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INCÊNDIOS RASTEIROS EM FLORESTAS SAZONALMENTE ALAGÁVEIS POR ÁGUA PRETA NA AMAZÔNIA: CARGA DE COMBUSTÍVEL E RECUPERAÇÃO LENTA

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Sinopse: Foram medidas as quantidades de combustível sobre o solo de florestas de terra firme, campinarana e igapó. Nessa última, a recuperação da estrutura da vegetação após o fogo foi estudada.

Palavras-chave: Fogo; igapó; pulso de inundação; regeneração; resiliência; EVI

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Resumo

O fogo é um dos principais instrumentos de desmatamento na Amazônia. No entanto, apesar de sofrerem pouca pressão antrópica, as florestas de igapó e campinarana, ambas sazonalmente alagáveis pelas águas pretas e ácidas do Rio Negro e tributários, são altamente inflamáveis na estação seca. Em de imagens de satélite e observações em campo, essas florestas apresentam uma maior suscetibilidade à propagação do fogo e mortalidade de árvores do que florestas de terra firme adjacentes. Medimos as diferenças na quantidade de combustível entre os três tipos florestais para comparar a suscetibilidade ao fogo. Avaliamos também a influencia da porcentagem de areia no solo e do tempo de inundação no acumulo de combustível no igapó. A regeneração da estrutura florestal em igapós queimados foi inferida a partir do índice de vegetação *Enhanced Vegetation Index* (EVI) e inventários de campo. O EVI de uma queimada de 2.6 Kha foi acompanhado por 10 anos e foi medida a área basal em duas cicatrizes de igapós queimados à 11 e 15 anos. Nossos resultados confirmam que as florestas de campinarana e igapó são mais inflamáveis por possuírem maiores quantidades de combustível, principalmente húmus, liteira fina e raízes finas. Somente no igapó, combustíveis finos (< 8cm) foram observados em grandes quantidades. Essas florestas passam quase a metade do ano alagadas e sob alta precipitação, o que justifica a importância desses combustíveis finos na suscetibilidade ao fogo. Além disso, o EVI mostrou ser uma ferramenta adequada para avaliar a regeneração de florestas alagáveis. Os igapós queimados utilizados nesse estudo mostraram uma resiliência extremamente baixa, com muito pouca regeneração mais de dez anos após uma única passagem do fogo.

Fire in amazonian seasonally waterlogged blackwater forests: fuel loads and slow post-fire recovery

Abstract

One of the most important instruments of deforestation in the Amazon is fire. However, despite not having much human pressure, igapó and campinarana, both seasonally waterlogged forests in the Rio Negro basin, are highly flammable during the dry season. Based on satellite images and field observations, these forests present higher fire propagation and tree mortality then the adjacent lowland forests. We measured the differences in fuel load between these three forest types in order to compare their flammabilities. We tested the influence of sand content and average length of inundation in fuel accumulation in igapó forests. In addition, we address the regeneration of burned igapós with basal area field inventories and Enhanced Vegetation Index (EVI) as a tool for inferring the re-growth of vegetation in these blackwater floodplains. Our results confirmed that campinarana and igapó forests have higher flammability as a consequence of having superior amounts of fuel load, in the form of a peat-like root mat layer above the mineral soil. Only in igapó, fine fuels (< 8cm) were found in large quantities. These forests spend most of year under water or heavy rainfall, thus the presence of fine fuels may be important for their flammability. Moreover, EVI has confirmed to be an adequate tool for accessing seasonally flooded forests regeneration. The burned igapós we studied showed an extremely low resilience, with a slow re-growth 11 years after the fire.

