SOUTH-EASTERN AUSTRALIA EUCALYPT FOREST CASE STUDY

Canopy leaves: Lamington National Park, Queensland. Photo: Heather Keith.

INTRODUCTION

The location of the study region is shown in Figure 2. Our approach draws on existing methods plus some innovations necessary to deal with various problems that arise, including: a) stand ages are often unknown and stands are commonly multi-aged; b) disturbance and land-use history might be unknown; c) forests that have remained undisturbed by human land-use activity usually occur in rugged topography; and d) little information exists about the growth curves over time of many tree species. Analyses drew on a range of inputs: remote sensing data, spatially explicit environmental variables and site data that sampled carbon pools.

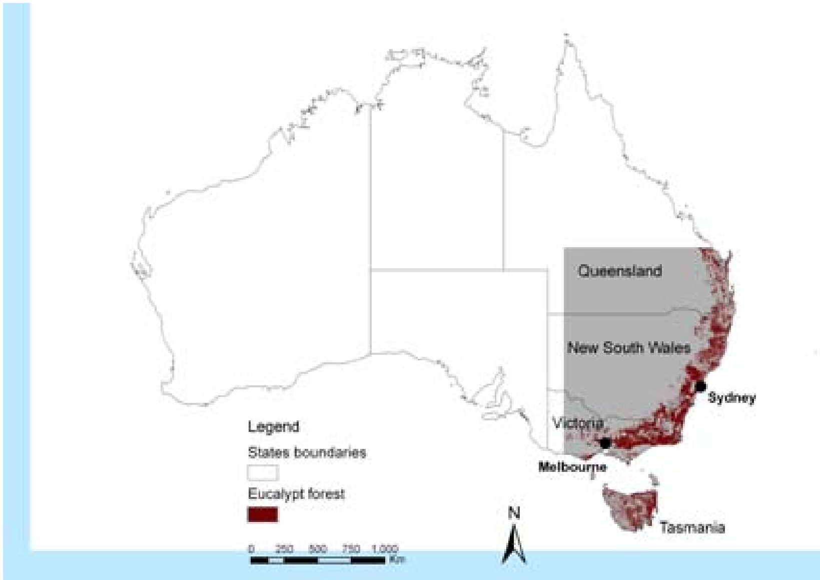


FIGURE 2: LOCATION OF THE CASE STUDY REGION, AND THE NATURAL EUCALYPT FORESTS IN SOUTH-EASTERN AUSTRALIA

The analytical framework developed to estimate the carbon carrying capacity of eucalypt forests in south-eastern Australia was based on knowledge of ecological processes as represented in Figure 3. Gross primary productivity (GPP) is the annual rate of carbon uptake by photosynthesis. Net primary productivity (NPP) is the annual rate of carbon accumulation in plant tissues after deducting the loss of carbon dioxide by autotrophic (plant) respiration (R_a). This carbon is used for production of new biomass components—leaves, branches, stems, fine roots and coarse roots—which increments the carbon stock in living plants. Mortality and the turnover time of carbon in these components vary from weeks (for fine roots), months or years (for leaves, bark and twigs) to centuries (for woody stem tissues). Mortality produces the dead biomass components that provide the input of carbon to the litter layer and soil through decomposition. The carbon that is consumed by herbivores and micro-organisms is emitted as carbon dioxide to the atmosphere by the process of heterotrophic respiration (R_h). The remaining carbon contributes to accumulation in the soil. Accumulation

CARBON POOLS IN NATURAL FORESTS

(pools as an average per cent of total carbon stock)

Living aboveground biomass (43%): *Corymbia maculata*, south coast NSW. Photo: Sandra Berry.

Litter layer (2%): *E. fastigata* forest, Shoalhaven catchment. Photo: Sandra Berry.

Dead biomass in stags (6%): *E. regnans*, central highlands, Victoria. Photo: Luke Chamberlain.

Root biomass (8%): *E. delegatensis*, Bago State Forest, southern NSW. Photo: Heather Keith.

Coarse woody debris (7%): *E. obliqua*, Mt. Wellington, Tasmania. Photo: Rob Blakers.

Soil profile (34%): Red Dermosol, Bago State Forest, southern NSW. Photo: Heather Keith.

