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EMISSÃO E ESTOQUE DE CARBONO DO SOLO SOB EFEITOS DE BORDA E EXTRAÇÃO DE MADEIRA EM ÁREAS DE FLORESTA NA AMAZÔNIA CENTRAL

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Sinopse: Avaliamos os efeitos de borda e da extração de madeira sobre o efluxo de CO_2 do solo, o estoque de carbono orgânico do solo e a fração leve livre da matéria orgânica no solo superficial em dez áreas de floresta do Assentamento Tarumã Mirim, ao norte de Manaus. Para auxiliar na compreensão da variação espacial destes parâmetros, avaliamos também variáveis como temperatura, umidade e densidade do solo e espessura da camada de liteira.

Palavras-chave: aquecimento global, fluxo de carbono, solo, fragmentação.

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Resumo

As mudanças ambientais causadas pela fragmentação florestal podem modificar o fluxo de carbono de um ecossistema florestal e contribuir para maiores emissões de dióxido de carbono (CO_2) para a atmosfera. Considerando que o solo possui um grande estoque de carbono (138 Gt de carbono até 8 m de profundidade na Amazônia Legal), a emissão desse carbono em forma de CO_2 poderia acelerar as mudanças climáticas. Para melhor compreender o efeito de borda e da extração de madeira sobre o carbono no solo, medimos a variação espacial do efluxo de CO_2 e do estoque de carbono do solo superficial em relação à distância até 200 m da borda. Além disso, mensuramos variáveis ambientais que pudessem explicar tal variação espacial dentro de uma parcela de 20 x 200 m, posicionada perpendicularmente à margem da borda de dez áreas sob efeito de exploração madeireira. A complexa variação espacial do efluxo de CO_2 pelo solo de áreas alteradas está relacionada a diversos fatores ambientais, tais como: percentual de carbono total e da fração leve livre do solo superficial, temperatura do solo, espessura da camada de liteira e densidade do solo. O efeito de borda sobre o efluxo de CO_2 do solo mostrou-se complexo e difícil de ser mensurado, mas encontramos evidências de que a presença de borda aumenta o estoque de carbono no solo superficial. Extração seletiva de madeira sem controle e por períodos prolongados também aumenta o estoque de carbono do solo superficial, mas aumenta a emissão de CO_2 pelo solo. Estes resultados sugerem que, apesar do estoque de carbono do solo superficial aumentar com a deposição de material vegetal sobre o solo em virtude do efeito de borda e da atividade de extração de madeira, este estoque tem sido decomposto, aumentando as emissões de CO_2 para a atmosfera.

Abstract

The environmental changes caused by forest fragmentation may affect the forest carbon fluxes and increase the efflux of CO_2 to the atmosphere. The emission of stored soil carbon can accelerate the global warming because of the large amount of soil carbon (138 Gt carbon up to 8 m of depth in Legal Amazon). To understand the edge and logging effects on the forest soil carbon, we analyzed the soil efflux of CO_2 and topsoil carbon stock spatial variation in relation to the edge distances (0-200 m) at ten sites in the Central Amazon. Furthermore, some environmental variables that could explain this spatial variation were measured to get a better understanding of this spatial variation. The complex spatial variation of soil CO_2 efflux is related to many environmental variables as total carbon and free light fraction carbon in topsoil, soil temperature, depth of the litter layer and soil density. The edge effect on soil CO_2 efflux was complex and difficult of be measured, but we find evidences of edge effect increases the top soil carbon stock. Logging without control and during by long time also increases the top soil carbon stock, but increases the soil CO_2 efflux too. These results suggest that despite increase of top soil carbon stock by deposition of vegetal material on soil caused by edge effect and logging, this stock has been decomposed, increasing the soil CO_2 emission to atmosphere.

Sumário

Lista de Figuras

Introdução

O dióxido de carbono (CO_2) é um dos principais gases causadores do efeito estufa e sua concentração atmosférica tem sofrido acréscimos desde a Revolução Industrial, atingindo valores alarmantes nas últimas décadas. Este aumento é uma conseqüência de dois principais fatores: a queima de combustíveis fósseis e o desmatamento (IPCC, 2007). A derrubada de florestas, seja para agricultura, pecuária ou exploração madeireira, é considerada uma das principais causas da emissão de dióxido de carbono para a atmosfera, uma vez que os solos e a fitomassa são os principais compartimentos de carbono no ambiente terrestre (Bernoux *et al.*, 2001). Na Amazônia, a participação do solo no fluxo total do ecossistema foi estimada em até 84% do CO2 emitido pela floresta (Meir *et al.,* 1996).

Centenas de milhões de hectares de florestas tropicais, contudo, continuam sendo desmatados; somente no ano de 2007, 11.532 km^2 de floresta da Amazônia Legal foram desmatados (INPE - Instituto Nacional de Pesquisas Espaciais, 2008). Apesar dos inúmeros desmatamentos, a Amazônia ainda é a mais extensa floresta tropical úmida do planeta, e a região da Amazônia Legal representa aproximadamente 61% do território brasileiro, com área de 5.217.423 km^2 (SUDAM, 2008).

O desmatamento na Amazônia transforma paisagens de floresta contínua em paisagens de fragmentos de floresta inseridos em matrizes de terra drasticamente modificada, como pasto ou áreas de fazenda cortadas e queimadas. Estas áreas de pasto acabam se tornando improdutivas e, conseqüentemente, são abandonadas e recolonizadas espontaneamente por vegetação secundária. Este processo progressivo de sucessão das terras abandonadas no sentido de gerar fragmentos de florestas secundárias, entretanto, é bastante lento, principalmente se comparado à velocidade dos desmatamentos. Além disso, as florestas remanescentes fragmentadas e com bordas expostas também sofrem sérios impactos ambientais.

Florestas tropicais chuvosas não perturbadas são úmidas, sujeitas a pouco vento, com temperaturas estáveis e cobertura vegetal quase contínua (Laurance *et al*., 2002), mas, na presença de bordas ou clareiras, estas condições são alteradas. Nestas áreas (com bordas ou clareiras) ocorrem o aumento da temperatura e da iluminação e diminuição da umidade, o que causa estresse para plantas sensíveis à seca (Malcolm, 1994). Estas alterações físicas diretas podem penetrar de 40 a 60 m para o interior da floresta (Didham & Lawton, 1999; Sizer & Tanner, 1999). Entretanto, o aumento brusco da mortalidade de árvores e os danos causados por estas alterações físicas podem chegar a atingir 100-300 m para o interior da floresta (Ferreira & Laurance, 1997; Laurance *et al*., 1997).

As bruscas mudanças na umidade, temperatura, luz e intensidade de vento aparentemente excedem as tolerâncias fisiológicas de algumas plantas, levando a um aumento da mortalidade de árvores e alterando a composição da comunidade de plantas, as dinâmicas de biomassa e o estoque de carbono (Laurance, 2004). Em um experimento de indução de seca, por exemplo, onde 60% da chuva foi interceptada, as maiores árvores foram as primeiras a morrer, aumentando muito o aporte de matéria orgânica ao solo e a descarga de carbono para a atmosfera (Nepstad *et al*., 2007). Na Amazônia central, árvores maiores que 60 cm de diâmetro são especialmente vulneráveis, caindo cerca de três vezes mais rápido próximo às margens do que no interior das florestas (Laurance *et al*., 2000). Adicionalmente, algumas árvores próximas às margens simplesmente morrem em pé (Sizer & Tanner, 1999).

A matéria orgânica do solo (MOS), principal compartimento de carbono na biosfera, pode ser fracionada de acordo com sua taxa de decomposição ou tempo de permanência no solo. A MOS Ativa é constituída pela biomassa microbiana do solo e seus produtos, é de fácil decomposição e curto tempo de reciclagem (1 a 5 anos), dependendo do ambiente e do conteúdo de areia do solo. A MOS Lenta é derivada do material vegetal estrutural e da matéria orgânica química e fisicamente protegida com tempo intermediário de reciclagem (20 a 40 anos). A MOS Passiva, por sua vez, é composta por material muito resistente à decomposição, sendo quimicamente recalcitrante e fisicamente protegida, com tempo de reciclagem longo (200 a 500 anos).

O fluxo de CO_2, entretanto, é determinado não só pelas características químicas da matéria orgânica do solo, mas também por inúmeros fatores físicos, químicos e biológicos inter-relacionados (Wagai *et al.*, 1998; Vanhala, 2002; Yim *et al.*, 2002; Zanchi *et al.*, 2009). O solo pode estocar ou liberar consideráveis quantidades de carbono através de processos naturais como deposição, decomposição e respiração de raízes (Drewitt *et al.*, 2002). Parte deste estoque é composto pela matéria orgânica passiva do solo que tem uma alta capacidade de estocagem de carbono (Trumbore, 1995).

