



## Collaboration for Environmental Evidence

Systematic Review No. CEE 10-011

***WHAT IS THE EVIDENCE OF THE IMPACT ON  
NET CARBON SEQUESTRATION FROM REDD+  
(WITH A FOCUS ON TROPICAL FORESTS)?***

**Draft Protocol (amended)**

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## Cover Sheet

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# 1. Background

Approximately 17% of global greenhouse gas emissions are estimated to come from the clearing and degradation of tropical forests (IPCC, 2007). A series of negotiations within the UN Framework Convention on Climate Change have resulted in the development of a mechanism for compensating tropical nations that succeed in reducing emissions from deforestation and degradation, known by the acronym REDD (Gullison, Frumhoff, & Canadell 2007)□. The 13th Conference of the Parties (COP 13) held in 2007 presented the Bali Action Plan. This calls for “Policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries” (Decision 1/CP.13). The concept of enhancement of forest carbon stocks is the addition to REDD that led to it becoming known as REDD+. If REDD+ is successful in maintaining and enhancing existing forest cover in developing countries it is likely to deliver a range of environmental and social benefits, in addition to contribution to climate change mitigation. However, some of the activities for enhancing carbon stocks under REDD+ are controversial. Concerns have been expressed regarding risks to the wider environment as a result of narrowly focussing on carbon. While there is widespread consensus that projects that result in the avoidance of deforestation and degradation are highly likely to have a positive effect on net carbon sequestration(Olander et al. 2008) there is greater uncertainty regarding the effect of activities such as plantation forestry and growth enhancement (Stickler et al. 2009). When contemplating a management intervention its effect should be considered in the context of a counterfactual, i.e., the situation that would have prevailed in the absence of any intervention. The purpose of this systematic review is to evaluate the quantity and quality of the evidence base that could be used to estimate the effect size for a range of management interventions that could form part of REDD+ . The review will be based on empirical studies that allow valid comparisons to be made.

REDD+ is constantly evolving as a concept. A single definition has not yet been developed that is used in a consistent manner between countries, organisations and individuals. At present REDD+ is used as an umbrella term encompassing any planned actions at a local, national and global scale aimed at reducing emissions from deforestation and forest degradation, and enhancing forest carbon stocks in developing countries (Angelsen et al. 2009). However there are clearly three types of changes that are included in REDD+ Deforestation means forest area is reduced, degradation means carbon density that is reduced and regeneration and rehabilitation means carbon density is increased. Enlarging the area of forests (e.g., through afforestation and reforestation, A/R), is another way to increase forest carbon stocks, but A/R is not part of REDD+. Future decisions by UNFCCC might change this. (A/R is part of the Clean Development Mechanism, CDM.)

Changes in:	Reduced negative change	Enhanced positive change
Forest area number of hectare	Avoided deforestation	Afforestation and reforestation (A/R)
Carbon density (carbon per hectare)	Avoided degradation	Forest regeneration and rehabilitation (carbon stock enhancement)

**Figure 2.1. Creditable activities in a REDD+ mechanism**

Source: Angelsen and Wertz-Kanounnikoff (2008)

The systematic review will be based on comprehensive literature searches with specific inclusion criteria and formal assessment of the quality and reliability of the studies retrieved. Emphasis will fall on finding valid comparisons by searching for paired studies. Meta-analysis and sub-group analysis will be used to evaluate the overall effectiveness of REDD+ activities as means of enhancing net carbon sequestration from tropical forests. The policy implications of the size and strength of the available evidence base will be discussed. The review will have wide international relevance and be of use to practitioners in the field of carbon management.

There is broad consensus that a substantial pool of carbon is held in the trees of tropical forests (Stickler et al. 2009). The immediate and persistent threat of land use change in the tropics means that this carbon is highly susceptible to anthropogenic release to the atmosphere. However, a review of global carbon stocks by Lussaert et al (2007) concluded that considerable uncertainties remain regarding the amount and the ultimate fate of carbon held in vegetation over short and long timescales. Modelling studies or landscape and regional analyses based on remotely sensed data often use biome scale averages of carbon stocks and sequestration rates, rather than comparative studies (Vankooten 2004; Gibbs et al. 2007; Pregitzer & Euskirchen 2004). The assumptions used to estimate the effect of REDD interventions at the site level have rarely been formally tested against empirical evidence.

