An estimate of carbon in the above-living biomass of Finca las Piedras

Laura Coomber

Corresponding emails: lauracoomber21@gmail.com & info@sustainableamazon.org

Abstract

Climate change is a massive issue globally, with widespread and irreversible implications if mitigation does not occur. Land use changes are one of the major sources of greenhouse gasses, producing more carbon annually than the whole of the transport sector. As such, forest conservation has the potential the play a significant role in climate change mitigation, and research into to carbon storage can provide important information to support this. In this study I estimated the amount of carbon in the above-ground living biomass of the forested area of Finca Las Piedras, the research station for the Alliance for a Sustainable Amazon. This was done using ground-based forest inventory methods, with sampling carried out across 10 modified gentry plots (50 x 10m). The average biomass per hectare was 404.02 T dry weight ha^{-1}, with the average carbon per hectare being 189.88 T C ha^{-1}. Assuming a forested area on the property of 23 hectares, the total above ground living biomass is 9,292.23 T dry weight ha^{-1} and the stored carbon is 4,367.24 T C ha^{-1}. However, there was high variability in carbon storage across the site, with biomass ranging from 203.088 to 644.74 T ha^{-1}, making an accurate estimate difficult. These findings suggest a significant carbon store, highlighting the significant contribution that even degraded tropical forests can play in climate change mitigation. Forest inventories such as these have the potential to support REDD+ projects, which would bring further funding for sustainability projects. There is also a large scope for further similar work, such as a comparison of different forest types.

Introduction

Anthropogenic climate change is a massive issue globally, with levels of CO_2 in the atmosphere 28% higher than pre-industrial levels as of 2008 (Raupach and Canadell, 2008) and as of 2013 levels rose to 400pm, the highest concentrations of atmospheric carbon for the past 3 millions years (NASA, 2017). Human activity leads to changes in the climate via the production of greenhouse gasses (GHG's), with the primary GHG being carbon dioxide; these absorb heat from the sun leading to increased temperatures and a variety of other effects.The potential implications if mitigation does not occur are widespread and irreversible, with potential impacts including loss of biodiversity, permanent changes to entire ecosystems, effects on food security and many more potential impacts (IPCC, 2014). One of the major ways in which humans lead to C02 emissions is via land use change, primarily via deforestation, agriculture and livestock use (Edenhofer et al., 2014). The United Nations report for 2014 estimated that this sector accounts for roughly 25% of anthropogenic emissions, or 10-12 gigatons of C02 per year, greater than the all emissions produced by the transport sector at 14% (Edenhofer et al., 2014).

The world's forests are a significant sink of carbon in the global carbon cycle (Pan et al., 2017). Currently the carbon stock of the world's forests is estimated at 861 T ± 66Pg C, and of this, rainforests are

Copyright © 2017 Laura Coomber & Alliance for a Sustainable Amazon

the most significant store at 55% (471 T ± 93 Pg C) (Pan et al., 2017). However, rainforest area is being lost at an alarming rate with 1.4% of the total area of global humid tropical forests lost in 5 years, equivalent to 274,615 km2 (Asner et al., 2009). The most recent research adds to the growing scientific consensus that the level and extent of tropical forest destruction is so large that these ecosystems are now acting as carbon sources not carbon sinks (Baccini et al., 2017). The study found that roughly 425 million tonnes of carbon are released annually as a result of destruction and degradation (Baccini et al., 2017). Reduction of deforestation and degradation of tropical rainforests therefore has the potential to play a substantial role in the mitigation of climate change. One estimate suggests that with a globally implemented policies for reducing land use changes could reduce emissions by 77GT CO2 (Popp et al., 2014).