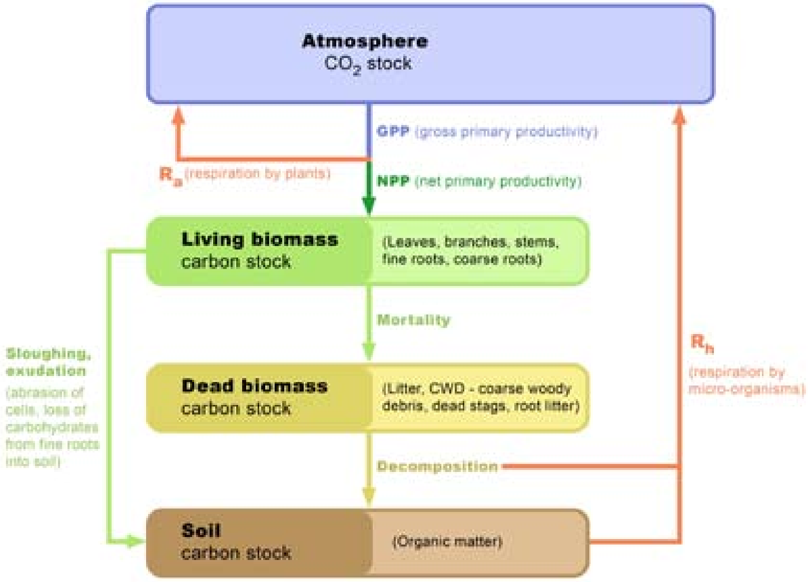


FIGURE 3: FRAMEWORK ILLUSTRATING THE ECOLOGICAL PROCESSES INVOLVED IN ESTIMATING THE CARBON CARRYING CAPACITY OF NATURAL FORESTS (THAT IS, GREEN CARBON STOCKS).

Boxes represent stocks of carbon, and arrows represent fluxes (movement) of carbon.

of carbon in the plant and soil reservoir is highly dependent on the residence time of each of the components of living and dead biomass and soil. Little information about these processes exists for natural forests. Therefore, our empirical approach to estimate carbon carrying capacity used site-specific data from natural forests largely undisturbed by human land-use activity.

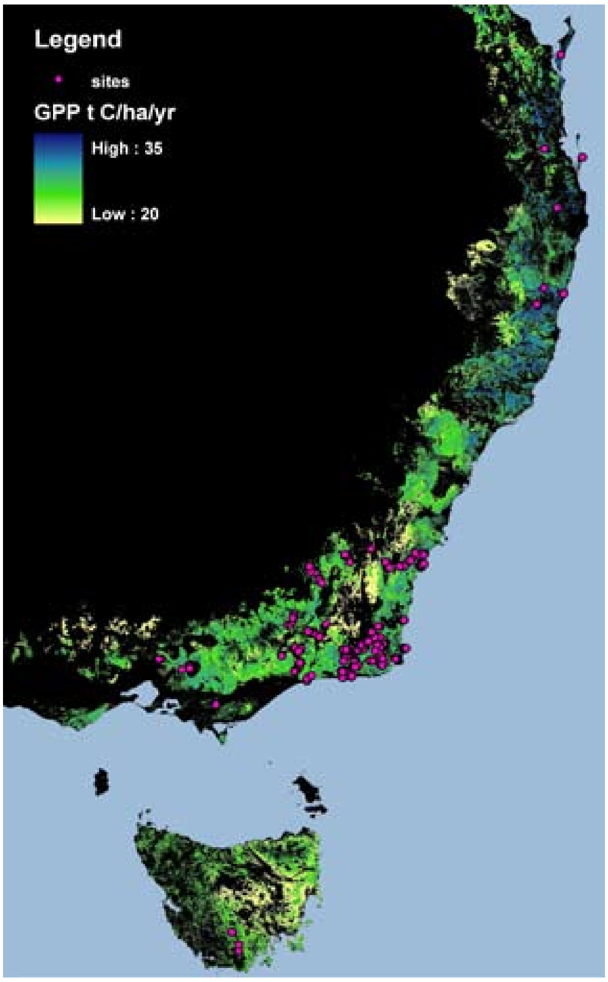
The outcome of our analyses was an estimate of the carbon carrying capacity of the natural eucalypt forests in south-eastern Australia[10], which are shown in Figure 2. Analyses were restricted to forested land with environmental conditions that were within the numerical ranges sampled by our site data—yielding an area of approximately 14.5 million ha.