Some recent research shows that the highest absolute values of accumulated carbon at a site scale have been measured for temperate, rather than tropical, forests (Keith, Mackey, & Lindenmayer 2009). This study also showed that the forest with the highest recorded carbon stock has been disturbed periodically by naturally occurring fire. Above ground productivity in tropical forests has been found to vary by as much as a factor of three across a set of neotropical plots (Malhi et al., 2004). Net primary productivity in tropical forests is no longer thought to greatly exceed that of temperate forests, and may be lower (Clark et al. 2001; Huston & Wolverton 2009). These results challenge some common assumptions regarding the nature of the tropical forest carbon pool. A further source of uncertainty arises from the lack of information concerning the role of below ground carbon storage in tropical forests. At least 40% of the carbon stock in tropical forests is held in the soil. In some tropical forests soil carbon storage may be the major component (Berry et al. 2010). Land use change typically results in this stock of carbon being partially lost. However the soil carbon pool may be retained or even augmented under some conditions (Rhoades, Eckert, & Coleman 2000; Carvalho et al. 2010; da Silva et al. 2009; Feldpausch et al. 2004). One review found limited evidence of a general trend towards lower soil carbon stocks after forest harvesting or conversion to grassland, although soil carbon was found to decline consistently when either forests or grassland are converted to cropland (Johnson 1992). A more recent meta-analysis

of soil carbon stocks provided evidence that measurements on soil carbon sequestration rates are extremely variable across land use types (Guo & Gifford 2002). This study also suggested that there is limited evidence for a general difference between total forest and grassland soil carbon stocks, although the vertical distribution of carbon within the soil profile does differ markedly between the two land uses. However, these reviews were not based on explicitly paired studies.

There are a number of reviews of tropical forest carbon sequestration that may provide useful syntheses (Pfaff et al. 2007; Liao et al. 2010; Stickler et al. 2009; Murty et al. 2002; Vankooten 2004; Kindermann et al. 2008; Gibbs et al. 2007; Keith, Mackey, & Lindenmayer 2009; Carvalho et al. 2010; Lorenz & Lal 2009; Guo & Gifford 2002; Costa 1996; Goetz et al. 2009; Vagen, Lal, & Singh 2005; Silver, Ostertag, & Lugo 2000; Post & Kwon 2000; Malhi, Baldocchi, & Jarvis 1999; Malhi et al. 2004). However none of these reviews have systematically combined measurements on above ground and below ground carbon from paired studies and none have included detailed subgroup analysis in order to establish where and when an intervention can be effective. The uncertainty surrounding the relative importance of above ground and below ground processes that result in carbon sequestration from tropical forests suggests that the evidence base used to quantify the benefits of REDD+ requires further systematic review.

## 2. Objective of the Review

### 2.1 Primary question

What is the evidence of the impact on net carbon sequestration from REDD+ (with a focus on tropical forests)?

### 2.2 Secondary question

Based on the activities promoted under REDD+ the following subsidiary questions will be evaluated.

1. What is the evidence of the impact of **avoided deforestation of tropical forests** on net carbon sequestration?
2. What is the evidence of the impact of **avoided degradation of tropical forests** on net carbon sequestration?
3. What is the evidence of the impact of **enhancement** of the carbon storage potential of tropical forest land through **plantation, enrichment** or **fertilisation** on net carbon sequestration?

The meta-analysis will estimate effect sizes for relatively homogeneous subsets with similar intervention characteristics with respect to valid comparators (paired studies).

**Table 1. Components of the systematic review question.**

Subject	Intervention	Outcome	Comparator	Designs
Tropical forests	REDD+	Net carbon sequestration.	Carbon sequestration that would have occurred in the absence of intervention under an alternative land use.	Replicated paired experimental designs with valid intervention and comparator.
Vegetation derived from the conversion of tropical forest will form the comparator.	Avoided deforestation Avoided degradation Tree plantation Growth enhancement Sustainable management Reduced impact logging Fire suppression	Carbon accumulation above ground + carbon accumulation below ground	Cattle pasture, cropland, secondary or disturbed forest	Single site studies and unpaired designs will be included when a complementary study can be found that provides an appropriate comparator.

### 3. Methods

The systematic review will be based on a literature search with fully documented search terms and inclusion criteria. Effect size will be analysed through meta-analysis on a set of defined subgroups. The analyses will weight individual study's contribution to the overall conclusion as a function of within study variability, sample size and reliability of methods used (Borenstein et al. 2009). Effect moderators will be analysed through meta-regression and subset analysis.

#### Search terms

##### 3.1 Search strategy

The review will first search for peer reviewed publications on the following online data bases.

