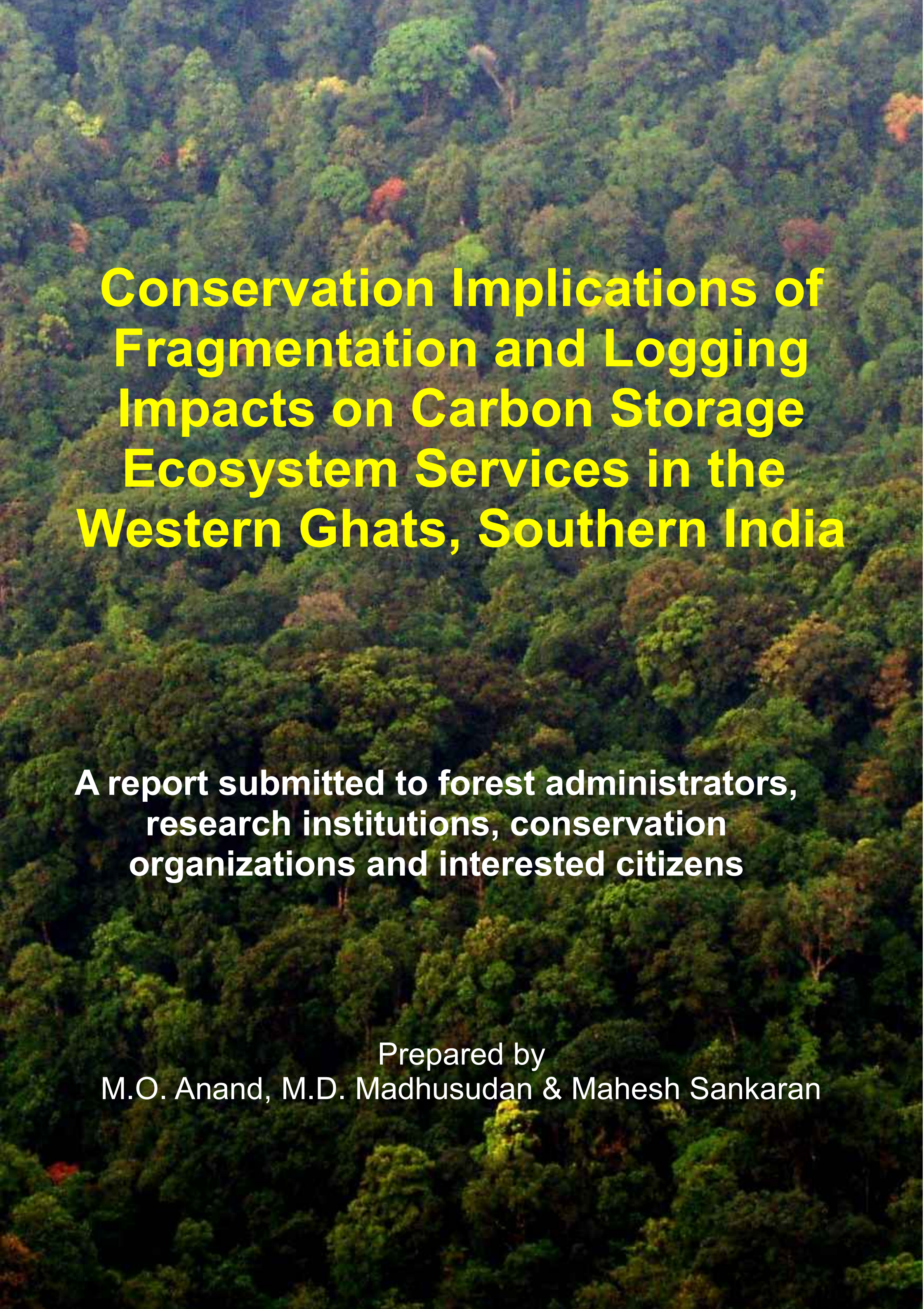

Conservation Implications of Fragmentation and Logging Impacts on Carbon Storage Ecosystem Services in the Western Ghats, Southern India