SUMMARY OF METHODS

Gross primary productivity (GPP) was calculated using the method of Roderick et al. (2001), as applied by Berry et al. (2007; see also Mackey et al. 2008). The source data were a continental time series of GPP modelled from the NASA MODIS (MOD13Q1) satellite data (Barrett et al. 2005) at a resolution of 250 m. The value of GPP used was the maximum annual value for the period from 1 July 2000 to 30 June 2005 (the maximum was used in order to exclude periods of major disturbance such as the 2003 bushfires).

---

10 These forests were defined as Major Vegetation Groups 2 and 3 in the National Vegetation Information System (NVIS 2003), where tree height is greater than 10 m and canopy cover is greater than 30%.



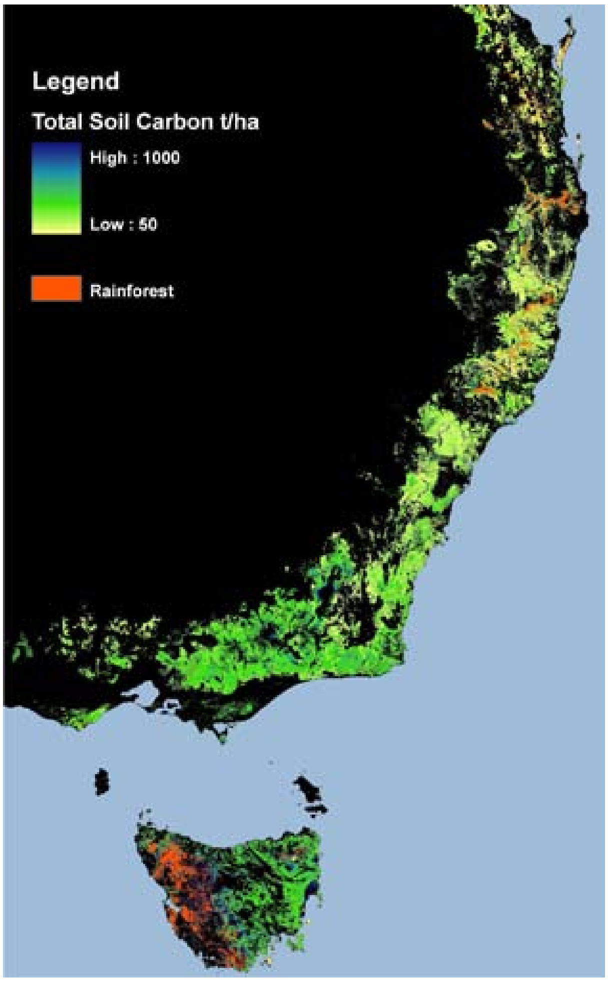
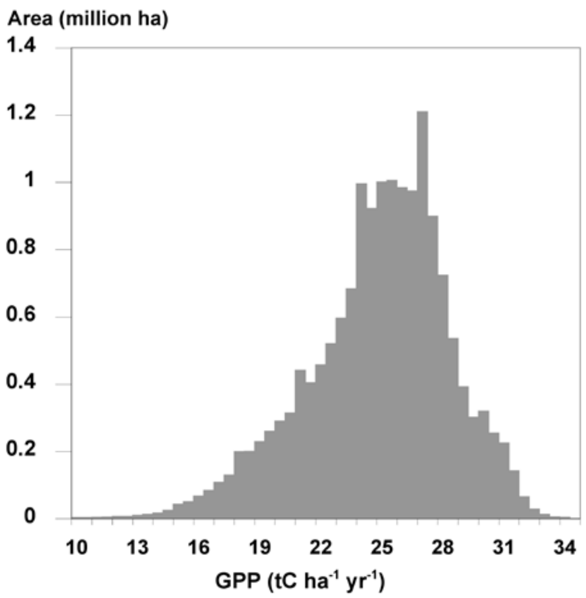