1. ISI Web of Knowledge (ISI Web of Science and ISI Proceedings)
2. CAB Abstracts
3. Science Direct
4. Scopus
5. Directory of Open Access Journals (DOAJ)
6. Google scholar
7. Index to Theses Online (1990-present)
8. Digital Dissertations Online

With the exception of databases of dissertations, these sources all draw on a similar literature base and therefore return a large number of duplicates. After at least three searches have been completed an accumulation curve will be fitted to the data in order

to estimate confidence intervals for the asymptote. See appendix one for details. Searching will be considered to be complete if the fitted accumulation curve demonstrates a greater than 97.5% probability that at least 95% of studies that meet the inclusion criteria have already been found.

The following compound search terms have already been screened and proved effective in the scoping stage.

1. (deforestation OR degradation) AND carbon AND tropical forest\* AND (sequest\* OR capture OR storage)
2. enhance\* AND carbon AND tropical forest\* AND (sequest\* OR capture OR storage)
3. logging AND carbon AND tropical forest\* AND (sequest\* OR capture OR storage)
4. (primary OR secondary) AND tropical forest\* AND (sequest\* OR capture OR storage)
5. plantation AND carbon AND tropical AND (sequest\* OR capture OR storage)
6. (crop\* OR maize OR rice OR coffee OR oil palm OR soya) AND carbon AND tropical AND (sequest\* OR capture OR storage)
7. (pasture OR cattle OR grassland) AND carbon AND tropical AND (sequest\* OR capture OR storage)

Further modifications to the search terms may be necessary and these will be documented as the review progresses.

A search using a general internet search engine (Google) will be used to identify the web sites of organisations that may hold data and publications that may also be relevant. These web sites will be searched using the same set of search terms. Only peer reviewed publications and data will be included in the review. Publication bias will be evaluated during meta-analysis using funnel plots and appropriate statistical tests.

### **3.2 Study inclusion criteria**

#### **Geographical location**

Study area should fall within the tropics (23.438°S to 23.438°N) or reported for a large country with most of its land area within the tropics (Brazil, Madagascar, Burma, Paraguay). Studies from Southern Australia (below 23.5S), Northern Mexico (above 23.5N), Northern India and mainland China will be excluded. Study sites that fall marginally outside the limits of the tropics can be included if they are explicitly reported as within a “tropical forest” ecoregion.

## **Vegetation type**

Tropical forest or vegetation that has been derived from previously existing tropical forest through human intervention. Studies on natural savannah, naturally occurring scrubland or desert will be excluded.

## **Study type and outcomes**

In order to be included in the meta-analysis studies must report quantitative data on carbon capture and storage. The full text of all review papers will be retrieved in order to identify further sources of primary quantitative data. Position documents or studies of policy options which express subjective opinion will be excluded from the review process. Papers reporting the results of modelling studies will be excluded from quantitative meta-analysis, although the strength of evidence that they provide will be discussed and synthesised qualitatively as part of the review process. Studies based on remote sensing, which do not include original ground based measurements, will be excluded from the meta-analysis. Although remote sensing provides valuable baseline deforestation information, the development of methods that provide accurate site level estimates of carbon stocks using remotely sensed data remains a topic requiring further research (Houghton, 2003; Houghton, Hall, & Goetz, 2009).

## **Intervention**

Interventions include deforestation, degradation through logging or timber extraction, change of land use from pasture or cropland to plantation, enhancement of forest productivity through fertilisation or enrichment planting. These define subgroups for meta-analysis.

Studies will be included even if they do not report the effect of a direct intervention providing that there is a known threat of intervention that would be removed as a result of REDD+ implementation. For example, a study quantifying the carbon stocks in mature forests provides the baseline data against which other studies quantifying carbon stocks in secondary vegetation, plantations, cropland or pastures can be compared. Valid comparators must always be found within the same broad ecoregion using geographical coordinates and GIS overlays.

### **3.3 Potential effect modifiers and reasons for heterogeneity:**

As the study will look at a range of different interventions, each will be analysed as a separate subgroup. Within each subgroup the effects of climate, soil type and management practice are expected to lead to considerable heterogeneity. GIS overlays will be used to extract consistent effect modifiers based on the geographical coordinates of the study site. Meta-regression will be used to investigate the effects of latitude, rainfall and temperature on the effect size.

### 3.4 Study quality assessment

Studies that include control measurements made on appropriate comparators are the most valuable direct source of evidence for the meta-analysis. These include before and after, control intervention (BACI) studies, randomised controlled trials (RCT), control trials (CT) and site comparison studies (SCS).