Sumário

Introdução Geral

O fogo é um dos principais instrumentos do desmatamento e degradação em florestas tropicais, tendo sido o foco de diversos estudos por pelo menos 25 anos. Uhl e Buschbacher (1985) primeiramente descreveram a interação entre o uso de fogo em pastagens e a extração seletiva de madeira em florestas de terra firme adjacentes na Amazônia oriental. Extração seletiva de madeira, com uso de tratores, mata e danifica muitas arvores, alterando o micro-clima e tornando essas florestas suscetíveis ao fogo. Por outro lado, o manejo das pastagens com uso do fogo na estação seca gera fontes de ignição. O micro-clima no sub-bosque de diferentes coberturas vegetais foi estudado por Uhl e Kauffman (1990), incluindo floresta de terra firme madura e que sofreu extração de madeira. Encontraram uma maior suscetibilidade ao fogo nessas últimas, como conseqüência de um maior aporte de combustíveis e maiores taxas perdas de umidade. Concluíram também que as finas cascas das árvores da terra firme geram pouca proteção contra o fogo. Nepstad *et al*. (1999) registraram secas severas também alterando o micro-clima de florestas por provocarem uma redução do estoque de água disponível pra planta no solo, levando a um aumento na perda de folhas, com as mesmas conseqüências para a suscetibilidade ao fogo. Estimaram que incêndios rasteiros penetrando "florestas em pé" na Amazônia estavam degradando uma área aproximada equivalente à área desmatada intencionalmente todo ano e com potencial muito maior em anos mais secos. Com base nessas alterações de micro-clima, Cochrane *et al*. (1999) demonstraram a retroalimentação positiva na suscetibilidade ao fogo. Cada evento de fogo leva a um aumento no aporte de combustível e da abertura do dossel, tornando a floresta mais suscetível. No ano seguinte, Cox *et al*. (2000) criaram o primeiro modelo climático que incluiu feedbacks do ciclo de carbono, prevendo mudanças climáticas aceleradas para o século, no entanto não considerando o papel do fogo. A simulação desse modelo indicou mais seca e calor para a Amazônia, resultando nas mais altas anomalias negativas de chuva para a região centro-norte da Amazônia, levando ao colapso da estrutura florestal e savanização (Cox *et al*., 2004).

Outros dois tipos florestais comuns no centro-norte da Amazônia – igapó e campinarana – são naturalmente suscetíveis a propagação do fogo (Prance e Schubart, 1978; Anderson, 1981; Uhl *et al*., 1988; Kauffmann *et al*., 1988; Vicentini, 2004; Williams, 2005), apesar de essa região ter alta precipitação média e pouca pressão antrópica, como desmatamento e extração mecanizada de madeira. Florestas de igapó são sazonalmente alagadas pelo pulso anual de inundação (Junk *et al*., 1989) de rios de água preta ou clara

(Sioli, 1984). Campinaranas são florestas com dossel fechado sobre solos de areia branca e freqüentemente impermeáveis no horizonte C causando encharcamento do solo na estação chuvosa (Anderson, 1981; Pires e Prance, 1985). Ambas as florestas possuem solos ácidos ($pH \leq 4.0$) e extremamente pobres em nutrientes. Imagens landsat do médio Rio Negro mostram diversas cicatrizes no igapó, indicando alta suscetibilidade a propagação do fogo, quando comparadas as florestas de terra firme adjacentes. Essas últimas possuem dossel alto, fechado e pouco acumulo de liteira sobre o solo. Por outro lado, florestas de igapó e campinarana são conhecidas por possuírem uma camada de húmus sobre o solo, penetradas por uma rede de raízes finas (Stark e Jordan, 1978; Singer e Araujo, 1979; Singer e Araujo-Aguiar, 1986), mantendo o húmus bem aerado e suscetível ao fogo durante a estação seca. Em anos muito secos, turfeiras tropicais podem agir como combustível, produzindo incêndios severos. Na seca do El Niño de 1997, o fogo queimou vastas áreas de florestas alagaveis sobre turfa no Sudeste Asiático (Yeager *et al*., 2003), contribuindo com o equivalente a 13-40% da quantidade média de gases de efeito estufa emitidos anualmente pela queima de combustíveis fosseis (Page *et al*., 2002). Esses estudos mostraram incêndios mais intensos nas florestas sobre turfa, que nas florestas adjacentes, sobre solos argilosos. No alto Rio Negro dois estudos mostraram grandes quantidades de combustível sobre o solo de igapós baixos (Kauffman *et al*., 1988; Uhl *et al*., 1988). Esses autores encontraram mais de 90% do combustível na forma de húmus, liteira e principalmente raízes finas. Ao tentarem iniciar incêndios experimentais no igapó baixo, obtiveram sucesso após nove dias consecutivos sem chuva.