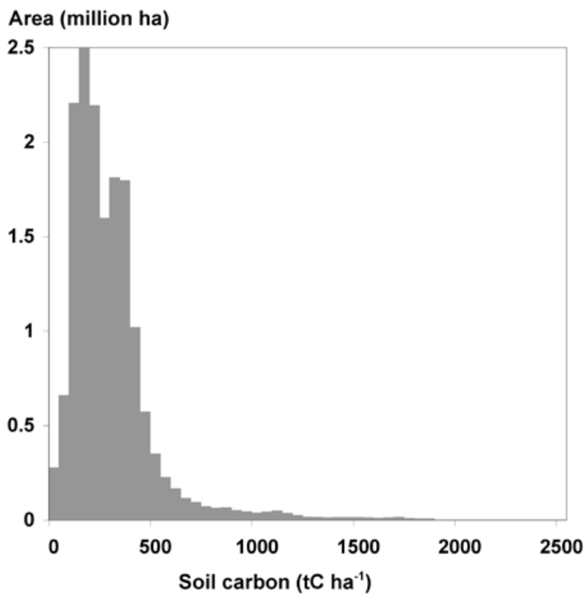
FIGURE 4: ESTIMATED GPP FOR THE STUDY REGION AND THE LOCATION OF FIELD SITES

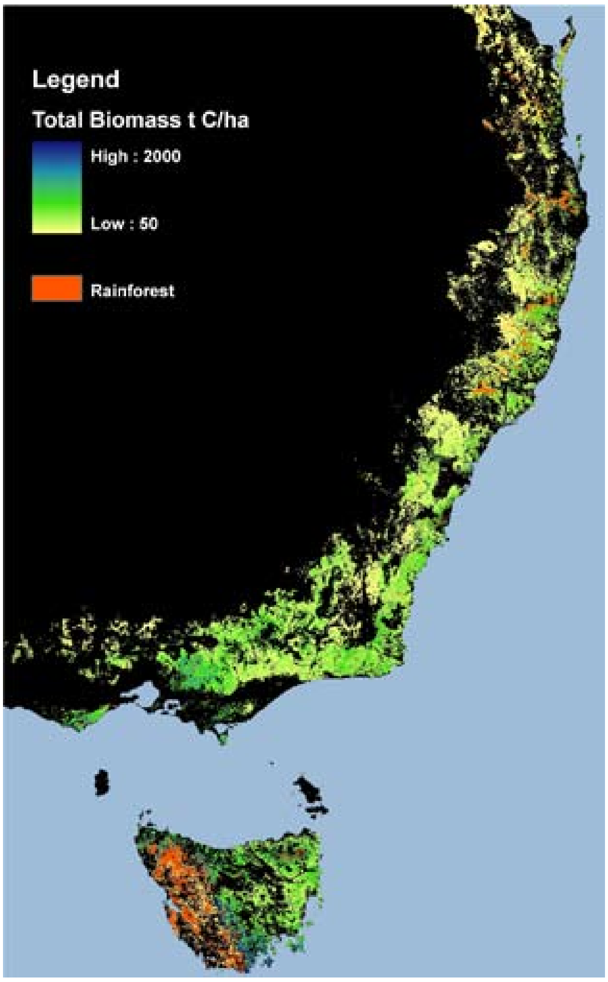
The distribution of GPP by area is shown in the histogram, with a range of 12 to 33 t C ha^{-1} yr^{-1}.

FIGURE 5: SPATIAL DISTRIBUTION OF TOTAL SOIL CARBON

The distribution of soil carbon by area is shown in the histogram, with a range of <50 to 2000 t C ha^{-1}.







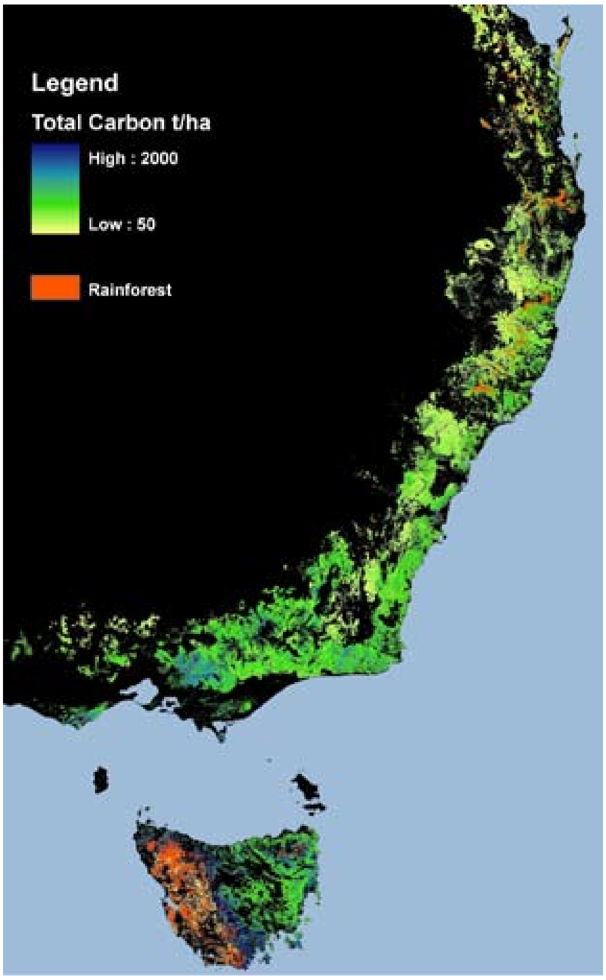
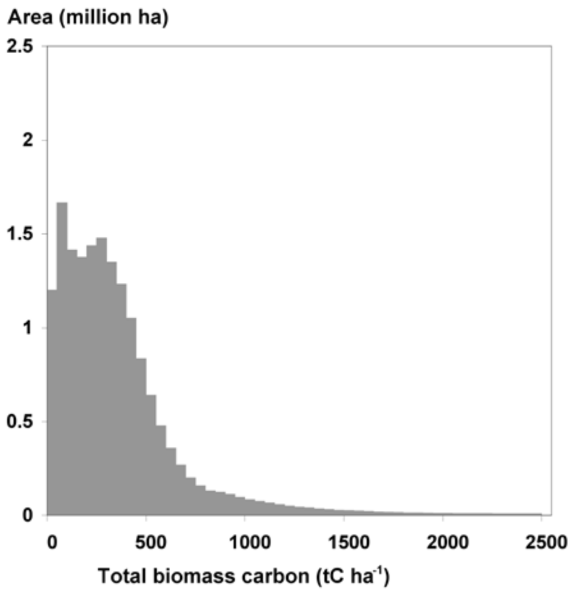