The focus of this study is in the Peru, the fourth biggest rainforest country in the world, with half of Peru's land mass classified as forest (Environmental Investigation Agency, 2012). However, like tropical forests across the globe, Peruvian forests are victim to large levels of destruction primarily in the form of selective logging and gold mining (Asner and Tupayachi, 2017).The biggest issue, particularly in the Madre De Dios region, the area of study here, is arguably gold mining. While the government attempted to tackle this issue in 2012, a recent study found that deforestation due to mining in the area doubled between 2012-2014 (Asner and Tupayachi, 2017). Peru, like many countries, suffers from large levels of corruption making any positive action from the government difficult (Environmental Investigation Agency, 2012). Further research in this area and the work of NGO's therefore has the possibility to provide important information and the potential to reduce such high levels of deforestation, therefore reducing emissions.

Research into carbon storage in the Amazon has the potential to provide several forms of valuable information. Estimations of biomass in the amazon show massive variation, such as Houghton et al. (2001) finding that estimates of biomass in the Brazilian amazon range between 39 to 93 PgC. Studies also suggest there are large variations in biomass across both the amazon basin, and the whole of the pan-tropical region (Avitabile et al., 2017). Study of different regions therefore provides information both of accurate estimates of rainforest biomass and on how it varies between regions. Perhaps more urgently, there is the need to understand how human activity impacts carbon storage (Berenguer et al., 2017). Human activities leading to degradation include selective logging, understory fires, fragmentation and overhunting (Berenguer et al., 2017). Asner et al., (2009) found that between 2000 and 2005 over 20% of worlds tropical forests had been affected by selective logging. However, data is lacking from disturbed forests making it different to estimate the effects the such impacts on carbon stocks (Berenguer et al., 2017). As such, studies of degraded areas such as that of property of studied here, provide vital information. The UN project, REDD+ (Reduced Emissions from Deforestation and Degradation), also calls for forest inventories. This is a project developed by the United Nations Framework Convention on Climate Change with the aim of reducing emissions from deforestation and degradation in developing countries based on the concept of payments for ecosystem services. The idea is that communities receive payments based on the carbon saved because of the prevention of deforestation and degradation. REDD+ hopes to produce an international

Copyright © 2017 Laura Coomber & Alliance for a Sustainable Amazon

mechanism which allows for the reduction of emissions from developing countries (Nunes et al., 2012).

For carbon estimations, the IPCC (Intergovernmental Panel on Climate Change) recommends that 5 functionally distinct pools should be measured which are; above ground living biomass, dead wood (coarse woody trees, standing dead trees and palms), litter (fine woody debris and leaf litter), soil and below ground biomass (IPCC, 2006). This study focuses on the above ground living biomass (AGLB), primarily due to limited time and resources, however several studies have shown that this carbon pool makes up the most significant fraction of carbon storage in tropical forests (Cummings et al., 2002, Houghton et al., 2008, Berenguer et al., 2017). There are various methods for estimation of carbon within rainforests. The IPCC developed a set off guidelines based on a 3-tier graded system of quality. The most accurate of these, tier 3, is based on high resolution methods such as LiDAR. While LiDAR may be the future of carbon research, ground based forest inventories are still used in large scale carbon studies (Baccini et al., 2017) and have other important uses. One such use is ground truthing, estimates produced by LiDAR are first based on ground-based measurements (Chave et al., 2015). Another is the availability of resources, for areas and communities interested in estimating carbon for programmes such as REDD, equipment such as LiDAR is not available and quick, inexpensive, readily available methods are required (Baralotti et al., 2012). Here, a direct ground based measurements of tree diameters was used, which can then used to determine biomass via the use of allometric relationships. In this study, direct ground based measurements of tree diameters were used, which were then applied to allometric relationships to determine biomass. This is the standard method for ground based estimates (Baralotti et al., 2012) and has several benefits including widely available and accessible allometric equations, low costs and a relatively simple method. This was the method of estimation used here to provide an estimation of the above ground living biomass (AGLB) and hence carbon stored within the disturbed forested land of Finca Las Piedras, the field site of the Alliance for a Sustainable Amazon (ASA).