Neste contexto, o papel do carbono do solo em relação ao efeito estufa torna-se uma preocupação mundial, uma vez que a liberação desse carbono representa uma alça de retroalimentação positiva (Fearnside, 2008). Ou seja, quanto mais carbono é liberado pelos solos, maior o aumento da temperatura devido ao efeito estufa, o que aumentaria ainda mais a liberação de carbono do solo. Este carbono liberado pelo solo, mesmo em pequena quantidade, pode ser significativo para o aquecimento global, uma vez que existem cerca de 1,6-2,0 trilhões de toneladas de carbono nos solos da Terra apenas no primeiro metro de profundidade (Prentice *et al.*, 2001). As primeiras estimativas dos estoques de carbono no solo para a Amazônia legal foram dadas por Moraes *et al.* (1995) que se basearam nas análises de 1162 perfis de solo do levantamento realizado pelo projeto RADAMBRASIL nas décadas de 70 e 80.

As medições do CO_2 voltadas para a estimativa do efluxo do solo utilizando analisadores de gás por infravermelho (IRGA) iniciaram-se na década de 50 (Zanchi, 2004). Estes analisadores são sensores de amostragem direta do ar e de rápida aquisição contínua de dados, ligados a sistemas de câmaras. Os sistemas de câmaras mais utilizados e mais adequados para a realização de medições de respiração do solo são os sistemas de fluxo aberto com o método de analisador por gás infra-vermelho, o método de câmara fechada e o método de câmara fechada dinâmica (Bekku *et al.,* 1997). Em câmaras de ciclo fechado, que podem ser dinâmicas ou estáticas, a estimativa é feita através da determinação da taxa de aumento da concentração de CO_2 dentro do espaço de amostragem da câmara, quando sobreposta sobre o solo por um tempo conhecido (Meir *et al.*, 1996). Estas câmaras atualmente são as mais utilizadas, devido ao seu relativo baixo custo e fácil manuseio.

Desta forma, é possível medir a emissão de carbono do solo e contribuir para a compreensão de seu efeito sobre o aquecimento global. A inclusão dessas emissões na contabilidade nacional é importante para que a *Convenção sobre Mudança Climática da Organização das Nações Unidas (UNFCCC)* tenha êxito em controlar o efeito estufa por meio de compromissos negociados sob o Protocolo de Quioto, já que o solo ainda é omitido nesses compromissos (Fearnside, 2008), e suas emissões de carbono podem ser afetadas tanto por desmatamentos como por outras alterações menos drásticas, como a fragmentação e a extração seletiva de madeira (Nascimento & Laurance, 2004).

Trabalhos anteriores na Amazônia central mostraram que próximo às bordas de floresta primária, há um aumento na produção de liteira fina e grossa (Nascimento & Laurance, 2004; Vasconcelos & Luizão, 2004) e também um aumento do acúmulo de liteira sobre o solo (Didham & Lawton, 1999), susceptível à decomposição e liberação de carbono para a atmosfera. Esta taxa de decomposição da liteira, que é a principal via de entrada de nutrientes (carbono em especial) para o sistema do solo, está relacionada não só às condições ambientais, mas à composição química da liteira.

O material vegetal é composto de frações metabólicas (fácil decomposição) e estruturais (difícil decomposição), e sua velocidade de decomposição está relacionada à proporção lignina/nitrogênio (Parton *et al.*, 1994). Ou seja, quanto maior for a relação lignina/nitrogênio do material vegetal, menor sua taxa de decomposição. As bordas de florestas fragmentadas sofrem importantes mudanças estruturais, modificando sua composição florística e, consequentemente, a composição e a qualidade da liteira produzida (Vasconcelos & Luizão, 2004).

Assim, a determinação do efeito de borda sobre o estoque de carbono e a respiração do solo e liteira de florestas, por sua vez, pode contribuir na construção de modelos preditivos a respeito das mudanças climáticas e para cálculos de seqüestro de carbono do ecossistema. Diferentes modelos preditivos de matéria orgânica do solo (MOS) foram desenvolvidos nos últimos 30 anos.

O modelo CENTURY tem se destacado como uma importante ferramenta no estudo da dinâmica da MOS, tanto em ambientes de regiões temperadas quanto tropicais (Parton *et al.*, 1994). Este modelo inclui os três compartimentos de MOS (ativo, lento e passivo), com diferentes taxas de decomposição, compartimentos de resíduos vegetais acima e abaixo do solo e um compartimento microbiano superficial (Parton *et al.*, 1994; Figura 1). Os fluxos e as taxas de decomposição dos compartimentos são calculados pelo modelo levando em consideração a quantidade de carbono do compartimento, a taxa de decomposição máxima do compartimento (que podem ser modificadas se, por exemplo, houver revolvimento do solo), o efeito da umidade, temperatura e textura do solo.

No que diz respeito à textura, o modelo CENTURY considera que a textura do solo afeta a taxa de reciclagem da MOS ativa e a eficiência de estabilização da MOS lenta. A taxa de reciclagem da MOS ativa decresce linearmente com o aumento do conteúdo de silte mais argila, enquanto a eficiência de estabilização da MOS lenta aumenta (Parton *et al.*, 1994). Isso se deve ao fato de que à medida que o conteúdo de argila aumenta, a área superficial da matriz mineral do solo e o potencial de estabilização da MOS aumentam (Scott *et al.*, 1996). Além disso, a distribuição do tamanho e continuidade dos poros e tamanho e estabilidade de agregados alteram a disponibilidade de água do solo, a difusão de gases e o movimento de organismos do solo (Hassink *et al.*, 1993) e conseqüentemente, o acesso microbiano à MOS. Assim, o carbono que sai do compartimento ativo é dividido em quatro diferentes fluxos, os quais incluem respiração microbiana, lixiviação de C orgânico solúvel, e a estabilização de C nos compartimentos lento e passivo. O desenvolvimento de modelos de simulação com conotação ambiental, desta forma, requer o entendimento das influências, processos, compartimentos e fluxos de matéria orgânica no solo.

Objetivos

Objetivo Geral

Este estudo pretende contribuir para aumentar este conhecimento gerando novas informações a respeito de fatores que podem contribuir para uma maior ou menor emissão de dióxido de carbono (CO_2) para a atmosfera por solos de florestas remanescentes em áreas sob ação antrópica recente.

Objetivos Específicos

1. Verificar como o efeito de borda influencia a estocagem e o efluxo de CO_2 do solo em áreas de floresta de um assentamento rural;
2. Verificar se a extração de madeira afeta a estocagem e a CO_2 do solo argiloso de áreas de floresta de um assentamento rural;
3. Verificar quais as variáveis ambientais que mais influenciam a variação espacial do efluxo de CO_2 do solo.

Soil carbon stocks and effluxes in fragmented and logged forest areas in central Amazonia

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Keywords: carbon, efflux, stocks, forest fragmentation, edge effects, selective logging

Manuscrito seguindo as normas da revista *Global Change Biology*. As figuras com as legendas foram inseridas como elementos pós-textuais para obedecer às normas da revista, sem prejudicar o trabalho dos revisores.

Abstract

Environmental changes caused by forest fragmentation can alter the flow of carbon from a forest ecosystem and contribute to higher emissions of carbon dioxide (CO_2) into the atmosphere. Considering that the soil has a large stock of carbon (138 Gt of carbon up to 8 m depth in the Amazon), the emission of carbon as CO_2 could accelerate climate change. To better understand the edge effect and impact of selective logging on soil carbon, we measured the spatial variation of CO_2 efflux and topsoil carbon stocks over a distance up to 200 m from the edge. In addition, we measured environmental variables that could account for this spatial variation within 20 x 200 m plots perpendicular to the forest edges of ten areas under the logging effect. The complex spatial variation of CO_2 efflux from the soil of disturbed areas is related to several environmental factors, such as the percentage of total carbon and free light fraction of soil upper layer, soil temperature, thickness of litter layer, and soil density. The edge effect on soil CO_2 efflux was shown to be complex and difficult to measure, but we did find evidence that the presence of a forest edge increases the stock of carbon in the topsoil. Uncontrolled selective logging for long periods also increases the carbon storage of topsoil, at the same time increasing the emission of CO_2 from forest floor. These results suggest that although the carbon stock of topsoil increases with the deposition of plant material on the soil surface under the edge effect and logging activity, part of this stock is decomposed and released, increasing soil CO_2 emissions to the atmosphere.

Introduction

The increased concentration of carbon dioxide (CO_2) is a major cause of global warming. This increase is due to two main factors: the burning of fossil fuels and changes in land use (IPCC, 2007). Forest clearance, whether for farming, ranching or logging, emits carbon dioxide into the atmosphere by burning or decomposing organic material from vegetation and soil.