A report submitted to forest administrators, research institutions, conservation organizations and interested citizens

Prepared by
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Summary

By storing half of all carbon in terrestrial vegetation and regulating global climate, tropical forests provide a vital ecosystem service. While habitat fragmentation across this biome increasingly alters the nature of these forests, resulting changes in carbon storage are poorly assessed. This project in the Kodagu district of the Western Ghats biodiversity hotspot assessed these effects on carbon storage. The study documented significant declines in carbon storage services both in trees and soils of forest fragments (sacred groves) when compared to contiguous forests (reserve forests and wildlife sanctuaries). Importantly, these declines were a result not only of reduced basal area of trees in the fragments but also changes in the species functional compositions. There are indications that losses in carbon storage in the fragments are likely to increase as time progresses, highlighting the need for urgent conservation interventions. In order to take better advantage of conservation incentives such as payments for ecosystem services, the forest department and local communities need to develop a mutually beneficial scheme for both the stakeholders who own the forest fragments (mostly forest department) and those that mostly affect and use the lands (local community).

Keywords: *Wet evergreen forests, forest fragmentation, carbon storage, conservation, Western Ghats.*

Introduction

The landscape of Kodagu, in the Western Ghats of southern India, is dotted with over a thousand tropical forest fragments, set amidst rolling hillsides of shade coffee plantations and lush valleys with rice paddies. These fragments hold tremendous cultural and religious importance to local communities such as the Kodavas, and are protected as Devarkadus, or sacred groves[1]. These pockets of forest are also extremely important from an ecological point of view, serving as corridors and sheltering a rich and unique biodiversity[2], and providing people with a number of ecosystem services such as crop pollination and climate regulation through carbon storage.

Tropical forests are particularly important contributors to carbon storage ecosystem services[3]. A hectare of mature and undisturbed forest can store over 500 tonnes of carbon in its trees, and even greater quantities of carbon in its soils. But as forests, through fragmentation, get isolated and exposed to edges, trees die, species compositions slowly change and soils get warmer and drier, increasing the chances of carbon losses both above ground and below ground[4].

The main goal of this study was to describe patterns of change in tree communities and carbon stocks in the fragmented forests of Kodagu's Devarkadus. The specific objectives of the project were to:

1. Quantify above-ground and below-ground carbon storage in Kodagu's Devarkadus and compare these with contiguous forests (Reserved Forests and Protected Areas).

2. Assess differences between Devarkadus and contiguous forests in physical structure and species composition of tree communities.

3. Compare the dominant tree species of Devarkadus with those in contiguous forests in terms of plant functional traits that are related to carbon storage.

Study site description

The study was carried out between 1st October 2010 and 30th September 2011 in Kodagu District, Karnataka State, India. Sampling was carried out in twelve forest fragments (Devarkadus) and eight contiguous forests sites. The twelve Devarkadu sites (listed on the next page) all fell within the Virajpet Territorial Forest Division while the eight contiguous forests sites were distributed across the Virajpet Territorial Forest Division as well as the Madikeri Wildlife Division. The study sites ranged in elevation from 650 to 900 m above sea level, represented by the mid-elevation wet evergreen forest type dominated by *Mesua ferrea* and *Palaquium ellipticum*[5]. The Deverkadus were embedded in a complex landscape matrix comprising both tree-covered shade coffee plantations and open rice paddies.