Methods

Site description

The location of this study is Finca Las Piedras, the research station of Alliance for a Sustainable Amazon (Co-ordinates: -69.10986503, -12.22730169). The forest has been selectively logged in the past, meaning many of the large ironwood species have been lost. However, the majority of this activity is believed to have occurred more than 20 years ago.

Field Sampling

Modified gentry plots were used here, as inspired by Baraloto et al. (2012). This method has previously been found by others to be the best in terms of time and effort required, while still producing accurate results (Baraloto et al., 2012 and Philips et al., 2003). These plots consisted of “belt” shaped transects 50m long and 10m wide. The initial 50m transect was set up with a string using a compass to ensure a straight line. Then a 5m string, attached to the main transect via carabiner, was used to determine 5 meters either side of this. To ensure non-biased sampling of the area 10 random sampling points were assigned using the “random points” generator on QGIS, each of these points acted as the starting point. From each starting point the transect was set up facing exactly south. Within each plot every tree with diameter at breast height (DBH) of 3cm or more, meaning the diameter of the tree at a standardised height of 1.3m. In the case of trees with large buttresses, DBH was measured at 10cm above the buttresses. The trees were always measured by the same person across all transects, reducing the potential for flaws in measurement.

Data analysis

Previously determined allometric relationships can be used for the determination of biomass using measurements from living trees. In this study equation 7 from Chave et al. (2015) was used as tree height was not measured. This equation is as follows:

$$AGB_{est}=\exp[-1.803-0.976E+0.976\mathrm{In}(p)+2.673\mathrm{In}(D)-0.0299[\mathrm{In}(D)]^2]$$

In the above equation "E" represents an amalgamation of bioclimatic variables, namely; climatic water deficit, temperature seasonality and precipitation seasonality. Chave et al. (2015) found that these variables explain a significant portion of the variation in diameter-height relationships; as such, including "E" allows for a more accurate estimate of biomass when height data is unavailable. A global gridded layer of "E" was created by Chave et al. (2015) to allow for use in the above equation, which is retrievable at http://chave.ups-tlse.fr/pantropical_allometry.htm. For the region of study, E= 0.0396455. Another large controller of variation in biomass across regions is wood specific gravity (p). Studies suggest that variation in wood specific gravity is one of the largest sources of variation in biomass between species and regions in the tropics, so it is important to include either region or species-specific values for p (Baker et al., 2004). Baker et al. 2004 compiled data for wood specific gravity across the whole of the Amazon and their compiled data was used to find the most appropriate figure possible for the region of study. The region-specific average used was 0.5983 gm^{-3}. With both "E" and "p", the diameters (D) of all trees were applied in the equation above to produce estimates of above ground biomass in each of the 10 plots, giving dry biomass in kg.

To extrapolate from the sample area to a standard hectare area, an extrapolation factor was created using the equation:

SF= 10,000/Area

In which SF = scaling factor, Area = the area of the plot and 10,000 is the area of a hectare in meters. This scaling factor was then applied to each plot.

Using the IPCC guidelines, the fraction of carbon within the biomass was assumed to be 0.47 T C T^{-1} (IPCC, 2006). I used the following equation:

$$C_p=DM\times CF$$

In which C_p = carbon stock in the plot (T C ha^{-1}), DM = dry biomass in plot (T dry matter ha^{-1}) and CF = carbon fraction (T C t^{-1}). This was calculated from the biomass data for each plot.

Due to the highly skewed nature of the data (Anderson-Darling test, p = 0.005), a Kruskal-Wallis test was used to test for significant differences between the plots. A large variation between plots suggests that there may be significant spatial heterogeneity in tree sizes or habitat types, and as such one average for the whole site may be inappropriate. An average of biomass and carbon per hectare was thus produced and then extrapolated to the forested area of the entire property (approximately 23 hectares as determined by analysis of satellite imagery).