On the Amazon region, there is an estimated stock of 80 Gt of carbon (C) in vegetation and about 138 Gt of carbon in the soil up to 8-m depth (Fearnside, 2000). Soil carbon efflux was estimated to correspond up to 84 % of all CO_2 emitted by the entire forest under natural conditions (Meir *et al*., 1996; Chambers *et al*., 2004). Therefore soil represents the largest component of ecosystem respiration in Amazonian forests, where both C storage and CO_2 emission from soil are results of natural processes such as deposition and decomposition of organic matter, and soil respiration (Drewitt *et al*., 2002). Thus, C storage and emissions are influenced by characteristics of organic matter in soil and numerous physical, chemical and biological inter-related factors (Waga *et al*., 1998; Vanhala, 2002; Yim *et al*., 2002), which are subject to climate changes.

Models capable of simulating the effects of climate change on soil organic matter (eg. CENTURY and RothC) and hence the stabilization levels of C in soil, discriminate the fractions of soil organic matter (SOM) according to their rates decomposition and their ability to release nutrients, into labile, recalcitrant and passive fractions. Sohi *et al*. (2001) proposed a method of physical separation of SOM into free light fraction (FLF), intra-aggregate light fraction (ILF) and heavy fraction (HF). The FLF consists of organic materials derived primarily from plant remains, but also contain quantities of microbial and micro-fauna residues, generally showing a rapid rate of transformation. The ILF, consisting of physically stabilized light fraction incorporated into soil macroaggregates (> 250 microns), comprises a diverse set of organic compounds, reduced in size and showing a degree of decomposition more advanced than the FLF fraction. Thus, the FLF is a C source more available to soil organisms, having a shorter cycling time (Swanston *et al*., 2005). The largest proportion of total organic carbon (TOC) in soil is associated with the HF (Poirier *et al*., 2005). This fraction presents more slow and gradual changes, making the light fractions, especially the free light fraction, an indicator more sensitive to changes in soil quality and in the land use (Garten *et al*., 1999).

The environmental characteristics of natural forests, including soil characteristics, are altered when exposed to human activities that can generate, for example, edges or clearings. Forest edges and clearings are subject to increases in temperature and lighting and to lowering humidity (Kapos *et al*., 1997), which can lead to increased tree mortality and changes in the dynamics of biomass and carbon stock (Laurance, 2004). In this context, an increased CO_2 emission from soil and its role in relation to the greenhouse effect become a global concern, since the release of this C represents a positive feedback loop (Knorr *et al*., 2005; Powlson, 2005; Fearnside, 2008) – the more carbon is released from the soil, the greater the temperature increase due to the greenhouse effect, which would further increase the release of C by soil. Through mathematical models, Jones *et al*. (2005) showed that CO_2 released by soil respiration on a global level could not be fully fixed in terrestrial vegetation by the expected global increases in primary productivity, resulting instead in an increased accumulation of atmospheric CO_2 at higher levels during this century than previously estimated. Moreover, it is estimated that the loss of biomass resulting from changes induced by forest fragmentation in the tropics may release up to 150 Gt $yr^{-1}$of carbon into the atmosphere, beyond what is produced by the deforestation (Laurance *et al*., 1997). This estimate of the fragmentation effect on the remaining forests, however, does not take into account the possible emissions of CO_2 by decomposition of C stored in soil, but only decomposition of above-ground biomass.

It seems plausible to imagine that, as the variables that affect the carbon cycle in the soil are modified with the opening of borders in forest, the edge effect would induce changes in the spatial variation of C storage and emissions by soil. Thus, we aim to contribute to a better understanding of the effects of deforestation on soil-C emissions in the remaining forest areas, evaluating if: 1. the edge effect influences the spatial variation of C storage and efflux in the soil surface of remaining forest areas; 2. the selective logging change the CO_2 efflux and carbon stocks of topsoil; and, 3. the spatial variations in CO_2 efflux and soil carbon stocks are correlated with environmental variables modified by the edge effect.

Materials and methods

Study area

This study was carried out in ten areas of plateau upland forest in the rural settlement called Tarumã-Mirim, located north of the city of Manaus (2 º 57'S, 60 º 07'W) at the secondary road known as “Pau Rosa” In this settlement, the properties are all small, in the range of 25 ha. According to the smallholders, forest edges were about 15 year old at the beginning of the study. All 10 areas selected for the study were submitted to selective logging at varying degrees of intensity and for different purposes. The settlement Tarumã-Mirim, has a total area of 42,911 hectares and capacity to house 1042 families. Besides the 25-ha rural properties, installed for agricultural purposes, the area of the settlement also includes five demarcated forest reserves totaling more than 7,000 ha.

In this region there is little monthly variation in temperature, with values between 24.6 and 26.9 ° C (Araújo *et al*., 2002). The period from December to May is characterized by a rainy season and from July to October by a dry season; June and November are the months of transition between seasons. The average annual precipitation is 2.431mm, with monthly rainfall varying between 95 and 304 mm for the dry and rainy seasons, respectively (Malhi *et al*., 1998). The year 2010, however, had an unusual rainy season that lasted until June, with a monthly rainfall of 249 mm (Fig. 1a) followed by 151 mm and 82.6 mm of precipitation in July and August, respectively.

The original forest of the central Amazon region is classified as Dense Upland Rainforest (Braga, 1979) and the predominant soil is a typic alic, clayey Oxisol (IPEAAOc, 1971). This soil is characterized by having low to very low potential for agricultural activities and livestock (RADAMBRASIL, 1987). This makes selective logging, in particular for the production of charcoal, the main source of income for the smallholders (Wandelli, 2008), which has caused deterioration of the remaining forests near the properties. Furthermore, the felling of forests for the establishment of houses and agricultural or pasture plots defined by the National Institute of Colonization and Agrarian Reform (INCRA) has exposed the remaining forests to edge effects.

Sampling design

To determine whether the edge effect influences the spatial variation of CO_2 efflux and of carbon stocks in topsoil, 54 sampling points were distributed within a 20 x 200 m plot, perpendicular to the edge of each of the ten study areas. Each plot was divided into three blocks of 20 x 50 m with 18 points systematically distributed and distant from each other at least 5 m (Fig. 2). In two out of the ten areas, the last block with 18 points was not installed because of the presence of slopes over a distance of 130 m from the edge. These were discarded because areas with different topographies differ in rates of CO_2 efflux from the soil (Epron *et al*. 2006). This arrangement of points was done aiming to increase the sampling effort to detect the spatial variation, especially near the edge region (initial 50 m of distance from the border), where we expected to observe greater edge effect on soil-C, but minimizing the time of sampling along the plot.

Soil CO_2 emissions

Measurements of soil respiration, as well as the collection of soil samples and measurements of environmental variables, were all done in the period from 3 to 15 August 2009, sampling one area per day. This sampling period corresponded to the onset of the drought that year, after a period of unusual rainfall, with a few rain events in late afternoon, after the completion of samplings (Fig. 1b). The duration of the measurements of CO_2 efflux from the soil at each point was 2 min, as suggested by the manual of the equipment (LICOR), and total time for the 54 sampling points in each area lasted around five hours, starting always around 10 am. The soil CO_2 efflux was measured with a portable IRGA infrared gas analyzer (LI-8100) connected to a chamber in a closed system. The chamber was attached to a PVC ring measuring 10 cm in diameter and about 4.5 cm tall, inserted up to 2 cm in the soil, ensuring the sealing of the soil-chamber interface. The sampling started two weeks after the insertion of the rings on the ground, period required for the soil to recover from the disturbance experienced at insertion of the rings (Meir *et al*., 1996).

Environmental variables

For each of the 54 sampling points in each area, soil temperature, moisture and density, and the thickness of the litter layer were measured. Soil temperature was measured simultaneously with the outflow, using the average between two sensors STP-1 (Soil Temperature Probe, PP Systems, UK) at the default soil depth of 15 cm. Soil bulk density was calculated from the dry weight of undisturbed samples taken at a depth of 3-8 cm using volumetric cylinders (rings of Kopecky), 5 cm in diameter and 5 cm tall. This depth was set to achieve an intermediate density value that could be compared to the values of the C content of soil samples collected at a 0-10 cm depth. The gravimetric soil moisture, in turn, was calculated by determining the wet weight and dry weight of undisturbed soil. The thickness of the litter layer for each of the sampling points was calculated as the average of six measurements, made close to the point of measurement for soil CO_2 efflux, with the aid of a ruler marked in millimeters.

Organic carbon in topsoil

We collected samples of surface soil (0-10 cm topsoil) for analysis of C contents in the same points where the flux measurements of CO_2 have been performed. Before sampling, the litter layer on soil surface was removed; all plant materials mixed into soil samples were also removed. Then, the samples were loosened and sieved through a 2-mm mesh. Analyses were performed at INPA´s Soil and Plant Laboratory (LTSP). To determine concentrations of total organic carbon in topsoil, a subsample of each sample was macerated and then analyzed by a Vario-Max CN Elementary Analyzer, which uses the dry combustion method. To separate the portion of soil-C that is easy to decompose, we used the method proposed by Sohi *et al*. (2001), obtaining the percentage of C in the free light fraction (FLF) for sub-samples consisting of three composite samples collected for analysis of total C. Therefore, to analyze the effects of environmental variables on the FLF and the effect of this fraction on soil CO_2 efflux, we used the average of three points from the 54 points sampled along the plot.

