Chapter 17
Heterogeneity in Ecosystem Services: Multi-Scale Carbon Management in Tropical Forest Landscapes

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OBJECTIVES

Landscape management is increasingly focused on trade-offs among various ecosystem services. For example, while clearing forests may produce timber and provide land for agriculture, it also releases significant amounts of carbon to the atmosphere, influencing the global climate system. Evaluating the tradeoffs among ecosystem services is made difficult by the inherent heterogeneity of social–ecological systems at many levels of ecological (and social) organization. For example, the provisioning of ecosystem services may change with the size of organisms, the species composition of communities, and with variation in landscape pattern through time. In this chapter, we introduce common methods for estimating the amount of carbon stored in forests and explore the implications of spatial and temporal heterogeneity for carbon management at the landscape level. Assuming little prior knowledge of these issues, these exercises will enable students to:

1. Estimate standing stocks of carbon using methods appropriate to different spatial scales;
2. Explore the social–ecological implications of the relationship between tree sizes, wood density, and carbon stocks;
3. Quantitatively evaluate the relative impact of forest loss versus forest fragmentation on landscape-level carbon storage; and
4. Contrast the impact of alternative management regimes on total carbon stocks as well as flows through time.

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In Part 1, we introduce basic methods appropriate for carbon accounting at the level of individual trees and forest stands. In Part 2, we explore why variation in landscape composition as well as landscape arrangement are both important to consider. Lastly, in Part 3, students use a simple landscape simulation model (in Excel) to explore how management activities may impact carbon storage in forests, including a consideration of nonlinearities in the amount of carbon stored over space and time. The only material needed for the exercise is access to a computer and the spreadsheet entitled **carbon.xlsx**, downloadable from the book webpage. Your instructor may wish to assign Part 1 as a "pre-class" assignment (to be completed prior to coming to class) in order to save classroom time for Parts 2 and 3.

Part 1. Estimating Carbon Stocks: From Trees to Forest Stands

Forests are "living storage units" for carbon. As plants grow, they sequester atmospheric carbon (CO_2) through photosynthesis. The sequestered carbon is incorporated into plant structures (e.g., stems and foliage) so that approximately 50% of the biomass, or dry weight, of plants is carbon. This stored carbon (referred to as **carbon stocks)** is only released back into the atmosphere after plants (or their parts) break down, usually through decomposition or sometimes fire. The **flux** of carbon through forests is thus determined by the relative rates of photosynthesis (sequestration) and decomposition (emissions). Deforestation and logging accelerate the release of carbon stored in vegetation back into the atmosphere through tree death and decomposition. Because elevated levels of atmospheric carbon are driving global climate change, scientists are increasingly interested in quantifying the impacts of forest management on forest carbon.

One method commonly used to quantify forest carbon storage combines models of tree allometry with nondestructive measurements of trees (e.g., measurements collected as part of standard forest inventories). For example, **allometric models** have been developed that relate tree diameter to total tree biomass. Tree diameter is typically measured during forest inventories as **DBH**, or diameter-at-breast-height, so-called because it is measured at a standard height of 130 cm above the ground. Applying a DBH-biomass allometric model to forest inventory data therefore produces an estimate of biomass for the inventoried forest. This can be transformed into an estimate of carbon based on the relationship between biomass and carbon (on average, 47% of the biomass of tropical trees is carbon) (Martin and Thomas 2011).

EXERCISE 1: Predicting Carbon Stocks Using Diameter at Breast Height (DBH) for a Common Neotropical Tree Species

Anacardium excelsum is a rather conspicuous tree in the forests of Panama. It is known locally as "espavé," from the Spanish phrase "es para ver" ("is to see"), a reference to its tall height and utility as a look-out point when climbed. *A. excelsum* is harvested for timber, but is also used to make furniture, boats, and dugout canoes.

Here, you will estimate the carbon stored in *Anacardium excelsum* trees of different diameters using an allometric model that relates tree DBH to biomass (Chave et al. 2005).

- Open the workbook **carbon.xlsx**, and go to the worksheet **Tree**.
- The allometric model of Chave et al. (2005) has been entered for you in the spreadsheet as an Excel function [cell **C12**]. Apply this function to *A. excelsum* trees with DBH ranging from 10–150 cm by adding an "=" sign in front of the function, then copying and pasting into the cells below.
- Multiply the resulting biomass estimates by 0.47 to convert biomass to carbon [cells **D12** to **D26**].
- Plot carbon vs. DBH.