Copyright © 2017 Laura Coomber & Alliance for a Sustainable Amazon

Results

In this study a total area of 5,000 m^2, which included measurements of a total of 945 stems. The DBH ranged from 3.00 - 81.17cm, with an average of 10.11cm. The average biomass per hectare was 404.02 T dry weight ha^{-1}, with the average carbon per hectare being 189.88 T C ha^{-1} (see table 1). Assuming a forested area in the property of 23 hectares, the total above ground living biomass is 9,292.23 T dry weight ha^{-1} and the stored carbon is 4,367.24 T C ha^{-1}.

A significant difference was found in the biomass between the plots (Kruskal Wallis, df = 9, H = 26.37, p = 0.002). This can clearly be seen in the above data, with the biomass ranging from 644.74 to 203.088 T dry weight ha^{-1}.

Discussion

Biomass and carbon

This study found that there is an average of biomass of 404.01 t dry weight ha^{-1} with an equivalent carbon of content of 189.89 t C ha^{-1} in the AGLB of the property. Extrapolating to the forested area of the property, the estimated total storage is 9,292.23 t C ha^{-1} and 4,367.47 t dry weight ha^{-1} for biomass and carbon respectively. However, large significant differences were found between the sites drawing into question the accuracy of the estimate produced. Biomass had a range from 203.1 to 644.7 t dry weight ha^{-1}, such large variation makes it very difficult to produce an accurate estimate. Such large variation however, appears to me normal for disturbed forests, with other studies finding major differences between areas (Berenguer et al., 2017 and Ioki et al., 2014). This is likely due to the inconsistent effects of human disturbance.

Two of the plots have a biomass of 613.24 and 644.74 t dry weight ha^{-1} for transects 3 and 4 respectively, this well above what would be expected. For example, Malhi et al., 2006 found that the highest biomass for the Amazon was 350 Mg dry weight ha^{-1}. Comparable results were found by Saatchi et al. (2007) with estimates only reaching as high as 400 Mg ha^{-1} in intact forest, while in Peru estimates were between 200 and 300 Mg ha^{-1}. Further examination of these plots show that the high biomass is because of a few very larger diameter trees, for example in plot four 90.91% of the biomass came from a few trees over 40cm in diameter. In plot 3 there was a similar finding with 75.25% of the biomass being made up of trees above 40cm in diameter. Hence, it may be that these findings are anomalous.

Excluding the two unusually high estimates above, several of the estimates fall in the range of what would be expected for biomass in intact amazon forest as found

Table 1. Summary of biomass and carbon estimate, number of stems sampled, and median diameter-at-breast height (DBH) of the stems, per 500 m^2 (0.05 ha) transect.

Transect	Biomass (dry t ha^{-1})	Carbon (t ha^{-1})	No. stems	Median DBH
1	487.75	229.244	80	7.05
2	372.13	174.90	108	5.37
3	613.24	288.22	104	7.00
4	644.74	303.02	86	5.71
5	255.29	119.98	113	4.99
6	408.05	191.78	93	8.46
7	366.93	172.46	99	6.39
8	210.57	98.97	103	6.30
9	203.08	95.45	84	7.40
10	478.30	224.80	75	5.44
Total	4040.12	1898.85	945	
Average	404.012	189.88	94.5	

Copyright © 2017 Laura Coomber & Alliance for a Sustainable Amazon

by Saatchi et al. (2007), such as transects 1 and 6. However, several of the estimates fall in the region of biomass for disturbed forests. While disturbed forests show a high level of variation, the range of figures is comparable to that of our findings. For example, in moderately degraded forests in Borneo findings ranged from 136.00-382.59 Mg ha^{-1} (Ioki et al., 2014) and were 241.04 Mg ha^{-1} on average in Australian degraded tropical forests (Alamgir et al., 2016). In degraded forests in the amazon, Berenguer et al. (2017) found an average of 238.53 Mg C ha^{-1} ± 7.62. This is akin to some of our findings such as transects 2 and 7. However, some of our findings were much lower than this, e.g. transects 8 and 9, which are more in line with findings in secondary regrowth forests (Berenguer et al., 2017).