Sl. No.	Site name	Habitat type	Latitude	Longitude
1	Aabailu	Contiguous	11.97866	75.86724
2	Ammathi	Fragment	12.26144	75.83751
3	Arji	Fragment	12.18201	75.79672
4	Arapattu	Fragment	12.23576	75.73536
5	Biruga	Contiguous	11.98366	75.94756
6	Devanageri	Fragment	12.25838	75.80714
7	Halagunda	Fragment	12.28341	75.78312
8	Halligattu	Fragment	12.13908	75.93233
9	Hathur	Fragment	12.17004	75.87442
10	Heggala	Contiguous	12.14502	75.77296
11	Kadanur	Fragment	12.21853	75.78178
12	Kedamullur	Contiguous	12.13684	75.70713
13	Kirgur	Fragment	12.14686	75.96359
14	Kodagadal	Fragment	12.37909	75.64886
15	Kokka	Contiguous	12.08964	75.83418
16	Makutta	Contiguous	12.14322	75.79533
17	Margodu	Fragment	12.3551	75.78915
18	Palangala	Contiguous	12.18525	75.71556
19	Pookala	Contiguous	12.06299	75.82723
20	Ruduraguppae	Fragment	12.15656	75.85566

List of study sites. Note: Map of study sites provided inside the back cover.

Methods

Vegetation sampling

In each of these 20 sites, 2 to 4 square vegetation plots of 30m side were sampled. Plots were placed at random within a site, but not at locations that were (1) closer than 50m from a habitat edge, (2) closer than 30m from a major road/footpath, (3) had evidence of other human disturbances such as soil removal or livestock grazing and (4) sites that have recently (in the last five years) been logged. Within each plot, every individual tree over 10cm girth at breast height (gbh) was identified to species/genus level. For each individual tree thus sampled, gbh was measured using a tape measure and height was estimated using a laser range finder (Bushnell Yardage Pro Sport 450 Rangefinder). Canopy openness readings were also taken at several locations within each plot.

Soil sampling

At each vegetation plot, three 30cm deep soil cores were collected using a soil auger. Each soil sample was cleaned to remove roots and stones and sieved through a 2mm mesh and air-dried in a dry, well-ventilated room for 72 hours. A minimum of 0.25kg of each sample was retained from each sample. In the laboratory, samples were oven-dried at 110°C for 72 hours to remove all moisture. They were then ground by hand, and passed through a 0.5mm mesh. The fine particles that passed through the mesh were used for subsequent analysis. Total carbon content was estimated by the dry combustion method using a Carbon-Nitrogen analyser (TruSpec Leco C-N analyzer) available at NCBS.

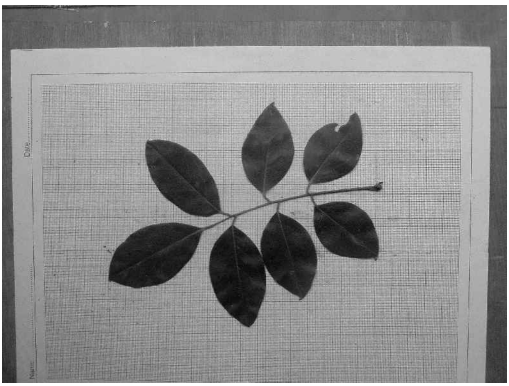
Trait data collection

Five samples of fully-expanded, undamaged sun-exposed leaves were collected from ten individuals of 49 tree species that were encountered during sampling. Leaves on adult trees, which were mature, well-exposed to the sun and minimally damaged were collected. These leaves were collected during vegetation sampling, and opportunistically even outside vegetation plots. Soon after collection, the fresh leaves were pressed onto a graph paper and photographed, in order to estimate their area.

The leaves were then air-dried in a well-ventilated room for 72 hours, and stored in paper bags. Air-dried leaves were then oven-dried at 60°C for 72 hours and ground to pass through a 0.5mm mesh in a leaf grinder. Ground leaves were then used to assess various leaf traits such as specific leaf area (leaf area/dry mass), leaf nitrogen content and leaf carbon content.

For some important species traits such as wood density and seed mass, data were collected from floras and other secondary sources.

Clockwise from above: Taking measurements in a vegetation plot, soil core collection and leaf area measurement.