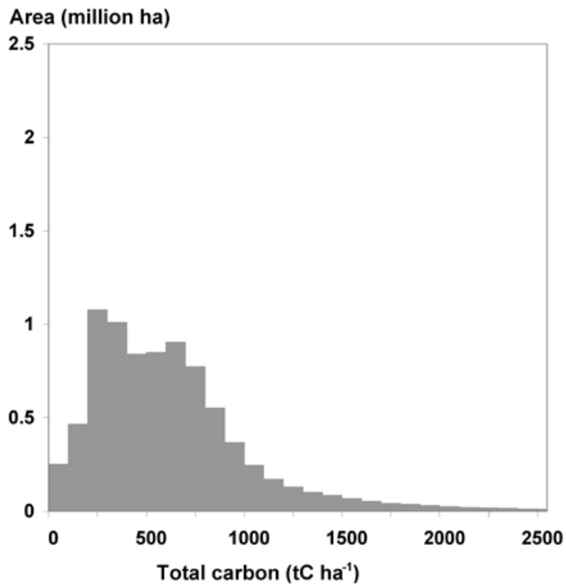
FIGURE 6: SPATIAL DISTRIBUTION OF THE TOTAL BIOMASS CARBON PREDICTED FROM THE MODEL

The distribution of total biomass carbon by area is shown in the histogram with a range of <50 to 2500 t C ha^{-1}.

FIGURE 7: SPATIAL DISTRIBUTION OF TOTAL CARBON PREDICTED FROM THE MODEL (THAT IS, THE CARBON CARRYING CAPACITY)

The distribution of total carbon by area is shown in the histogram, with a range of <50 to 2500 t C ha^{-1}.





The proportion of carbon uptake used for biomass production is represented by the ratio of NPP:GPP. Relationships between GPP, NPP and biomass have been assumed to have constant coefficients in many modelling studies in the literature (for example, Waring et al. 1998). There has, however, been controversy about this issue (Keeling and Phillips 2007). We reviewed a global data set of 28 forest sites where NPP and GPP were measured and found that the ratio varied from 0.29 to 0.61. We statistically related NPP:GPP ratios with the corresponding environmental conditions for each site. This relationship improved the prediction of the proportion of carbon uptake used for biomass production compared with using a constant fraction of 0.47, which is used commonly in the literature. NPP was then estimated spatially by multiplying GPP for each grid cell in the GIS database by the NPP:GPP ratio predicted for that cell[11].

The living biomass carbon stock represents the balance between carbon accumulation from NPP and loss by mortality to the dead biomass carbon stock. The relationship between NPP and biomass carbon stock was investigated empirically using data from 240 sites in south-eastern Australia. These sites were in undisturbed mature forests and the data were collated from a range of sources and ecological studies. These field data were converted to spatial estimates of living biomass using appropriate allometric equations. Dead biomass includes the litter layer, coarse woody debris and standing dead trees. These components were measured only at some sites and, where there were no data, averages for forest types were used from a synthesis of information in the literature.