Q1 What do you notice about the relationship between carbon stored and tree DBH (diameter at breast height)?

Q2 Considering this relationship, what type of tree or stand would be most valuable to managers aiming to maximize standing carbon stocks?

Q3 List some ecosystem services other than carbon storage provided by forests. Include at least one example each of services with ecological, economic as well as cultural value. Are any of these other ecosystem services dependent on individual trees? Do you expect these services to vary with the size and species of individual trees? Explain why or why not? (*HINT:* see Ellison et al. 2005; Manning et al. 2006 or Salick et al. 2007).

EXERCISE 2: Contrast the Carbon Stocks of a Hardwood and Softwood Tree Species

Wood density varies widely among tree species and impacts carbon storage by determining how much carbon is stored per unit of tree volume. The general allometric model you used in Exercise 1 can be applied to all species of tropical trees using average values for wood density; however, using species-specific wood density values greatly improves accuracy (Chave et al. 2005). Here, you will contrast carbon storage by two species of trees native to Central America. The first, *Dalbergia retusa* ("cocobolo" in Spanish, "rosewood" in English), is a hardwood species that is used by artisans for fine wood carving; it has a wood density of 0.86 g cm^{-3}. The second, *Ochroma pyramidale* ("balsa") is a light wood used locally to raft down rivers; it has a wood density of 0.16 g cm^{-3}.

- Go to the worksheet **Tree2**.
- The allometric model of Chave et al. (2005) has been entered for you in the spreadsheet as an Excel function. Apply this function to *D. retusa and O. pyramidale* trees with DBH ranging from 10–110 cm (add a "=" sign in front of the functions in cells **C14** and **E14**, then copy and paste into the rest of the cells in the column).

- Multiply the resulting biomass estimates by 0.47 to convert biomass to carbon [cells **D14**–**D24** and **F14**–**F24**].

Q4 Contrast the carbon stocks of a *D. retusa* and *O. pyramidale* individual of the same diameter. What is the difference in carbon storage among the two individuals? At what DBH would an *O. pyramidale* tree store the same carbon as a 30 cm DBH *D. retusa* tree?

Q5 Can you think of other groups of organisms in which the efficiency of ecosystem service provisioning differs among species? (*HINT:* for an example related to pollination, see Brittain et al. 2013).

EXERCISE 3: Scaling From Individual Trees to a Forest Plot

Barro Colorado Island, Panama, has been a site of intensive ecological research since 1923. Today, its lowland moist tropical forests are some of the best studied in the world. Beginning in 1982, and then every 5 years since 1985, a detailed inventory has been conducted of 50 ha of mature tropical forest on the island (Condit 1998; Hubbell et al. 1999, 2005). As part of the inventory, the DBH and species name of each tree exceeding 10 cm DBH are recorded. Here, you will work with inventory data from a one-hectare subplot on Barro Colorado Island, in which 416 individual trees belonging to 82 species were measured. (*NOTE:* Data from this site were also used for the exercises in Chapter 15 to explore spatial statistics). The data are contained in the worksheet **Plot**.

- The worksheet **Plot** contains a list of all of the individuals measured in the 1 ha plot, including their ID number, species name, wood density, and DBH.
- Apply the allometric model of Chave et al. (2005) to all the trees measured in the plot (the function has been entered for you in cell **F2**; copy it to the cells below). (*NOTE:* biomass is now being calculated in Mg (megagrams or metric tons) rather than kg).
- Convert biomass to carbon by multiplying by 0.47.
- Sum the carbon stored in all the trees in the 1 ha plot. Record your answer.

EXERCISE 4: Impact of Selective Logging on Forest Carbon Storage

Selective logging is typical in the tropics and differs from the clear-cut harvesting approach common in temperate coniferous forests. Trees in less diverse temperate conifer forests, which tend to be dominated by one or a few species, may have the same end-use and thus are easily processed at the same mill. However, the diverse panoply of tree species typically encountered in tropical forests may have a wide variety of end-uses that require different processing technologies. As a result, tropical loggers will typically remove only a subset of the tree species present, often targeting

hardwood species that reach the largest diameters when mature. This form of "high-grading" can have important implications for ecosystem services. Here, you will compare the impacts on plot-level carbon stocks of two approaches to logging.

First, simulate selective logging of the 10% of individuals with the largest diameters.
- Using the worksheet **Plot**, sort the list of trees by DBH.
- Select the 42 trees with the largest diameters at breast height, and delete them (as though you were harvesting 10% of the largest trees in the plot).
- Record the new carbon stock total for the plot.