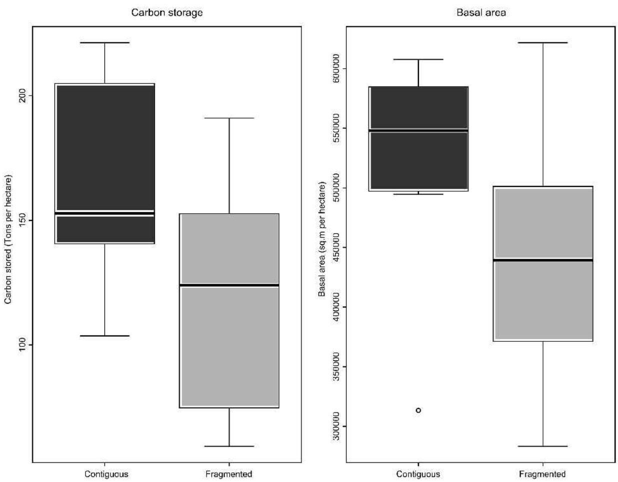


Results
Fragments store less aboveground carbon

A total of 8755 stems were sampled, including 3942 in contiguous forests and 4833 in fragmented forests. The dominant species in contiguous forests were *Dimocarpus longan*, *Palaquium ellipticum*, *Syzgium munronii*, *Humboltia brunonis*, *Reinwardtiodendron anamalaiense* and *Aglaia simplicifolia*, which together accounted for over 30% of all the stems in contiguous forests. In the fragments, *Dimocarpus longan*, *Nothopegia beddomei*, *Coffea robusta* and *Memecylon wightii* accounted for 37% of all the stems.

Above-ground carbon storage

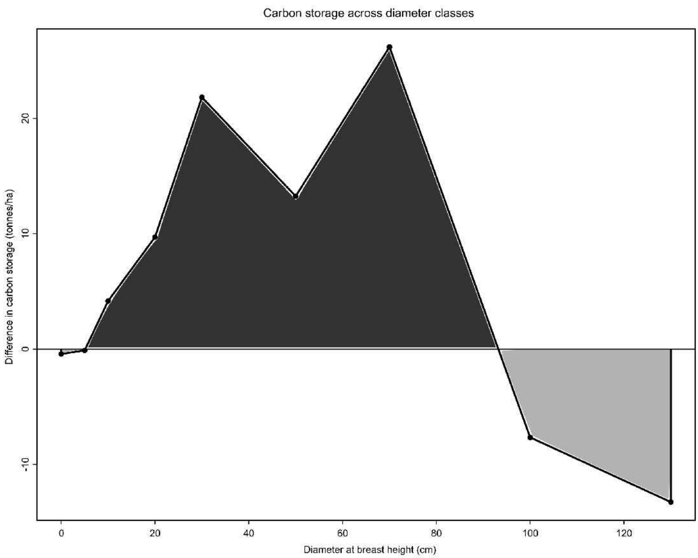
Contiguous forests stored 165.2±40.9 (mean±1 SD) tonnes carbon/ha in above-ground biomass, which was significantly higher than fragments which stored 119.8±43.2 tonnes carbon/ha (ANOVA F=5.5, p<0.05). The main reason for this difference is differences in the physical structure of the two habitats – fragments had significantly lower basal area than contiguous forests.



Differences in aboveground carbon (left) and basal area (right) between contiguous forests and forest fragments.