Recentemente, Lahteenoja *et al*. (2009) demonstrou a existência de espessos depósitos de turfa na Amazônia Peruana, com taxas de acúmulo equivalentes as turfeiras da Indonésia. Schulman *et al*. (1999) e Ruokolainen *et al*. (2001) estimaram uma área de 150.000 km^2 de turfeiras na Amazônia. Independente de considerarmos a camada orgânica de igapós e campinaranas turfa ou não, profundidades de ate 30 cm podem representar estoques de carbono bastante importantes sobre o solo dessas florestas. Além disso, o fogo pode ter um papel importante, restringindo o acúmulo de turfa nos ambientes favoráveis a formação. Considerando que a região do médio e alto Rio Negro esta normalmente exposta a altas taxas de precipitação, acima de 100 mm o ano todo (Sombroek, 2001), e baixas pressões antrópicas, não era de se esperar que pegassem fogo. Entretanto, extensos incêndios ocorrem e uma grande, porém desconhecida, quantidade de carbono pode estar sendo emitida para a atmosfera. Além disso, espécies endêmicas a esses ecossistemas podem estar em risco de sofrerem extinções locais, já que as florestas de igapó no médio Rio Negro podem queimar com maior freqüência, diante das previsões de redução nas chuvas da região, previstas por Marengo (2007).

Objetivos

Geral

Avaliar as causas da suscetibilidade ao fogo em florestas alagáveis por água preta no médio Rio Negro e demonstrar o padrão de lenta recuperação da estrutura florestal após o fogo

Específicos

1. Comparar a quantidade de combustível sobre o solo entre as florestas de igapó e terra firme no médio e baixo Rio Negro.
2. Relacionar a porcentagem de areia no solo superficial com a quantidade de combustível nas florestas da planície de inundação do médio Rio Negro.
3. Relacionar o tempo de inundação com a quantidade de combustível nas florestas da planície de inundação do médio Rio Negro.
4. Avaliar o estádio de recuperação da estrutura florestal na planície de inundação do médio Rio Negro após perturbações por fogo.

Capítulo 1

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Fire in Amazonian seasonally waterlogged blackwater forests: fuel loads and slow post-fire recovery

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Keywords: floodplain forest, Rio Negro, fire, fuel load, secondary succession, resilience, vegetation index

Abstract

One of the most important instruments of deforestation in the Amazon is fire. However, despite not having much human pressure, igapó and campinarana, both seasonally waterlogged forests in the Rio Negro basin, are highly flammable during the dry season. Based on satellite images and field observations, these forests present higher fire propagation and tree mortality then the adjacent lowland forests. We measured the differences in fuel load between these three forest types in order to compare their flammabilities. We tested the influence of sand content and average length of inundation in fuel accumulation in igapó forests. In addition, we address the regeneration of burned igapós with basal area field inventories and Enhanced Vegetation Index (EVI) as a tool for inferring the re-growth of vegetation in these blackwater floodplains. Our results confirmed that campinarana and igapó forests have higher flammability as a consequence of having superior amounts of fuel load, in the form of a peat-like root mat layer above the mineral soil. Only in igapó, fine fuels (< 8cm) were found in large quantities. These forests spend most of year under water or heavy rainfall, thus the presence of fine fuels may be important for their flammability. Moreover, EVI has confirmed to be an adequate tool for accessing seasonally flooded forests regeneration. The burned igapós we studied showed an extremely low resilience, with a slow re-growth 11 years after the fire.

Keywords: tropical forest, Rio Negro, fire, fuel loads, regeneration, resilience, vegetation indices

Introduction

One of the most important instruments of tropical deforestation and degradation is fire in standing forest, the focus of many studies for at least 25 years. Uhl and Buschbacher (1985) first described the “disturbing synergism” between the use of fire in pastures and selective logging in adjacent *terra firme* forests in the Eastern Amazon. (*Terra firme* is Amazonian upland on well-drained soil, with loam or clay-rich texture, hereafter referred to as “upland forest”). Selective logging with tracked vehicles kills or damages many trees, thereby altering the humid understorey microclimate, increasing forest flammability. Pasture management using fire during the dry season provides sources of ignition. Microclimate was studied by Uhl and Kauffman (1990) under different vegetation covers, including undisturbed and logged *terra firme* forests. They found greater susceptibility to fire in the latter, as a consequence of fuel input and faster rates of fuel moisture loss. They also concluded that the thin bark of *terra firme* tree species provides little protection from fire. In 1999, Nepstad and co-authors found severe droughts also altering forest microclimate by causing leaf-shedding as a physiological response to depletion of plant-available water, producing more fuel load and higher rates of moisture loss. They estimated that ground fires penetrating standing Amazon forest were degrading an area approximately equal to the area deforested each year, with a potential for much more extensive forest fires during severe drought years. Moreover, Cochrane et al. (1999) demonstrated a positive feedback in fire susceptibility: a first fire leads to fuel rain from dead trees and a more open canopy, leading to more intense subsequent fires. In the following year, Cox et al. (2000) created the first climate model that included feedbacks from the carbon-cycle, predicting faster climate changes for the current century, however not considering in the system. Their simulation indicated a dryer and warmer climate in the

Amazon, resulting in high suppression of rainfall in the northern Amazon and dieback of the forest (Cox et al., 2004).