Second, simulate logging of a random selection of 10% of individuals in the 1 ha plot (as though you were clear-cutting 10% of individuals in the forest stand, without regard to species identity or tree size).
- Start again with the original plot of trees. (You can either undo your changes to make sure the trees you deleted are back in the plot or download the file again and save as another name).
- In column **H** in the worksheet **Plot**, use Excel's random number generator "**=RAND()**" to generate a random number for each tree in the plot.
- Select the column, Copy it, then go to **Paste Special > Paste Values** (this ensures that the random numbers will not be recalculated every time you sort the worksheet).
- Sort the worksheet by the random number column.
- Select the first 42 trees for simulated harvest (i.e., those with the highest random numbers). Delete these trees, thereby removing a random selection of 10% of trees from the plot.
- Record the new carbon stock total for the plot.

Q6 Determine the relative impact of removing 10% of the largest diameter trees as opposed to removing 10% of trees via random selection on total carbon storage. Does removal of 10% of trees reduce total carbon storage by 10%?

Q7 Which natural disturbances remove random vs. large diameter trees? How does this compare to anthropogenic disturbances? Are there differences in tropical versus temperate forests?

OPTIONAL: Field Exercise

A field exercise has been developed building on Part 1 that provides an opportunity for students to estimate carbon stocks using their own forest sampling data. For the exercise, students establish local sample plots and collect DBH measurements and species names for trees in the plots. As in Exercise 3, these data are converted to estimates of carbon stocks per unit area, allowing students to compare carbon stocks among sample plots and/or land-cover and forest types. Please see Powers and Velásquez-Runk (2016) which is part of the online supplementary materials for this book chapter.

Part 2. Impact of Forest Loss and Forest Fragmentation on Landscape-Level Carbon Stocks

EXERCISE 5: Relationships Between Land Cover and Carbon Stocks

The relationship between biomass and carbon stocks (as in Part 1) means that land-cover types with more vegetation—and, in particular, with more large trees—store more carbon above ground. The following table presents the average above-ground carbon stocks for one hectare of six common land-cover types in eastern Panama. Keep in mind that these values are averages: initially, the carbon stocks of fallow areas will be lower than the average presented in Table 17.1, and eventually they will surpass them. Later, in Part 3, we will address these assumptions by incorporating growth curves into a temporally explicit model.

Q8 Briefly consider the impacts of transitions among the different classes (e.g., converting mature forest to pasture or allowing pasture to regenerate as secondary forest). Which land-cover transitions would result in the greatest loss of carbon stocks (i.e., emissions of carbon to the atmosphere)? Which result in the greatest increase in carbon stocks (i.e., sequestration of atmospheric carbon)? (*NOTE:* Some of the changes occur over very short time periods whereas others occur over many years.)

Q9 Just as there is variation in carbon storage among tree species (Part 1), there is also variation in carbon storage among sites. For example, forests on rich soils may reach greater statures and therefore store more carbon then nearby forests on poor soils. How could this be taken into account by researchers aiming to provide general values for forest carbon for an entire region? (*HINT:* Pelletier

Table 17.1 Mean above-ground carbon stocks in 1 ha of six common land-cover classes in eastern Panama (based on Pelletier et al. 2012).

Class	Description of Forest type	Above-ground carbon $(Mg\ C\ ha^{-1})$
Mature forest	Old-growth and mature secondary forest	140
Old secondary forest	Secondary forest that is approx. 40 years old	129
Young secondary forest	Secondary forest that is approx. 10 years old	48
Fruit-tree agroforest	Orchard dominated by fruit trees, sometimes also containing fuelwood, timber, fiber, and medicinal tree species	50
Fallow	Crop field or pasture recently abandoned (regrowing forest less than 5 years old)	36
Pasture or annual crop field	Land used for growing annual crops or for cattle grazing	4.2

et al. 2012 explore this problem and show that it can have important impacts on landscape-level carbon estimates).

EXERCISE 6: Exploring the Effects of Forest Loss and Forest Fragmentation on Carbon Stocks

The total carbon stored in a landscape is affected not only by the amount of each land-cover type present, but also by the configuration of those land-cover types. More fragmented forests have more **edges**, which are exposed to more wind and other disturbance than are forest interiors. As a result, forest edges typically store less carbon than forest interiors (Laurance et al. 1998). The following exercise explores the impacts of these two factors (forest loss and forest fragmentation) on landscape-level carbon stocks.

