteristics with canopy composition and growth rates in *Nothofagus cunninghamii* associations," *Australian Journal of Botany*, vol. 49, no. 2, pp. 121–135, 2001.

[55] I. Mansergh and D. Cheal, "Protected area planning and management for eastern Australian temperate forests and woodland ecosystems under climate change—a landscape approach," in *Protected Areas: Buffering Nature against Climate Change. WWF and IUCN World Commission on Protected Areas Symposium*, pp. 58–72, Canberra, Australia, June 2007, http://www.wwf.org.au/publications/cc-report.pdf.

[56] R. J. Williams, R. A. Bradstock, G. J. Cary et al., *The impact of climate change on fire regimes and biodiversity in Australia—a preliminary assessment*, Unpublished report to the Australian Government, CSIRO, Canberra, Australia, 2009.

[57] S. Venevsky, K. Thonicke, S. Sitch, and W. Cramer, "Simulating fire regimes in human-dominated ecosystems: Iberian Peninsula case study," *Global Change Biology*, vol. 8, no. 10, pp. 984–998, 2002.

[58] MBAC, *Forestry Tasmania's Carbon Sequestration Position*, MBAC Consulting Group Pty, Melbourne, Australia, 2007, http://www.forestrytas.com.au/assets/0000/0369/CARBON_200712_MBAC_report_on_FT_carbon_stocks.pdf.