Even though some of the results are unusual, one of the main results that has emerged is the high biomass in the degraded tropical forest studied here. While no direct comparison was made to intact forests in the region, comparison to literature suggests that the biomass here is high. This re-iterates the findings of others that degraded forests can still act as important carbon stores (Berenguer et al., 2017, Ioki et al., 2014). This is important because, as previously stated, larger and larger areas of the amazon are becoming degraded (Asner et al., 2009), however very little is known about the effects of degradation on carbon stocks (Berenguer et al., 2017). As such there is a gap in policy related to carbon emissions as the role of degraded forests are often not considered (Mertz et al., 2012). Specifically, in REDD (Reducing Emissions from Deforestation and Degradation) policy and approaches, there is a focus on deforestation while the role of degraded forestry in rarely considered (Mertz et al., 2012). Findings such as these therefore suggest that degraded forest need to be taken into consideration in climate mitigation strategies.

Criticisms of methodology

It should be noted that this study was carried under time constraints and with highly limited resources, this should potentially be considered a pilot study, with consequent work improving the estimate produced. There are two primary ways via which the estimate produced could be improved. The first is the measurement of tree height data, using this information in the alternate equation provided by Chave et al. (2015) provides a more accurate estimate. The other way is via measurement of wood specific gravity, via sampling in one area and creating a site-specific average for the property, which can then be using with the calculation of biomass.

Another issue with the study here is the large variation that exists between plots, this appears to be common in disturbed forest (Berenguer et al., 2017), however it makes producing an accurate estimate from the current data difficult. More random samples across the property would potentially provide a more information and a hence a better estimate.

Further work

Further work could involve the measurement of other carbon pools, not just AGLB, to provide a more accurate estimation of total carbon. Other carbon pools include soil carbon, below ground biomass and deadwood (IPCC, 2006). The forest inventory methods used here could also be applied to other areas nearby, to provide a comprehensive study of carbon in the area and to show potential differences across forest types.

There is a developing body of REDD+ projects in Peru, with varying findings on the success of such projects. Some studies have found that the international discussion of REDD+ initiatives has led to positive developments in Peru at the governmental level with institutional changes and fresh resources, however these changes were often shallow, "paper" changes with little effect on the extractive based economy of Peru (Ochieng et al., 2016). There has also been reports of manipulation of the REDD+ system, with the development of "carbon pirates" who convince communities to sign away land and carbon rights and take the profits (Forest Peoples Programme, 2011). It also often claimed that REDD, in its current form, works against the rights of indigenous communities (Forest Peoples Programme, 2011). However, there are reports of success in REDD+ projects in Peru, with several examples in the Madre de Dios, the common denominator for success being projects that are tailored to local needs of the communities and with design from the ground up (Hajek et al., 2011). Therefore, it is possible, for the implementation of such a project in the area. However, the process requires large amounts of time and resources and a decent knowledge of REDD+ processes (Hajek et al., 2011).

Conclusion

The primary finding of the study is the large amounts of carbon still stored in the partially degraded forests of ASA, highlighting the significant role such forests can play in climate change mitigation strategies. However, these findings are only preliminary with further work able to enhance the estimation and provide more useful information.

Acknowledgments

I would like to thank ASA for the amazing opportunity and specifically G. Gallice and J. Reyes Quintero for being so welcoming and helpful. I would also like to give a massive thanks to M. Stauder for all the hours she put in helping me with field work and for her amazing company; and to thank all the other interns and volunteers that helped with field work. I would also like to thank E. Iverson for assistance. Last, but not least, I'd like to thank J. Cueva for the constant supply of coffee and amazing food.