You will examine three hypothetical landscapes for the exercise (Figure 17.1). In these landscapes, each pixel represents one hectare (100×100 m²). All three landscapes contain the same proportion of mature forest and pasture (0.50 each); however, the degree of forest fragmentation increases from left to right. As a result, the number of forest edge pixels also increases from left to right.

- In the **carbon.xlsx** workbook, go to the **Landscape calculations** worksheet. Notice that the total number of pasture, mature forest edge, and mature forest interior pixels in each of the three landscapes of Figure 17.1 has been tallied for you (cell **B8** and below).
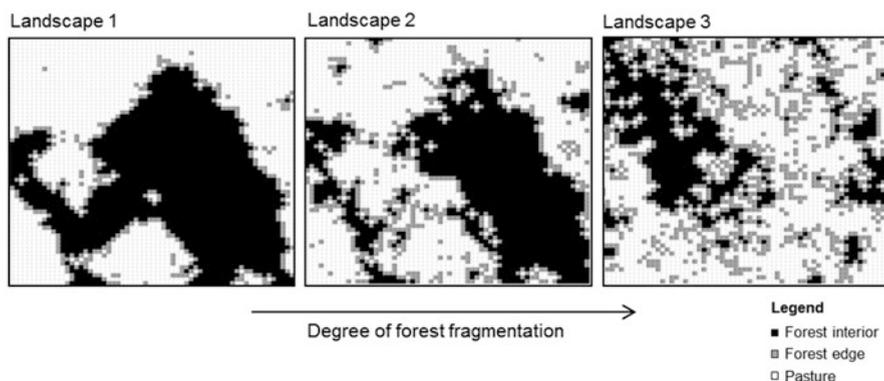

Figure 17.1 Three landscapes with identical proportions of pasture and mature forest but differing levels of forest fragmentation. Fragmentation creates forest edge (*grey pixels*), with different environmental conditions producing different ecosystem services than interior forest (*black pixels*). (*NOTE:* The landscapes were created using QRule neutral landscape software introduced in Chapter 6—with levels of clumping set at $H=0.9$, $H=0.5$, and $H=0.1$. You may wish to experiment with other configurations, and/or introduce additional land-cover types to these landscapes)

- Enter the above-ground carbon estimates for mature forest (interior) and pasture from Table 17.1 into the spreadsheet (cell **C8** and below), then multiply these values by the number of hectares of each land-cover type (column **B**) to calculate total carbon for these land-cover categories.
- To incorporate edge effects, assume that mature forest edges store 10% less carbon than mature forest interior. Reduce the mature forest carbon value in Table 17.1 by 10%, and use this as an estimate of mature forest edge carbon stocks [cells **C10, C16, C22**].
- For each landscape, sum across land-cover types to calculate total landscape-level carbon stocks in cells **D11**, **D17**, and **D23**.

Q10 What is the effect of forest fragmentation on landscape-level carbon stocks? How does the effect of fragmentation on carbon stocks compare to net losses of forest? (*HINT:* try recalculating landscape-level carbon stocks after "converting" an additional proportion of forest pixels to pasture pixels in each landscape).

Q11 Determine the sensitivity of your answer to the previous question to your assumptions regarding the carbon stocks of edges. Assume that forest edges lose carbon not just because of natural disturbances along edges (e.g., increased tree death due to wind damage) but also because of increases in human activities, such as fuel wood collection. Recalculate landscape-level carbon stocks assuming a reduction of 40% of carbon in edge forest relative to interior forest. Now what is the effect of fragmentation on landscape-level carbon stocks?

Q12 Consider the variety of ecological and abiotic differences between forest edges and forest patch interiors. Can you think of other ecosystem services that might differ between forest patch edges and interiors? Explain the differences you might expect, and why. (*HINT:* see Laurance et al. 2011).

Part 3. Impacts of Alternative Forest Management Regimes on Carbon Stocks and Fluxes Through Time

So far you have explored the effects of tree size and land-cover types on carbon stocks *at a single point in time*. However, trees sequester carbon as they grow and emit it when they die and decompose—these are *fluxes* or flows of carbon *through time*. You have already seen that large trees store disproportionately more carbon, but perhaps counterintuitively, younger trees actually have higher rates of carbon sequestration (because they are growing quickly). This has led some managers to argue that the best way to use forests to mitigate climate change is to clear mature forests and replace them with young, fast growing forests that sequester a lot of carbon. The following exercise tests this idea over a one-hundred year time period for a hypothetical tropical landscape. It uses the model contained in the **StockFlux** worksheet in the **carbon.xlsx** Excel workbook.