Differences in distribution across populations

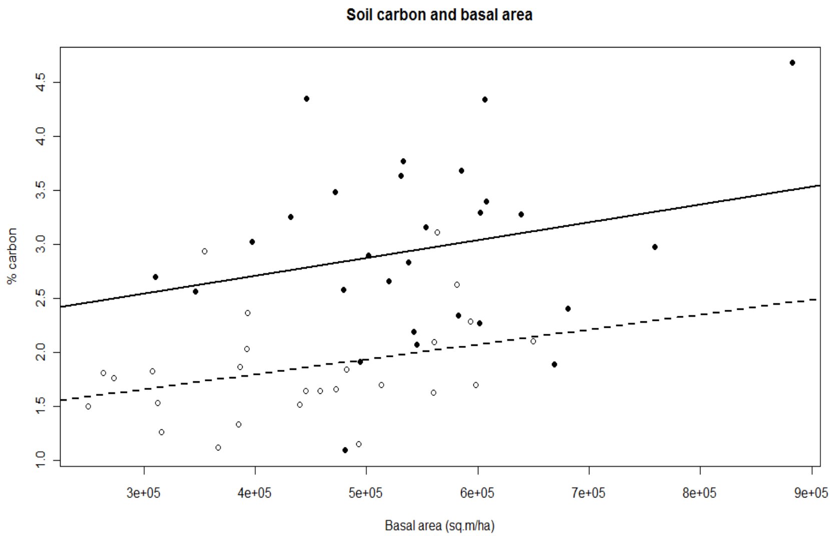
Differences in stand structure and the distribution of carbon across trees of different size classes were also noteworthy. Forest fragments had far greater numbers of seedlings and young recruits (<10 cm dbh), far fewer numbers of young adult to adult trees (10-60 cm dbh), and comparable numbers of large adult trees (>60 cm dbh). While the differences at the smallest size classes did not translate into large differences in carbon storage (because of the very small size of the trees), the differences at the young adult to adult size class resulted in the greatest differences in above-ground carbon storage between contiguous forests and fragments. Interestingly, species like *Dimocarpus longan* which were super-abundant in the recruiting class became very rare in the young-adult class in fragments.



Differences between contiguous and fragmented forests in aboveground carbon storage across diameter classes of trees. Dark grey areas are those diameter classes which store more carbon in contiguous than fragmented forests and light grey areas represent those classes for which there is more carbon stored in fragments than contiguous forests.

Fragments store less soil carbon too

As in the case of above-ground carbon, percentage soil carbon too was significantly higher in contiguous forests (2.95±0.8) than in fragmented forests (1.85±0.5) ($F=35.5$, $p<<0.0001$). While the results fall along the expected lines, multiple regression analysis highlighted not only the role of basal area, but an additional treatment effect between the two sites. At any given basal area, contiguous forests stored over 1.5 times as much soil carbon as fragmented forests, suggesting the role of species composition (possibly acting through leaf C:N ratios) and other micro-habitat conditions in sustaining higher levels of carbon in contiguous forest soils.

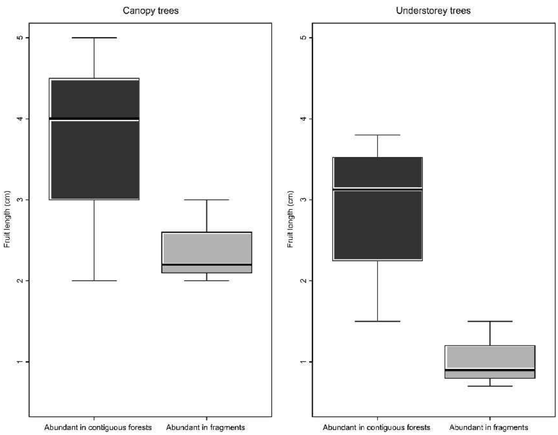


Variation in % soil carbon with respect to basal area in contiguous forests (filled circles) and fragmented forests (open circles). Lines indicate fitted linear models for changes in soil carbon in response to basal area in contiguous forests (solid line) and fragmented forests (dashed line).

Functional shifts in tree communities

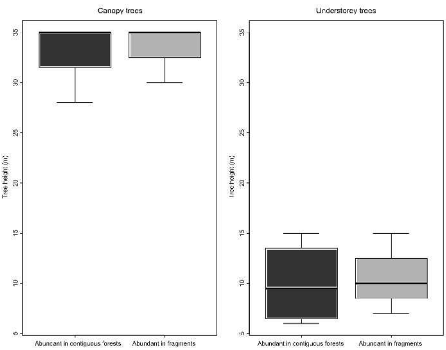
There were a number of differences in functional trait values between tree species that were most abundant in contiguous forests and those in fragments. These differences point both to the mechanisms driving tree community change in fragments as well as some of the ecosystem consequences of these community changes.