Works Cited

Alamgir, M., Campbell, M., Turton, S., Pert, P., Edwards, W. and Laurance, W. (2016). Degraded tropical rain forests possess valuable carbon storage opportunities in a complex, forested landscape. *Scientific Reports*, 6(1).

Asner, G P. Rudel, T K. Aide, T M. Defries, R. Emerson, R. . (2009). A Contemporary Assessment of Change in Humid Tropical Forests. *Conservation Biology.* 23 , 1386–1395 .

Asner, G. and Tupayachi, R. (2017). Accelerated losses of protected forests from gold mining in the Peruvian Amazon. *Environmental Research Letters*, 12(9), p.094004.

Baccini, A., Goetz, S., Walker, W., Laporte, N., Sun, M., Sulla-Menashe, D., Hackler, J., Beck, P., Dubayah, R., Friedl, M., Samanta, S. and Houghton, R. (2012). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*, 2(3), pp.182-185.

Baccini, A., Walker, W., Carvalho, L., Farina, M., Sulla-Menashe, D. and Houghton, R. (2017). Tropical forests are a net carbon source based on aboveground measurements of gain and loss. *Science*, 358(6360), pp.230-234.

Baker, T., Phillips, O., Malhi, Y., Almeida, S., Arroyo, L., Di Fiore, A., Erwin, T., Killeen, T., Laurance, S., Laurance, W., Lewis, S., Lloyd, J., Monteagudo, A., Neill, D., Patino, S., Pitman, N., M. Silva, J. and Vasquez Martinez, R. (2004). Variation in wood density determines spatial patterns in Amazonian forest biomass. *Global Change Biology*, 10(5), pp.545-562.

Baraloto, C., Molto, Q., Rabaud, S., Hérault, B., Valencia, R., Blanc, L., Fine, P. and Thompson, J. (2012). Rapid Simultaneous Estimation of Aboveground Biomass and Tree Diversity Across Neotropical Forests: A Comparison of Field Inventory Methods. *Biotropica*, 45(3), pp.288-298.

Berenguer, E., Ferreira, J., Gardner, T., Aragão, L., De Camargo, P., Cerri, C., Durigan, M., Oliveira, R., Vieira, I. and Barlow, J. (2017). A large-scale field assessment of carbon stocks in human-modified tropical forests. *Global change biology*, 20(12), 3713-3726.

Cummings, D., Boone Kauffman, J., Perry, D. and Flint Hughes, R. (2002). Aboveground biomass and structure of rainforests in the southwestern Brazilian Amazon. *Forest Ecology and Management*, 163(1-3), pp.293-307.

Entenmann, S K. Schmitt, C B. (2013). Actors' perceptions of forest biodiversity values and policy issues related to REDD+ implementation in Peru. *Biodiversity Conservation*. 22, 1229-1254.

Environmental Investigation Agency (2012). The Laundering Machine, How Fraud and Corruption in Peru's Concession System are Destroying the Future of its Forests. [online] Environmental Investgation Agency. Available at: https://eia-global.org/reports/the-laundering-machine [Accessed 17 Oct. 2017].

Evans, K. Murphy, L. Jong, W d. (2014). Global versus local narratives of REDD: A case study from Peru's Amazon. Environmental Science and Policy. 35. 98-108.

Forest Peoples Programme (2011). The reality of REDD+ in Peru: Between theory and practice. [online] Available at: http://www.forestpeoples.org/sites/fpp/files/publication/2011/11/reality-redd-peru-between-theory-and-practice-website_0.pdf [Accessed 20 Oct. 2017].

Hajek, F., Ventresca, M., Scriven, J. and Castro, A. (2011). Regime-building for REDD+: Evidence from a cluster of local initiatives in south-eastern Peru. *Environmental Science & Policy*, 14(2), pp.201-215.

Houghton, R., Lawrence, K., Hackler, J. and Brown, S. (2008). The spatial distribution of forest biomass in the Brazilian Amazon: a comparison of estimates. *Global Change Biology*, 7(7), pp.731-746.