As the fractionation of soil organic matter in this work was only partial, discriminating only the amount of C in the free light fraction of the soil organic matter, we determined the percentage of total C corresponding to the FLF using the following formula:

$$FLF = \frac{FLF\_C}{Total\_C} * 100$$

Where:

FLF = percentage of total C belonging to the FLF;

FLF_C = amount of C in the FLF of the sub-sample;

Total_C = sum of the total amount of carbon present in three sub-samples that comprise the sample.

Concentrations of total soil-C were converted into carbon stocks (tC ha^{-1}) by multiplying the percentage of C divided by 100, by the density (*d*) of the soil at the sampling point (g cm^{-3}) and by the thickness (*e*) in centimeters (cm) of the soil layer (10 cm), according to the following equation:

$$\text{EC (t ha}^{-1}) = \frac{\text{C}}{100} \text{ x } d \text{ (g cm}^{-3}) \text{ x } e \text{ (cm)}$$

To calculate the C stock in the FLF, this equation was adapted by multiplying the percentage of C in the FLF divided by 100, by the average density (*d*) of the soil in the three sampling points (g cm^{-3}) and by the thickness (*e*) of the soil layer (10 cm).

Selective logging

The level of selective logging of the ten study areas was evaluated using an "selective logging index" (SLI). This index was calculated by dividing the sum of all areas of the stumps of logged trees (from the diameter of the stump at the height of the cut) by the total area of sampling (20 m x 200 m). To assess the extent of selectively logged areas according to the distance from the edge, we divided the plots into six sub-plots of 20 m x 15 m distant from each other about 20 m. Thus, each sub-plot corresponded to the following distance classes: A (0-15 m), B (35-50 m), C (75-90 m) and D (110-125 m), E (150-165 m), and, F (185-200 m).

Statistical analysis

Analysis of variance (ANOVA) were used to test if the ten areas studied are similar with respect to the environmental variables measured (soil density, moisture and temperature, soil CO_2 efflux, and total and FLF carbon in topsoil). Pearson correlation analysis was used to test the correlation of environmental variables (soil temperature, respiration and density, and thickness of the litter layer) with the efflux of CO_2, the total and FLF-C in topsoil. To test the effect of environmental variables on the spatial variation of CO_2 efflux in the ten areas, we performed an ANCOVA (area as a factor) for each of the variables that correlated with efflux. To test whether there is an effect of edge distance on the emission of CO_2 by soil, and on the stocks of total organic C and FLF-C in topsoil, we used analysis of covariance (ANCOVA), where the area was the factor and the distance to the edge was a covariate. To check the distance at which the edge effect still occurs on the C effluxes and on C stocks of topsoil, we performed linear regression for each of the ten areas individually.

Results

Characterization of the areas

The ten areas studied were statistically different for changes in soil density ($F = 57.1$; $p < 0.01$), moisture ($F = 46.8$; $p < 0.01$) and temperature ($F = 6.3$; $p < 0.01$) (Fig. 3). With respect to density (Fig. 3a), areas 1 and 8 were the most different from the others, presenting average values equal to 1.2 (sd = ± 0.19) and 1.4 (± 0.13), respectively, while other areas had a combined average score of 1.0 (± 0.12). Areas 1 and 10 were the most different for soil moisture (Fig. 3b) with average values equal to 27.1 (± 7.52) and 39.9 (± 3.59), respectively, and temperature (Fig 3c), with average values of 26.0 (± 0.26) and 25.6 (± 0.39). The other eight areas combined, in turn, had an average moisture content equal to 33.3 (± 3.22) and temperature equal to 25.7 (± 0.36). Despite the differences in soil temperature and moisture, no significant differences in soil CO_2 emissions were found in areas 1 and 10 in relation to the other areas.

However, CO_2 efflux (Fig. 3d) also showed variations statistically different between areas ($F = 3.3$; $p < 0.01$). Area 4, with an average efflux of 4.7 ± 1.6 μmol CO_2 m^{-2} s^{-1}, was the most differentiated from the average value of efflux of the other nine areas (4.6 ± 1.64). However, this area was not significantly different in relation to other environmental variables that could explain these high values of CO_2 efflux.

The total carbon stock of the upper soil layer (0-10 cm) was significantly different between areas ($F = 25.4$; $p < 0.01$). The area 1 was the most different from the other showing smaller amounts of C, with an average of 29.4 t C ha^{-1}, while the area 8 differed by having the highest values, averaging 51.3 t C ha^{-1}. The remaining areas pooled together had an average stock of 37.8 t C ha^{-1} in topsoil. C stocks belonging to the FLF were also statistically different ($F = 5.2$ and $p < 0.01$) and highly variable between areas (Fig. 3f), as well as the stock of total carbon: area 1 showed the lowest stocks, with an average of 3.3 t C ha^{-1}, while area 8 had the highest values with an average of 5.8 t C ha^{-1}, compared to the average stocks of FLF-carbon in all the other areas combined, equal to 4.6 t C ha^{-1}.

Variables controlling the soil CO_2 efflux

Among the environmental variables measured, the thickness of the litter layer, the concentrations and stocks of total carbon in topsoil, the soil temperature and bulk density were the most correlated with the spatial variation of the soil CO_2 efflux (Table 1). The percentage of total soil-C was correlated with all environmental variables measured, except with soil temperature. The environmental variables that most strongly correlated with the spatial variation in the percentage of the FLF were the concentration of total carbon soil-C, the thickness of the litter layer and the soil bulk density (Table 1).

In the ANCOVA, the correlated variables which significantly influenced the spatial variation of soil CO_2 efflux, were: the percentage of FLF ($p = 0.01$; $F = 6.2$; $r^2 = 0.18$), concentration of total-C($p < 0.01$; $F = 14.1$; $r^2 = 0.09$), the soil temperature at 15 cm depth ($p < 0.01$, $F = 18.4$, $r^2 = 0.09$), the soil density ($p < 0.01$; $F = 16.7$; $r^2 = 0.09$) and the thickness of the litter layer ($p < 0.01$; $F = 16.0$; $r^2 = 0.09$). Soil moisture had no significant effect on the spatial variation of soil CO_2 efflux.

Edge Effect

The ANCOVA on the variation in the soil CO_2 efflux in ten areas, using distance to the edge and soil bulk density as covariates, showed no significant edge effect on the soil CO_2 outflow. Likewise, no significant edge effect on CO_2 efflux was found when we examining the changes over all the 200 m distance from the border in each area individually (Fig. 4). The edge effect, however, was significant on the stocks of total soil-C ($p < 0.01$; $F = 11.0$; $r^2 = 0.340$), soil-C in the FLL ($p < 0.01$, $F = 16.0$; $r^2 = 0.288$), as analyzed by an ANCOVA, with the area as a factor and the edge distance as covariate. The relationship between the distance from the edge and these forms of organic C in soil was shown to be complex; it is not evident along the distance from the edge in most areas when analyzed individually (Figs. 4 and 5).

In four areas (1, 2, 7 and 8) we found an edge effect on the stock of total C in the topsoil (Fig. 5), where the total soil-C stock decreases from the edge into the forest. The C stock belonging to the free light fraction (FLF), in turn, was subject to edge effect in five out of ten areas (Fig. 6). In areas 3 ($p < 0.01$; $r^2 = 0.65$), 9 ($p < 0.05$; $r^2 = 0.58$) and 10 ($p < 0.05$; $r^2 = 0.59$) the edge effect on the stocks occurred within 100 m from the edge, whereas in areas 1 ($p < 0.01$; $r^2 = 0.52$) and 8 ($p < 0.01$; $r^2 = 0.42$) this effect reached up to a 200 m distance from forest edge (Fig. 6).

Selective logging

The study areas had different levels of logging impact, expressed as a selective logging index (SLI), both between areas and between their internal plots (Fig. 7). The SLI was underestimated in areas 3 and 4, because these areas had large gaps caused by accidental fall and death of neighboring trees to the logged trees, and these were not considered in calculating the SLI. Moreover, the first 15 meters from the edge (distance class A) presented the lowest values of SLI, while the highest values in most areas occurred after 75 m distance from forest edge (at distance classes C, D, E and F) (Fig. 7b).