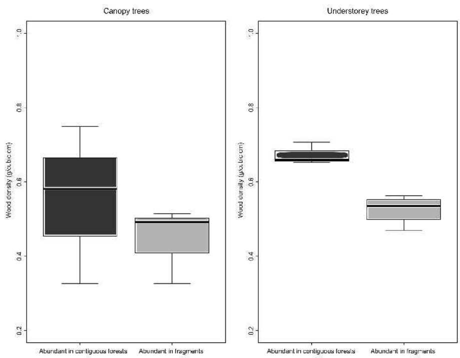
Both canopy and understorey tree species that were more abundant in fragments tended to have smaller fruits than those that were abundant in contiguous forests. Abundant species in fragments also had comparable heights but lower wood densities than those that were abundant in contiguous forests. While abundant species in fragments also appeared to have lower values of carbon:nitrogen ratios than abundant ones in contiguous forests, more data are required to substantiate this claim. These differences in dominant species wood density and C:N ratios are important, because they point to future fragmented forest communities dominated by lower wood density and C:N ratio species, which would likely result in reduced above-ground and below-ground carbon storage.



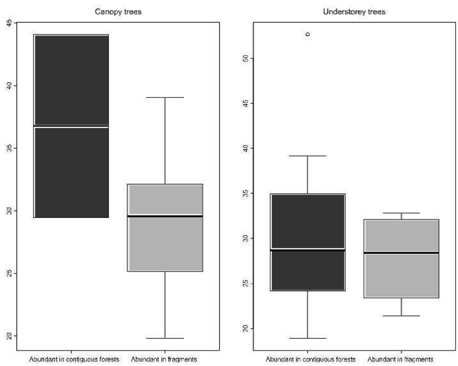
Smaller-fruited species fare better than larger-fruited species in fragmented forests.

Functional shifts in tree communities





Clockwise from above: Differences in tree height, wood density and leaf C:N ratios between more abundant species in contiguous forests and those in fragmented forests.



Conservation implications

This work has highlighted interesting and important patterns in tree communities and carbon storage services across contiguous and fragmented forests in the Kodagu landscape of the central Western Ghats.

It shows that as large areas of forest are reduced to smaller forest fragments, there are clear and predictable changes in the tree community (e.g. small-seeded species do better than large-seeded species), with important consequences for ecosystem services such as carbon storage. The study also suggests that simply protecting fragments might not be sufficient to conserve their tree communities. Some active interventions such as habitat restoration and improvement of corridors, both guided by good science, might be required to ensure the persistence of a number of ecologically important species.

The work also uncovered some interesting patterns in stand structure between the sites. Similar to fragmented sites elsewhere in the tropics (e.g. Amazon[6]), there were much higher levels of regeneration in forest fragments here than in contiguous forests, especially of pioneer species. But these abundances in fragments dropped very sharply in the slightly larger girth classes, the reasons for which are not yet clear. More work is required to understand the natural (mortality) and anthropogenic (biomass extraction) causes of these patterns.

Finally, the work highlights the strong linkages between the above- and below-ground systems in terms of carbon storage services. Losses in above-ground carbon were closely mirrored by losses in soil carbon, indicating that overall losses in carbon storage ecosystem services in fragmented forests can be quite high. Interestingly, soils in fragments consistently stored less carbon than those in contiguous forests, even at comparable basal areas, suggesting the additional role of other micro-habitat changes brought about by edge effects, and changes in litter quality resulting from changes in species composition in driving this pattern.

In terms of conservation strategies, there appear to be some overlaps between the goals of biodiversity conservation and ecosystem service conservation in this landscape. Species that are important from a biodiversity point of view (native forest species, endemic species) are also the ones that are important for carbon storage (e.g. having higher wood density and C:N ratios). These species tend to decline the most in abundance in fragments when compared to contiguous forests. There is therefore an opportunity to integrate biodiversity conservation and ecosystem service conservation through incentive schemes such as payments for ecosystem services. The implementation of such schemes would be conceivable, however, only after overcoming a few immediate hurdles. Most importantly, one would have to develop a mutually beneficial scheme for both the stakeholders who own the forest fragments (mostly forest department) and those that mostly affect and use the lands (local community).