EXERCISE 7: Stocks vs. Flux in a Forest Landscape Through Time

In this exercise, you will compare how different forest management regimes change the stocks and fluxes of carbon in a forest landscape through time. The **StockFlux** worksheet contains a series of tables that track changes in stand age, carbon stocks, and carbon flux through time in response to forest logging and regrowth. The landscape is 10,000 ha, and the model tracks forest growth in 10-year age cohorts every 10 years over a 100-year time period. Rather than estimate carbon based on the DBH of individual trees in a stand, the model uses a carbon growth curve based on stand age. This is less accurate than estimating carbon using DBH, but is more efficient for estimating carbon over large areas.

- Open the **StockFlux** worksheet.
- Examine **Excel.Table 1** embedded within the worksheet, which shows how the forest stand age distribution of the landscape changes through time.

(*NOTE:* At the beginning of the simulation, the entire landscape (10,000 ha) is old-growth (100+ years old) **[cell K6]**, and remains this way in the absence of logging).

- Examine the graphs at the top of the sheet showing carbon stocks and fluxes over time.

Q13 Assuming no forest logging, how much above-ground carbon is stored in trees in the 10,000 ha of old-growth forest? How much carbon is sequestered and emitted through time? (*HINT:* Answers to this question also appear in embedded **Excel.Table 3** (carbon sequestered) and **Excel. Table 4** (carbon emitted) within the spreadsheet).

You can simulate logging in the model by entering the number of hectares to cut each decade in cell **B2**. Each decade, the oldest available forests will be cut, and the table will track the fate of these cut forests (which move into the youngest stand age in the following time period) and the growth of uncut forests for each 10-year period. The resulting changes in above-ground tree carbon through time are shown in **Excel.Table 2** (change in carbon stocks), **Excel.Table 3** (carbon sequestered), and **Excel.Table 4** (carbon emitted) within the worksheet.

- Log 1% of the landscape each year (10%/decade) by entering "1000" in cell **B2**.

Q14 Describe what happens to the forest stand age distribution and carbon stocks and fluxes under a 10%/decade logging regime. After 100 years, what is the mean stand age [cell **M16**], the landscape-level carbon stocks [cell **L31**], and cumulative carbon sequestered [**M44**] and emitted [**M57**]? How do these differ from the unlogged forest?

- Explore the impact of alternative forest management regimes on landscape-level carbon stocks/flux. Open the sheet **Landscape balance**, which has been linked to the sheet **StockFlux** used in the previous exercises.
- Simulate different management regimes by systematically varying the area of forest cut per decade [cell **B2** in worksheet **StockFlux**]. Record the impacts of

each simulation on: mean stand age, total carbon stocks, and cumulative carbon sequestration and emission using the table provided in worksheet **Landscape balance** (see worksheet for further instructions).

- Create two graphs: (1) total carbon stock (*Y*-axis) *vs.* mean stand age (*X*-axis), and (2) carbon sequestered and carbon emitted (both on the *Y*-axis) *vs.* mean stand age (*X*-axis)

Q15 How do carbon stocks and fluxes vary with stand age? Are the relationships linear? What type of forest has the highest carbon stocks? Highest carbon flux?

- Next, calculate the carbon balance for the landscape after 100 years of each simulated management regime in column **G** of the table in the **Landscape Balance** worksheet.

Q16 It has been suggested that replacing old-growth forest with young quickly growing forests would be a good way to help mitigate climate change. Based on your simulation results, do you agree?

In the simple model that you used in this exercise, old-growth forests reach a carbon equilibrium after 80 years of age (i.e., carbon storage ceases to increase). Recent research (e.g., Luyssaert et al. 2008) suggests that old-growth forests may in fact continue to accumulate carbon as they age. The model also assumes that when trees are cut, their entire carbon stocks are emitted. This may not be the case if, for example, timber is used for construction and so does not immediately decay.

Q17 If these two primary model assumptions discussed above are not true, would it change your answer to *Q16*? How? (*HINT:* see Harmon et al. 1990).

CONCLUSIONS

Managing forests for multiple ecosystem services requires a careful consideration of the heterogeneity of these services across scales and through space and time. These challenges become especially obvious when trying to implement policies to enhance ecosystem service provisioning that require reliable measurements of the services. For example, international climate negotiations over the past decades have included discussions on financial incentives that would either reduce emissions from deforestation and forest degradation (e.g., the United Nation's "REDD" programme), or increase reforestation and afforestation (e.g., the Kyoto Protocol's Clean Development Mechanism). But questions such as how best to measure the gains in carbon stocks, how to ensure that deforestation isn't simply shifted in space, and what historical time period to use as a reference point, continue to be challenging. With thoughtful management, forests can play an important role in climate mitigation while contributing to local livelihoods and providing other ecosystem services.