The increased intensity of selective logging resulted in elevation of CO_2 efflux from the soil ($p = 0.026$; $r^2 = 0.59$) and in the stocks of total C ($p < 0.01$; $r^2 = 0.65$) and FLF carbon ($p = 0.05$; $r^2 = 0.39$) in topsoil (Fig. 8). The significant effect of logging on the CO_2 efflux (Fig. 8a), however, only appears excluding the mean of areas 3 and 4, since these areas had higher average CO_2 efflux and an underestimated SLI because the creation of gaps caused by falling trees was not considered when the level of impact was calculated.

Discussion

Soil respiration rates are controlled by a range of biotic and abiotic factors that add complexity to their estimates. Among the abiotic factors, temperature and soil moisture have often been identified as dominant factors in controlling the temporal variation of CO_2 efflux from soil (Chambers *et al*., 2004; Zanchi *et al*., 2009). However, these appear insufficient to explain spatial variations in relatively homogeneous (Han *et al*., 2007) and even less efficient in areas such as heterogeneous forests altered by edge effects and logging, as it is the case of this study. The spatial variation of soil respiration seems to be influenced by a range of environmental factors such as root biomass (Epron *et al*., 2006), percentage of FLF carbon and concentration of total C in the topsoil, soil temperature, soil density and thickness of the litter layer.

However, like Sotta *et al*. (2004), who also studied the spatial variation of CO_2 efflux in pristine areas of the Amazon rainforest, we found no direct influence of soil moisture on the spatial variation of CO_2 efflux. Moreover, the positive effect of temperature at 15 cm soil depth on CO_2 efflux, although significant, had a low explanatory power ($r^2 = 0.09$). We believe that this effect of temperature on the efflux was underestimated and could be higher if the temperature had been measured at shallower soil depths, since the depth of measurements for soil temperature that better explains the variation of this efflux is up to 10 cm (Drewitt *et al*., 2002; Sotta *et al*., 2004; Savage *et al*., 2009).

Many environmental variables controlling soil respiration are modified by the presence of edges on the remaining forest. The edge effect, for example, changes the dynamics of litter production and decomposition of (Vasconcelos & Luizão, 2004; Vasconcelos & Laurance, 2005) and therefore increases the stocks of carbon accumulated in the soil surface by deposition of new organic matter, as found in this study.

The edge effect on the percentage of FLF carbon in the topsoil, however, proved more complex than the effect on the total soil-C stocks, with different behavior among the ten areas (Fig. 6). Such complexity may be a consequence of the disorderly logging activity throughout the plot in the areas we assessed (Fig. 7b), which, besides increasing the amount of plant residues deposited on soil surface by felling trees, allows the growth of pioneer species in the new clearings formed by selective logging.

Additionally, the formation of edges and clearings modifies the microclimate of the remaining forests, since it changes brightness, temperature and moisture (Kapos *et al*., 1997). Microclimatic changes, coupled with the increased speed of the winds at the edge region, add to the soil a large amount of organic matter by the death of trees and reduce the living biomass of roots (Ferreira & Laurance, 1997; Laurance *et al*., 2000). Despite all these changes in the variables controlling soil respiration caused by the edge effect, we found no relationship between CO_2 efflux from the soil and the distance from the edge, measured up to 200 m (Fig. 4). This may be related to increased complexity added by another possible edge effect, the growth of secondary vegetation in the region of old edges, such as the edges of the areas evaluated in this study. This secondary vegetation can close the borders reducing microclimate changes related to the edge effects in the remaining forest (Camargo & Kapos, 1995).

Another possible explanation for the lack of direct relationship between distance from edge and soil CO_2 efflux in this study is that the effect of the variation in soil temperature occurred throughout the sampling period could have masked a possible edge effect on CO_2 efflux from the soil. However, previous studies showed that the average variation of CO_2 efflux for this time of sampling (10 to 16 hours) in areas of central Amazon forest was less than 2 µmol CO_2 m-2 s-1 (Sotta *et al*., 2004; Zanchi *et al*., 2009), while the average spatial variation in the present study, from the border up to 200 m into the forest, was more than 7 µmol CO_2 m^{-2} s^{-1}.

It was assumed therefore that changes in the spatial variation of soil CO_2 efflux caused by the edge effect stood out on its temporal variation associated with soil temperature during the measurement period.

Besides the edge effect, the areas of remaining forest in Central Amazonian fragmented landscapes are commonly subject to logging activities that produce forest gaps of different sizes and shapes, further increasing the complexity of a possible edge effect since the gaps modify the microclimatic close to the soil (Camargo & Kapos, 1995) and add plant material to the soil surface. The lack of relationship between distance from the edge and CO_2 efflux from the soil, therefore, can be partly explained by the impact of logging along the entire length of the plot, especially after 50 m of distance from the border (Fig. 7b), extending a possible edge effect beyond 200 m into the forest. Depending on the parameters analyzed, the effects of selective logging may be manifested sooner or later in the remaining forest and in forest gaps.

For example, Yashiro *et al*. (2008) found no immediate effect of selective logging on the CO_2 efflux from the soil in a forest area in Malaysia, but they did find an increasing trend in CO_2 efflux from the soil over time. CO_2 emissions from the soil of selectively logged areas were significantly higher than emissions in control forest 18 months after the events of timber extraction (Yashiro et al., 2008). This long-term effect was confirmed in our study: in areas subject to ongoing logging activity for about 15 years, we found positive effects not only on the CO_2 emissions from the soil, but also on the soil carbon stocks to 10 cm depth (Fig. 8).

A thick layer of litter on the soil surface is common in the Amazon forest during the dry season (Luizão & Schubart, 1987). However, the deposition of plant material on the soil appears to be greater in areas of remaining forest that is subject to logging activity, since the greater the intensity of timber extraction, the higher the carbon stocks in the topsoil (Luizão *et al*., 2009). Therefore, logging activities increase the stock of total and FLF carbon by adding plant material, and its C previously stored into aerial biomass, to the soil surface; once decomposed, it adds C to the soil. However, at the same time that an intense logging activity increases the C stocks in the topsoil, it also increment the emissions of CO_2 by soil.

In this study, the soil CO_2 efflux was positively correlated with the total soil carbon content and with the percentage of more labile C in soil (free light fraction – FLF). Therefore, forest degradation caused by the edge effect and by selective logging on remaining forests can lead, among other effects, to increases of carbon stocks in soil due to the addition of plant material on soil surface. This stock, however, is partly decomposed and emitted into the atmosphere as CO_2, further contributing to global warming. Thus, such CO_2 effluxes are fostered when a combination of fragmentation and selective logging occurs in a residual forest area, as in the present study.

In order to separate the effect of logging from a possible edge effect on the soil carbon storage and CO_2 emissions, we suggest studies that seek to compare edge areas of remaining forest without logging to internal forest areas under selective logging and to internal areas of pristine primary forest, situations not available for our study in the rural settlement of the Tarumã Mirim region.

Hence it follows that the total carbon content and the percentage of C in the FLF in the topsoil, soil temperature, the thickness of the litter layer and soil density are variables that influence and add complexity to the estimates of the spatial variation of soil CO_2 effluxes. The edge effect on CO_2 efflux was shown to be complex and difficult to measure in areas altered by selective logging, but we found that the carbon stock of topsoil is greater in areas of remaining forest edge. Uncontrolled selective logging occurring during long periods contributes to the increase of carbon stocks in topsoil which, in turn, is associated with an increased emission of CO_2 by soil.

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Conclusão

A respiração do solo é controlada por uma gama de fatores bióticos e abióticos que agregam complexidade a suas estimativas. Dentre os fatores abióticos, a profundidade da liteira, a densidade do solo, o percentual de carbono no solo e a temperatura do solo, destacam-se por influenciar a variação espacial do efluxo de CO_2 do solo. O efeito de borda e a atividade de extração seletiva de madeira, por modificar as variáveis controladoras do efluxo de CO_2, aumentam a emissão média de CO_2 pelo solo durante o dia. Este efluxo de CO_2 pode ser proveniente da decomposição da matéria orgânica acelerada decomposição de frações não lábeis de carbono do solo e, consequentemente, pode estar contribuindo para a diminuição dos estoques de carbono do solo e aumentando as emissões de CO_2 para a atmosfera.

Tabela

Table 1 – Pearson correlation matrix coefficients between the analyzed variables. Bold values are statistically significant ($p \leq 0.05$).