Next steps

Looking ahead, a number of important tasks remain to be addressed in order to strengthen our understanding of tree community and carbon dynamics of Kodagu's forests, as well as to guide conservation efforts. A few of these are listed below:

1. Complete plant functional trait dataset – In the first year of the project, plant functional trait data were collected only for a limited set of species, and for a limited set of traits. Further, many functional trait data were collected from literature and secondary sources and need to be verified with primary data. In the next stage we will focus on further building the plant functional trait dataset with data on more species and more traits. Plant functional traits provide useful and powerful insights into understanding and predicting changes in forest tree communities and ecosystem services in response to various forms of ecosystem change.

2. Investigate species population trends – Why are there so few young adult trees in fragments when there are so many smaller recruits? Are there some factors leading to high mortality, or is it just that young trees are much more heavily harvested in fragments than in contiguous forests? We will conduct both field surveys and interviews with local communities to understand the reasons behind this pattern.

3. Understand processes driving soil carbon change – Soil carbon responds to a variety of drivers such as temperature, moisture, soil chemistry, soil biodiversity and leaf litter quality. In the next stage we will conduct field studies as well as experiments to understand the relative contributions of these different drivers to soil carbon storage, in order to better predict soil carbon response and better inform efforts to conserve and restore soil carbon.

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Appendix
Leaf C:N ratios

Species	Leaf C:N ratio
Actinodaphne malabarica	31.60
Antidesma menasu	23.82
Aporosa lindleyana	23.39
Archidendron monadelphum	14.06
Artocarpus hirsutus	28.11
Artocarpus integrifolius	20.58
Canthium dicoccum	34.99
Canarium strictum	29.70
Careya arborea	29.05
Carallia brachiata	27.02
Celtis philippensis	21.42
Chionanthus malabaricus	25.40
Chrysophyllum roxburdhii	13.98
Cinnamomum malabathrum	21.88
Dalbergia latifolia	18.48
Dillenia indica	30.57
Dimocarpus longan	30.86
Diospyros montana	21.42
Diospyros sylvatica	31.63
Elaeocarpus serratus	28.46

Species	Leaf C:N ratio
Elaeocarpus tuberculatus	27.80
Euodia lunu-ankenda	15.76
Euonymus indicus	33.54
Ficus asperima	13.64
Ficus hispida	26.44
Ficus racemosa	16.69
Flacourtia montana	34.91
Garcinia gummi-gutta	32.83
Grewia tiliaefolia	20.37
Holigarna arnottiana	29.45
Holigarna grahamii	27.05
Hydnocarpus pentandra	19.57
Knema attenuata	27.23
Litsea floribunda	28.68
Macaranga peltata	20.26
Madhuca neriifolia	31.36
Mallotus philippensis	18.91
Mallotus tetracoccus	20.81
Mangifera indica	37.08
Margrateria indica	19.82
Memecylon talbotianum	37.20

Species	Leaf C:N ratio
Michelia champaca	20.11
Mimusops elengi	32.12
Myristica dactyloides	29.64
Neolitsea scrobiculata	33.18
Neolitsea zeylanica	52.68
Nothopegia beddomei	26.72
Olea dioica	28.25
Pavetta indica	39.52
Persea macrantha	22.37
Reinwardtiodendron anaimalaiense	14.94
Syzygium caryophyllatum	39.07
Syzygium cumini	37.16
Syzygium densiflorum	29.46
Syzygium munronii	39.19
Tabernaemontana heyneana	16.34
Terminalia bellirica	19.93
Toona ciliata	44.10
Trema orientalis	16.26
Vepris bilocularis	16.74
Vernonia monosis	17.52
Vitex altissima	25.15

Study site location (above) and detailed study site map (below). Red circles indicate sampling locations, dark green areas are protected areas and light green areas are reserved forests