Coarse woody debris, central highlands, Victoria. Photo: Peter Halasz.

11 As noted in the introduction, full details of methods will be made available in a scientific paper currently in preparation.

The relationship between NPP and biomass stock is confounded by other factors that influence allocation and turnover rates. We investigated the use of environmental variables in conjunction with remotely sensed estimates of NPP as correlates to predict biomass. We used available spatial data for a selection of climatic, substrate and topographic environmental variables. A water availability index was also calculated and used as an ecologically meaningful expression of the interaction between precipitation and radiation. The effect of the environmental variables was described by a multiple regression model that accounted for 47 per cent of the variance in predicting total biomass in south-eastern Australian forests.

Soil carbon estimates were calculated from spatial data layers of soil depth, bulk density and soil carbon concentration as mapped by the Australian Soil Resource Information System (CSIRO 2007), and compared with site data where they existed. These values are for soil organic carbon only and would be higher if estimates of soil charcoal were available.

The analyses resulted in spatial predictions of living and dead biomass carbon and soil carbon, given prevailing environmental conditions, and assuming that the forests were ecologically mature and had not been disturbed by human activities. If the input field-site data have sampled landscape variability adequately, the effect of differences in climate, substrate, topography, wildfires and other natural disturbances should be reflected in these estimates. The statistical models enable the mean and standard deviation of carbon values to be calculated, where the latter can be interpreted in part to reflect the natural variability of conditions that affect forest growth in the region.

In this way, we were able to estimate and generate maps of the study region's natural carbon carrying capacity, thereby producing for the first time a baseline green carbon account for these natural forests.

RESULTS

The spatial distributions of the main components of the green carbon budget for the eucalypt forests of south-eastern Australia are shown for GPP (Figure 4), soil carbon (Figure 5), total biomass carbon (Figure 6) and total carbon (Figure 7) and are summarised in Table 1. Areas of rainforest are marked on these maps, but the carbon stock has not been predicted for them because there were insufficient site data from rainforests available for this study to predict biomass accurately. Predictions of carbon stocks have been made only within the numerical range of the input site data.

TABLE 1: SUMMARY OF THE CARBON STOCK OF EACH COMPONENT OF THE CARBON CARRYING CAPACITY OF THE EUCALYPT FORESTS OF SOUTH-EASTERN AUSTRALIA

Carbon component	Soil	Living biomass	Total biomass	Total carbon
Total carbon stock for the region (Mt C)	4060	4191	5220	9280
Carbon stock ha^{-1} (t C ha^{-1})	280 (161)	289 (226)	360 (277)	640 (383)

Carbon stock per hectare is represented as a mean and standard deviation (in parentheses), which represents the variation in modelled estimates across the region. The study region covers an area of 14.5 million ha, representing 2 279 358 pixels at 250 m resolution.

Accumulation of carbon in biomass is related positively to NPP. Wide variance occurs, with many sites having a lower biomass for a given NPP than this maximum. This high spatial variability reflects the influence of environmental variables and natural disturbance regimes on the residence time of carbon in biomass components. The high spatial variability in carbon stocks across the region is represented as high standard deviations in Table 1, with particularly high values of carbon stocks covering only relatively small geographic areas.

The highest biomass carbon stocks (more than 1500 t C ha^{-1}) are in the mountain ash (*Eucalyptus regnans*) forest in the Central Highlands of Victoria (based on the forest types where data were available). This is cool temperate evergreen forest with a tall eucalypt overstorey and dense *Acacia* spp. and temperate-rainforest tree understorey. Environmental conditions are ideal for plant growth and accumulation of biomass, with high rainfall, moderate temperatures, moderately fertile and deep soils and in a sheltered valley. Highest biomass occurs in stands with two or three age cohorts of overstorey trees and rejuvenated understorey trees, which have resulted from partial stand-replacing wildfires (see Lindenmayer et al. 1999; Mackey et al. 2002).

Forest types where biomass is relatively low for a high NPP occur in the subtropics of northern coastal New South Wales and southern Queensland, where tree longevity is relatively lower and decomposition rates are higher than in temperate forests, resulting in lower accumulation of living and dead biomass. Sites with limiting environmental conditions—such as low water availability, infertile or shallow soils—also have lower biomass for a given NPP. Additionally, some forest stands might not be at maximum age and hence biomass, because the site history was uncertain.