REFERENCES AND RECOMMENDED READINGS[1]

*Balvanera P, Kremen C, Martinez-Ramos M (2005) Applying community structure analysis to ecosystem function: examples from pollination and carbon storage. Ecol Appl 15:360–375. *Presents a framework for considering how community attributes other than simple species richness affect ecosystem functioning, and how species within a community differ in their relative contributions to the function. The framework is applied to case studies of watermelon pollination by bees and carbon storage by trees. Management implications are discussed.*

Brittain C, Williams N, Kremen C et al (2013) Synergistic effects of non-Apis bees and honey bees for pollination services. Proc R Soc B 280:20122767

Bunker DE, DeClerk F, Bradford JC et al (2005) Species loss and above-ground carbon storage in a tropical forest. Science 310:1029–1031

Chave J, Andalo C, Brown S et al (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145:87–99

Condit R (1998) *Tropical forest census plots*. Springer, Berlin

*Coomes OT, Grimard F, Potvin C (2008) The fate of the tropical forest: carbon or cattle? Ecol Econ 65:207–212. *Discusses alternate land-use scenarios proposed as carbon-emission reduction strategies in the tropics, and their economic costs and risks to rural households and communities. Based on a case study from Panama.*

Ellison AM, Bank MS, Clinton BD et al (2005) Loss of foundation species: Consequences for the structure and dynamics of forested ecosystems. Front Ecol Environ 3:479–486

Harmon ME, Ferrell WK, Franklin JF (1990) Effects on carbon storage of conversion of old-growth forests to young forests. Science 247:699–702

Hubbell SP, Foster RB, O'Brien ST et al (1999) Light gap disturbances, recruitment limitation, and tree diversity in a Neotropical forest. Science 283:554–557

Hubbell SP, Condit R, Foster RB (2005) Barro colorado forest census plot data. http://ctfs.arnarb.harvard.edu/webatlas/datasets/bci

Laurance WF, Laurance SG, Delamonica P (1998) Tropical forest fragmentation and greenhouse gas emissions. For Ecol Manage 110:173–180

*Laurance WF, Camargo JLC, Luizão RCC et al (2011) The fate of Amazonian forest fragments: a 32-year investigation. Biol Conserv 144:56–67. *Synthesizes findings from a 30-year experimental study of forest fragmentation in central Amazonia. Provides an excellent introduction to what is known about the impacts of tropical forest fragmentation on forest microclimate, tree recruitment and mortality, and various other species groups, from beetles to birds.*

Luyssaert S, Schulze ED, Börner A et al (2008) Old-growth forests as global carbon sinks. Nature 455:213–215

Manning A, Fischer J, Lindenmayer D (2006) Scattered trees are keystone structures—Implications for conservation. Biol Conserv 132:311–321

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[1]*NOTE:* An asterisk preceding the entry indicates that it is a suggested reading.

Martin AR, Thomas SC (2011) A reassessment of carbon content in tropical trees. PLoS One 6, e23533

*Pelletier J, Kirby KR, Potvin C (2012) Consequences of carbon stock uncertainties on emissions reductions from deforestation and forest degradation in developing countries. Forest Policy Econ 24:3–11. *Explores how forest heterogeneity, different field sampling protocols, and alternative allometric models contribute to uncertainty in forest carbon stock estimates. The impacts of this uncertainty on carbon emission baselines, and thus on projections of how much a given project could contribute to carbon-emission reductions, are discussed.*

Powers J, Velásquez-Runk J (2016) Field exercise: quantifying aboveground biomass stocks in different land-use and forest types. Online supplementary material for Heterogeneity in ecosystem services: multi-scale carbon management in tropical forest landscapes (Chapter 17). In: Gergel SE, Turner MG (eds) *Learning landscape ecology: A practical guide to concepts and techniques*. Springer, New York.

Salick J, Amend A, Anderson D et al (2007) Tibetan sacred sites conserve old growth trees and cover in the eastern Himalayas. Biodivers Conserv 16:693–706

Ziter C, Bennett EM, Gonzalez A (2013) Functional diversity and management mediate aboveground carbon stocks in small forest fragments. Ecosphere 4:art85