	Bulk Density	Moisture	Temperature	Efflux	FLF	FLF Stock	Total Carbon	C Stock	Liter
Bulk Density	1								
Moisture	**-0,397**	1							
Temperature	-0,016	**-0,250**	1						
Efflux	**-0,128**	0.008	**0,149**	1					
FLF	**-0,267**	0,085	0,103	0,099	1				
FLF Stock	-0,027	0,025	0,012	0,108	**0,858**	1			
Total Carbon	**-0,377**	**0,358**	-0,042	**0,171**	**0,414**	**0,668**	1		
C Stock	**0,249**	**0,148**	-0,050	**0,093**	**0,250**	**0,690**	**0,783**	1	
Liter	**-0,103**	0,003	-0,027	**0,195**	**0,272**	**0,346**	**0,221**	**0,189**	1

FLF – Free Light Fraction

Figuras

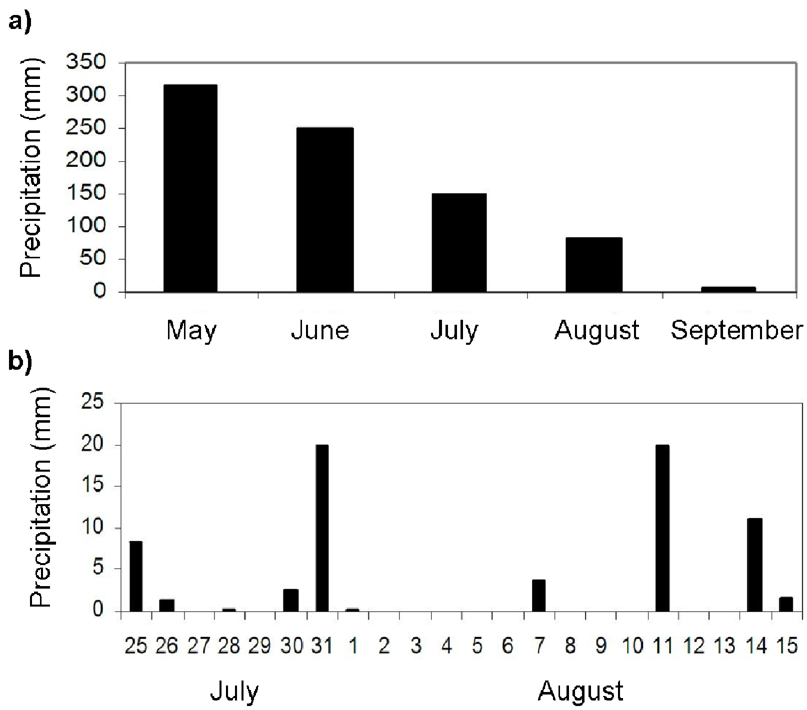

Figure 1 - Monthly (a) and daily (b) rainfall in the year 2009 in the region near the city of Manaus (Source: LBA Program – Central Office, Manaus).

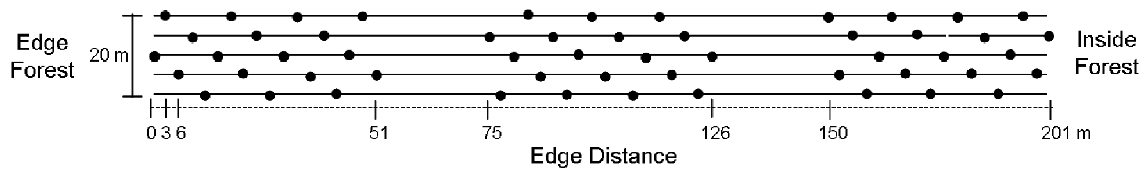

Figure 2 - Schematic layout of the 54 sampling points from the edge to the inside forest (up to 201 m) from each of the ten forest areas studied at Tarumã-Mirim settlement, Manaus-AM.

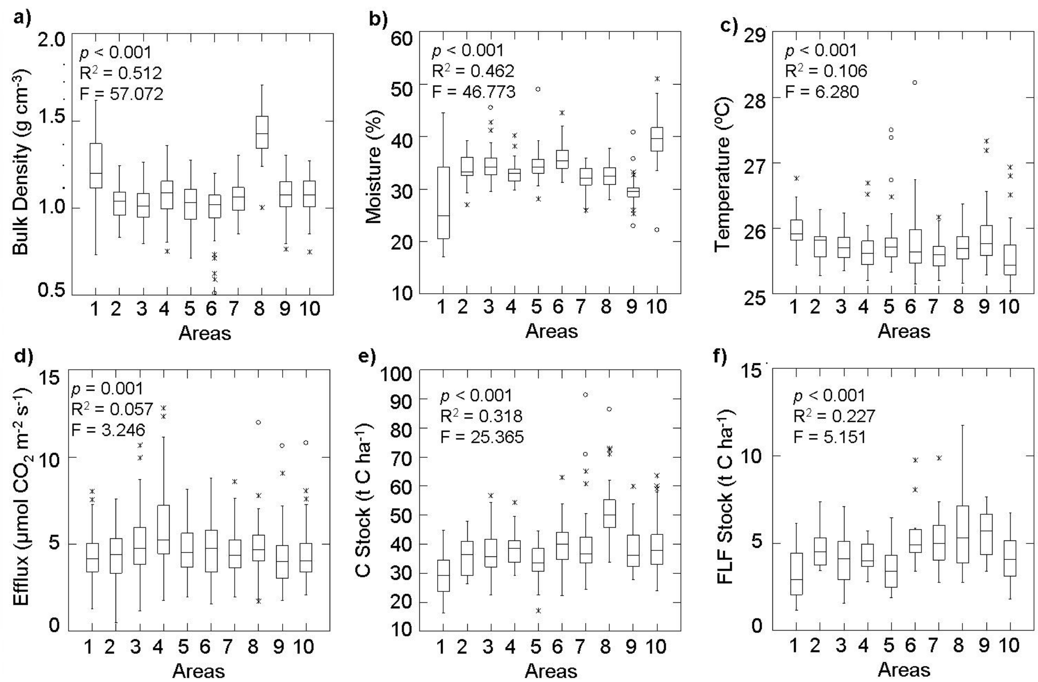

Figure 3 - Characterization of the 10 areas studied in relation to environmental variables measured: a) bulk density (depth 3-8 cm), b) soil moisture; c) soil temperature at 15 cm depth, d) soil CO2 efflux, e) total carbon stock of topsoil (0-10 cm depth), f) carbon stock of the free light fraction of surface soil (0-10 cm depth).

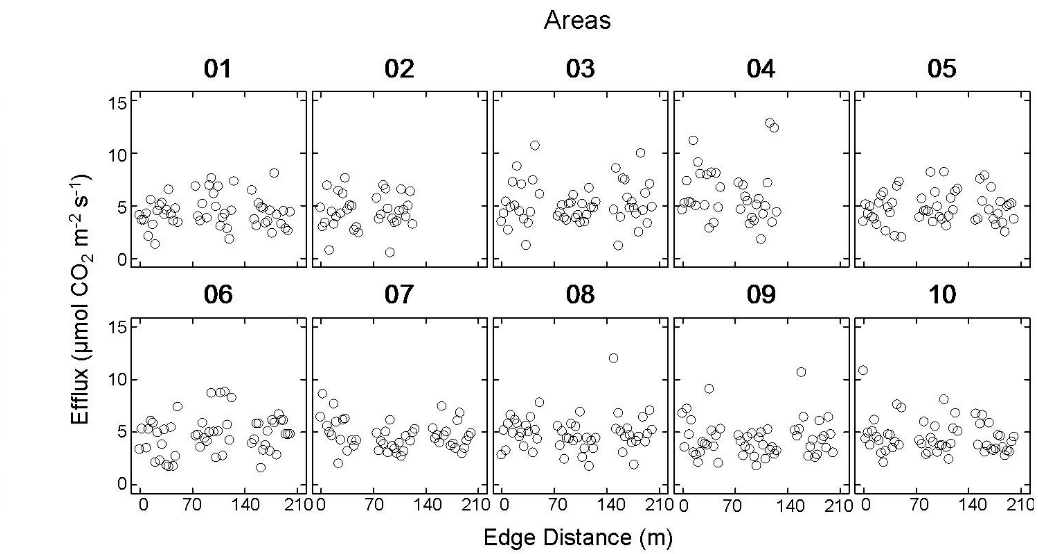

Figure 4 - Relationship between distance from edge and soil CO_2 efflux in the 20 m x 200 m plots (except in areas 2 and 4, where plots measured 20 m x 125 m), located perpendicularly to the edges of the ten areas individually. No significant results were found.