Intergovernmental Panel on Climate Change (IPCC), 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. https://www.ipcc.ch/report/ar5/ Accessed: 26/1/17

Ioki, K., Tsuyuki, S., Hirata, Y., Phua, M., Wong, W., Ling, Z., Saito, H. and Takao, G. (2014). Estimating above-ground biomass of tropical rainforest of different degradation levels in Northern Borneo using airborne LiDAR. *Forest Ecology and Management*, 328, pp.335-341.

IPCC (2006) Forestland. In: IPCC Guidelines for National Greenhouse Gas Inventories (eds Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K), pp. 4.1–4.83. IPCC, Japan.

Ladd, B. Peri, P L. (2013). REDD+ en Latinoamerica: el caso de Peru. *Bosque*. 34. 125-128.

Malhi, Y., Wood, D., Baker, T., Wright, J., Phillips, O., Cochrane, T., Meir, P., Chave, J., Almeida, S., Arroyo, L., Higuchi, N., Killeen, T., Laurance, S., Laurance, W., Lewis, S., Monteagudo, A., Neill, D., Vargas, P., Pitman, N., Quesada, C., Salomao, R., Silva, J., Lezama, A., Terborgh, J., Martinez, R. And Vinceti, B. (2006). The regional variation of aboveground live biomass in old-growth Amazonian forests. *Global Change Biology*, 12(7), pp.1107-1138.

Mertz, O., Müller, D., Sikor, T., Hett, C., Heinimann, A., Castella, J., Lestrelin, G., Ryan, C., Reay, D., Schmidt-Vogt, D., Danielsen, F., Theilade, I., Noordwijk, M., Verchot, L., Burgess, N., Berry, N., Pham, T., Messerli, P., Xu, J., Fensholt, R., Hostert, P., Pflugmacher, D., Bruun, T., Neergaard, A., Dons, K., Dewi, S., Rutishauser, E. and Sun, a. (2012). The forgotten D: challenges of addressing forest degradation in complex mosaic landscapes under REDD+. *Geografisk Tidsskrift-Danish Journal of Geography*, 112(1), pp.63-76.

Nunes, F., Soares-Filho, B., Guidice, R., Rodrigues, H., Bowman, M., Silverstrini, R. and Mendoza, E. (2012). Economic benefits of forest conservation: assessing the potential rents from Brazil nut concessions in Madre de Dios, Peru, to channel REDD+ investments. *Environmetal Conservation*, 39(2), pp.132-143.

Ochieng, R., Visseren-Hamakers, I., Brockhaus, M., Kowler, L., Herold, M. and Arts, B. (2016). Historical development of institutional arrangements for forest monitoring and REDD + MRV in Peru: Discursive-institutionalist perspectives. *Forest Policy and Economics*, 71, pp.52-59.

Pan, Y., Birdsey, R., Fang, J., Houghton, R., Kauppi, P., Kurz, W., Phillips, O., Shvidenko, A., Lewis, S., Canadell, J., Ciais, P., Jackson, R., Pacala, S., McGuire, A., Piao, S., Rautiainen, A., Sitch, S. and Hayes, D. (2017). A Large and Persistent Carbon Sink in the World's Forests. *Science*, 1201609.

Popp, A., Humpenöder, F., Weindl, I., Bodirsky, B., Bonsch, M., Lotze-Campen, H., Müller, C., Biewald, A., Rolinski, S., Stevanovic, M. and Dietrich, J. (2014). Land-use protection for climate change mitigation. *Nature Climate Change*, 4(12), pp.1095-1098.

Saatchi, S., Houghton, R., Dos Santos Alvalá, R., Soares, J. And Yu, Y. (2007). Distribution of aboveground live biomass in the Amazon basin. *Global Change Biology*, 13(4), pp.816-837.

Copyright © 2017 Laura Coomber & Alliance for a Sustainable Amazon