Initial scoping suggests that few studies with formal paired designs will be found, as carbon stocks and sequestration rates are typically measured as part of a monitoring program that has not been designed explicitly for comparative purposes. All appropriate comparators will be identified for by searching for similar studies within the same, or very similar, ecoregions. The process of compiling the information for the review is shown in the flow diagram in appendix 3. Because the geographical coordinates of all studies will be incorporated in the data base of included studies, GIS overlays can be used to assign studies to ecoregion (Olson, Dinerstein, & Wikramanayake 2001). The climatic conditions at the site will also be determined using GIS overlays on the Worldclim data set (Hijmans et al. 2005). The originality of this systematic review lies in the emphasis placed on using matched studies for meta-analysis. All comparators will be checked carefully for validity. Studies that report carbon sequestration rates as measured by eddy flux covariance will be included, providing a valid comparator can be found using the same criteria as applied to studies on carbon stocks.

#### Carbon sequestration vs carbon storage

A particular issue with carbon sequestration relates to temporal scope. Stored carbon is the integrated result of the carbon sequestration over time. The majority of empirical studies concentrate on carbon storage (stocks) rather than sequestration (rate), the exception being studies using eddy flux co-variance. The time over which stored carbon has accumulated is often not known. In some tropical forest ecosystems carbon is periodically released to the atmosphere through natural disturbance as a result of hurricanes or fire. In order to avoid recourse to modelling (which falls beyond the scope of a systematic review), separate meta-analyses may be necessary in order to analyse sequestration as a rate and carbon stocks held above-ground and below-ground.

#### Other elements of study quality

There are a wide range of techniques for measuring carbon stocks on the ground (Hoover 2008). The methodology that was used will be captured when the full text is reviewed and will be evaluated for its accuracy. The most reliable non destructive source of above ground biomass carbon data are from field measurements of tree and dead biomass. These structural measurements are converted to biomass carbon densities using allometric equations. However the accuracy of conversion varies. Much uncertainty arises as a result of the difficulty in accurately measuring below ground carbon stocks. Studies that do not include measurements on below ground carbon will be included in the review, but will be down-weighted during meta-analysis.

Standard national forestry inventories may provide input to estimates of carbon stocks, however raw site data are rarely made publicly available. The suitability of national forest inventories for estimating carbon stocks has been seriously questioned (Houghton 2005) □ . Such data will be excluded from analysis unless its quality has been assessed through peer review.

Studies will be scored for the reliability of the measurement protocol based on review of the methods section of the paper. The criteria for evaluating study quality will be established at a later stage during the review process and fully documented. Consistency in application of the criteria for scoring study quality will be tested using by selecting a subset of studies for evaluation by independent review by member of the review team and agreement evaluated.

### **3.5 Data extraction strategy**

Initial assessment of study relevance will be undertaken by one reviewer assessing study titles (and abstracts). Where there is insufficient information to make a decision regarding study inclusion when viewing titles or titles and abstracts, then relevance to the next stage of the review process will be assumed. The repeatability of study inclusion will be verified by assessing a random subset (of at least 25%) of references viewed at abstract and full text for relevance using a second independent reviewer. Disagreement will be resolved by consensus, or following assessment by a third reviewer.

### **3.6 Data synthesis and presentation**

#### **Meta-analysis**

Meta-analysis will concentrate on establishing effect sizes for subsets of studies with similar intervention characteristics. Measured variance will be used as a standard measure of reliability of replicated studies together with sample and plot size. The effect of plot size is taken into account explicitly in replicated studies, as (all else being equal) studies based on large plots will have smaller variances than similar studies on smaller plots. However it may be necessary to incorporate unreplicated studies into the metanalysis (see appendix 2). In this case plot size will be taken into account when imputing the variance in order to give the appropriate weight to the study.

Both random and fixed effects models will be fitted to data on each distinct subgroup of studies and the results compared (Borenstein et al. 2009). Subset homogeneity will be evaluated using Cochran's Q. However heterogeneity between studies is expected to occur making the random effects model most appropriate on a-priori grounds. The R package meta will be used for model fitting, analysis and presentation using forest plots (see appendix 2). Meta-regression will be carried out using the R package metafor (Viechtbauer 2010).

Effect sizes may be quantified as mean difference, standardised mean difference or response ratio (Hedges, Gurevitch, & Curtis 1999). The mean difference in terms of

Mg of carbon per hectare between intervention and comparator is a directly interpretable measure of effect size and as such may be most policy relevant. Response ratio (% increase or reduction in carbon stocks or sequestration rate) is also a useful measure of effect size. Hedge's standardised mean difference has good statistical properties for meta-analysis, although it lacks a direct interpretation.

Publication bias will be evaluated using funnel plots and radial plots.

#### **4. Potential Conflicts of Interest and Sources of Support**

There are no conflicts of interest. The study is supported by DFID.

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