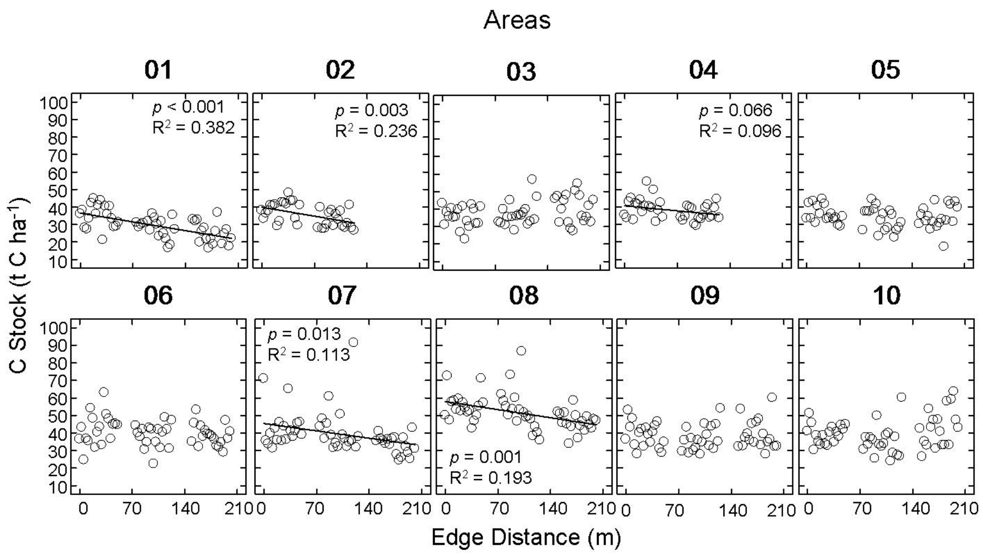

Figure 5 – Relationship between the edge distance and the total carbon stock of topsoil (0-10 cm depth) in the 20 m X 200 m plots, located perpendicularly to the edges of the ten areas, taken individually. Statistically significant relationships found in areas 1, 2, 7 and 8.

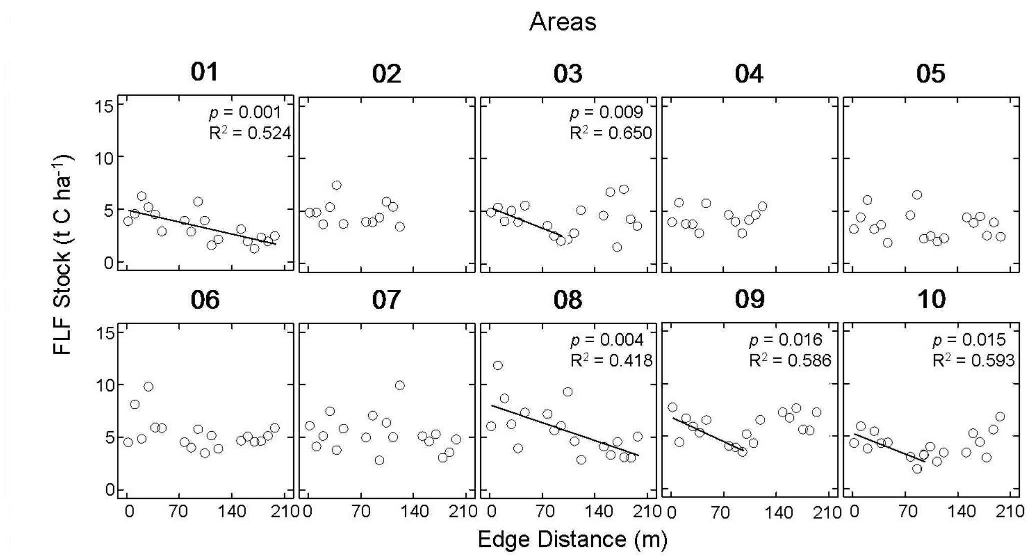

Figure 6 - Relationship between the edge distance and the carbon stock of the free light fraction (FLF) in the topsoil (0-10 cm depth) of the 20 m X 200 m plots, located perpendicularly to the edges of the ten areas, taken individually. Statistically significant relationships up to 100 m were found in areas 3, 9 and 10 and up to 200 m in areas 1 and 8.

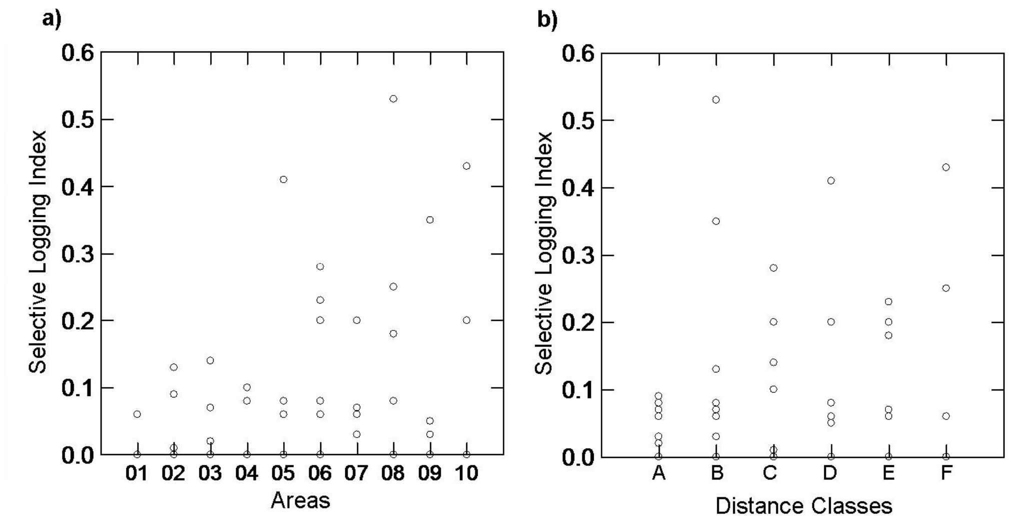

Figure 7 - Selective logging index (SLI) in the six distance classes by area (a) and by the distances from the edges (distance classes) in all ten forest areas (b). Distance classes: A (0-15 m), B (35-50 m), C (75-90 m) and D (110-125 m), E (150-165 m) F (185-200 m).

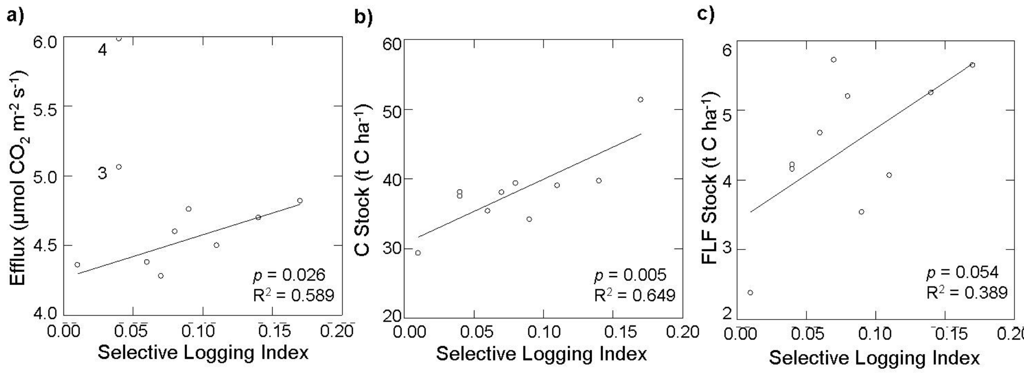

Figure 8 - Relationship between the average SLI (selective logging index) and the average soil CO_2 effluxes and carbon stocks in the study areas: a) average SLI and average CO_2 efflux; b) average SLI and average total carbon stock of topsoil (0-10 cm depth); c) average SLI and average carbon stock in the FLF of topsoil (0-10 cm depth). The values of p and r^2 in the chart "a" were calculated excluding areas 3 and 4, where the SLI was underestimated by not considering the presence of large gaps in these study areas.

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ANEXOS

ANEXO A – *Ata da Aula de Qualificação*

PG-ECO-INPA

INPA

Ministério da Ciência e Tecnologia

BRASIL

AULA DE QUALIFICAÇÃO

PARECER

Aluno(a): PATRÍCIA MARIA SOUSA DE ABREU
Curso: ECOLOGIA
Nível: MESTRADO
Orientador(a): FLÁVIO LUIZÃO

Título

"Efeito de borda sobre estoques e fluxos de carbono no solo em floresta de terra firme na Amazônia: estudo em um assentamento rural".

BANCA JULGADORA

TITULARES:
Philip Fearnside (INPA)
Wenceslau Teixeira (EMBRAPA)
Rita Guimarães Mesquita (INPA)

SUPLENTES:
Elisa Wandelli (EMBRAPA)
Niwton Leal (INPA)

EXAMINADORES	PARECER		ASSINATURA
Philip Fearnside (INPA)	(X) Aprovado	( ) Reprovado	[illegible]
Wenceslau Teixeira (EMBRAPA)	(X) Aprovado	( ) Reprovado	[illegible]
Rita Guimarães Mesquita (INPA)	(X) Aprovado	( ) Reprovado	[illegible]
Elisa Wandelli (EMBRAPA)	( ) Aprovado	( ) Reprovado	
Niwton Leal (INPA)	( ) Aprovado	( ) Reprovado	

Manaus(AM), 14 de abril de 2009

OBS: A banca recomenda que a aluna, junto com seu orientador, reveja a estratégia de coleta de dados, conforme as sugestões apresentadas, com especial atenção p/a variabilidade natural dos parâmetros e melhor distribuição espacial das amostras p/detectar efeito de borda. Recomenda ainda um aprofundamento teórico nos mecanismos e processos do aquecimento global. A candidata apresentou uma boa aula, embora a argumentação tenha revelado lacunas no conhecimento

PROGRAMA DE PÓS-GRADUAÇÃO EM BIOLOGIA TROPICAL E RECURSOS NATURAIS – PPG BTRN
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA PPG-ECO/INPA
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ANEXO B – *Ata da Defesa Oral*

PG-ECO-INPA
PÓS-GRADUAÇÃO EM ECOLOGIA

INPA
INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA

ATA DA DEFESA PÚBLICA DA DISSERTAÇÃO DE MESTRADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA DO INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA.

Aos 03 dias do mês de setembro do ano de 2010, às 10:00 horas, na sala de aula do Programa de Pós-Graduação em Ecologia PPG-ECO/INPA, reuniu-se a Comissão Examinadora de Defesa Pública, composta pelos seguintes membros: o(a) Prof(a). Dr(a). **Plinio Barbosa Camargo**, da Universidade de São Paulo, o(a) Prof(a). Dr(a). **Rita de Cássia Guimarães Mesquita**, do Instituto Nacional de Pesquisas da Amazônia, o(a) Prof(a). Dr(a). **Philip Martin Fearnside**, do Instituto Nacional de Pesquisas da Amazônia, tendo como suplentes o(a) Prof(a). Dr(a). Elisa Vieira Wandelli, da Empresa Brasileira de Pesquisa Agropecuária e o(a) Prof(a). Dr(a). Carlos Alberto Quesada, do Instituto Nacional de Pesquisas da Amazônia, sob a presidência do(a) primeiro(a), a fim de proceder a argüição pública da **DISSERTAÇÃO DE MESTRADO** de **PATRÍCIA MARIA SOUSA DE ABREU**, intitulada "Emissão e estoque de carbono do solo sob efeitos de borda e extração de madeira em áreas de floresta na Amazônia Central", orientado(a) pelo(a) Prof(a). Dr(a). Flávio Jesus Luizão, do Instituto Nacional de Pesquisas da Amazônia.

Após a exposição, o(a) discente foi argüido(a) oralmente pelos membros da Comissão Examinadora, tendo recebido o conceito final:

[X] APROVADO(A) [ ] REPROVADO(A)

[X] POR UNANIMIDADE [ ] POR MAIORIA

Nada mais havendo, foi lavrada a presente ata, que, após lida e aprovada, foi assinada pelos membros da Comissão Examinadora.

Prof(a).Dr(a). Plinio Barbosa Camargo ____________________

Prof(a).Dr(a). Rita de Cássia Guimarães Mesquita ____________________

Prof(a).Dr(a). Philip Martin Fearnside ____________________

____
Marina Anciães
Coordenação PPG-ECO/INPA

ANEXO C – *Ficha de Avaliação do Trabalho de Conclusão Escrito – Dr José Henrique Cattanio*

PG-ECO-INPA

Instituto Nacional de Pesquisas da Amazônia - INPA
Programa de Pós-graduação em Ecologia

INPA

Avaliação de dissertação de mestrado

Título: **Emissão e estoque de carbono do solo sob efeitos de borda e extração de madeira em áreas de floresta na Amazônia central**

Aluno: **PATRÍCIA MARIA SOUSA DE ABREU**

Orientador: **Flávio Jesus Luizão** Co-orientador: ------

Avaliador:

Por favor, marque a alternativa que considerar mais apropriada para cada item abaixo, e marque seu parecer final no quadro abaixo

	Muito bom	Bom	Necessita revisão	Reprovado
Relevância do estudo	(x)	( )	( )	( )
Revisão bibliográfica	( )	( )	(x)	( )
Desenho amostral/experimental	( )	( )	(x)	( )
Metodologia	( )	(x)	( )	( )
Resultados	( )	( )	(x)	( )
Discussão e conclusões	( )	( )	(x)	( )
Formatação e estilo texto	( )	(x)	( )	( )
Potencial para publicação em periódico(s) indexado(s)	( )	( )	(x)	( )

PARECER FINAL

( ) **Aprovada**

( ) **Aprovada com correções** (indica que as modificações mesmo extensas podem ser incluídas a juízo do orientador)

(x) **Necessita revisão** (indica que há necessidade de uma reformulação do trabalho e que o revisor quer avaliar a nova versão do trabalho antes de emitir uma decisão final)

( ) **Reprovada** (indica que o trabalho não tem o nível de qualidade adequado para uma tese)

Belém, 06/04/2010

Local **Data** **Assinatura**

Comentários e sugestões podem ser enviados como uma continuação desta ficha, como arquivo separado ou como anotações no texto impresso ou digital da dissertação. Por favor, envie a ficha assinada, bem como a cópia anotada da dissertação e/ou arquivo de comentários por e-mail para pgecologia@gmail.com e claudiakeller23@gmail.com ou por correio ao endereço abaixo. O envio por e-mail é preferível ao envio por correio. Uma cópia digital de sua assinatura será válida.

Endereço para envio de correspondência:

Claudia Keller
DCEC/CPEC/INPA
CP 478
69011-970 Manaus AM
Brazil

ANEXO D – *Ficha de Avaliação do Trabalho de Conclusão Escrito – Dr Steel Silva Vasconcelos*

PG·ECO·INPA
PÓS-GRADUAÇÃO EM ECOLOGIA

Instituto Nacional de Pesquisas da Amazônia - INPA
Programa de Pós-graduação em Ecologia

INPA
INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA

Avaliação de dissertação de mestrado

Título: **Emissão e estoque de carbono do solo sob efeitos de borda e extração de madeira em áreas de floresta na Amazônia central**

Aluno: **PATRÍCIA MARIA SOUSA DE ABREU**

Orientador: **Flávio Jesus Luizão** Co-orientador: **------**

Avaliador: **Steel Silva Vasconcelos**

Por favor, marque a alternativa que considerar mais apropriada para cada ítem abaixo, e marque seu parecer final no quadro abaixo

	Muito bom	Bom	Necessita revisão	Reprovado
Relevância do estudo	(x)	( )	( )	( )
Revisão bibliográfica	(x)	( )	( )	( )
Desenho amostral/experimental	(x)	( )	( )	( )
Metodologia	( )	(x)	( )	( )
Resultados	( )	(x)	( )	( )
Discussão e conclusões	( )	(x)	( )	( )
Formatação e estilo texto	(x)	( )	( )	( )
Potencial para publicação em periódico(s) indexado(s)	(x)	( )	( )	( )

PARECER FINAL

( ) **Aprovada**

(x) **Aprovada com correções** (indica que as modificações mesmo extensas podem ser incluídas a juízo do orientador)

( ) **Necessita revisão** (indica que há necessidade de uma reformulação do trabalho e que o revisor quer avaliar a nova versão do trabalho antes de emitir uma decisão final)

( ) **Reprovada** (indica que o trabalho não tem o nível de qualidade adequado para uma tese)

Belém, 20 de abril de 2010.

Steel Silva Vasconcelos

Assinatura

ANEXO E – *Ficha de Avaliação do Trabalho de Conclusão Escrito – Dr Philip Martin Fearnside*

PG-ECO-INPA

Instituto Nacional de Pesquisas da Amazônia - INPA
Programa de Pós-graduação em Ecologia

INPA

Avaliação de dissertação de mestrado

Título: **Emissão e estoque de carbono do solo sob efeitos de borda e extração de madeira em áreas de floresta na Amazônia central**

Aluno: **PATRÍCIA MARIA SOUSA DE ABREU**

Orientador: **Flávio Jesus Luizão** Co-orientador: ------

Avaliador:

Por favor, marque a alternativa que considerar mais apropriada para cada item abaixo, e marque seu parecer final no quadro abaixo

	Muito bom	Bom	Necessita revisão	Reprovado
Relevância do estudo	(X)	( )	( )	( )
Revisão bibliográfica	( )	(X)	( )	( )
Desenho amostral/experimental	( )	(X)	( )	( )
Metodologia	(X)	( )	( )	( )
Resultados	(X)	( )	( )	( )
Discussão e conclusões	( )	(X)	( )	( )
Formatação e estilo texto	(X)	( )	( )	( )
Potencial para publicação em periódico(s) indexado(s)	(X)	( )	( )	( )

PARECER FINAL

( ) **Aprovada**

(X) **Aprovada com correções** (indica que as modificações mesmo extensas podem ser incluídas a juízo do orientador)

( ) **Necessita revisão** (indica que há necessidade de uma reformulação do trabalho e que o revisor quer avaliar a nova versão do trabalho antes de emitir uma decisão final)

( ) **Reprovada** (indica que o trabalho não tem o nível de qualidade adequado para uma tese)

Manaus, 30/04/12 [assinatura] Dr. Philip M. Fearnside, Pesquisador Titular

Local Data Assinatura

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