In order to predict the consequences of more frequent and intense droughts for the Amazon, some studies examined ecosystem responses to climate variations in the past (Maslin and Burns, 2000; Haberle *et al*., 2001; Mayle *et al*., 2004; Maslin *et al*., 2005). Haberle and Ledru (2001) found that past fires were associated with rapid climate change and climate variability. On the other hand, Mayle and Power (2008) suggested that most parts of the forested Amazon have been resilient in the face of past drier climates and widespread fires, with the exception of ecotonal areas, contesting the proposed dieback scenario for the future of the Amazon forest. However, with current rates of deforestation, logging, fragmentation and road paving, increasing ignition sources, fire frequency and distribution, we may soon be reaching a "tipping point" where the forest could lose its resiliency (Nepstad *et al*., 2001; Scheffer *et al*., 2001; Oyama and Nobre, 2003; Salazar *et al*., 2007; Nepstad *et al*., 2008; Mahli *et al*., 2009).

Nevertheless, two Amazonian forest types common in the middle and upper Rio Negro – *igapó* and *campinarana* -- are susceptible to fire (Prance and Schubart, 1978; Anderson, 1981; Kauffman *et al*., 1988; Uhl *et al*., 1988; Vicentini, 2004; Williams, 2005), despite this region having high average rainfall, low population, little deforestation and almost no mechanized logging. *Igapó* forest is seasonally inundated by the annual flood pulse (Junk et al. 1989) of black or clear-water rivers (Sioli, 1984). C*ampinarana* is a closed-canopy forest on white sand soil, often with shallow inundation or perched water table in the rainy season (Braga, 1979; Anderson, 1981; Pires and Prance, 1985). Landsat images of the middle Rio Negro show many fire scars in the *igapó* forest indicating higher susceptibility to fire spread in comparison with adjacent upland evergreen forest. The latter have low litter accumulation and a tall closed canopy. Conversely, *campinarana* and *igapó* forests are known to have a peat-like humus layer above the soil, penetrated by a mesh of fine woody roots (Singer and Araujo, 1979; Singer and Araujo-Aguiar, 1986), which maintain the humus well aerated in the dry season. In unusually dry years, tropical peats act as fuel, producing severe fires. In the El Niño drought of 1997, fires burned vast areas of peat swamp forest in Southeast Asia (Page *et al*., 2002; Yeager *et al*., 2003), contributing greenhouse gases equivalent to 13-40% of the mean annual emissions from fossil fuels in that year (Page *et al*., 2002). These two studies described more intense fires occurring in the peatlands, when compared to the surrounding lowland forests. In the Upper Rio Negro, Kauffman *et al*. 1988 found high fuel loads over the soils of lower igapós, with the contribution of more than 90% from the humus, litter and root mat layer. In these same locations Uhl *et al*. 1988 successfully initiated ground fires that spread after nine consecutive rainless days and with a 65% of relative humidity. They also observed the extremely slow recovery of igapó forests after burning.

According to Singer and Araujo (1979), in upland Amazonian forests on latosols, the litter-decomposing organisms are mainly leaf-inhabiting fungi, rapidly recycling the nutrients and impeding the accumulation of litter. In contrast, *campinarana* forests grow on white-sand podzols, with low pH (≤ 4.0), higher leaching of nutrients by rainfall and occasional waterlogging, since many *campinarana* soils are poorly drained (Braga, 1979; Anderson, 1981; Pires and Prance, 1985). Most of the plants produce scleromorphic leaves, also reducing litter decomposition rates. Prance and Schubart (1978) argued that past indigenous clearing of *campinarana* forests by fires created the *campinas*, -- a low and open woody vegetation on white-sand podzols -- as a consequence of the extremely low resilience of these nutrient-poor environments. Local informants living in the middle Rio Negro state that the same ecosystem change happens to *igapó* forests after burning a few times.

Igapó forests grow on nutrient-poor alluvial soils, derived from infertile *terra firme* areas (Sioli, 1984) and highly leached by the annual floodpulse, described by Junk *et al*. (1989) as the major environmental factor driving the evolution of physiological adaptations of the floodplain ecosystem species. The igapó forests are mainly located in the floodplains of the Rio Negro basin and other blackwater tributaries (Keel and Prance, 1979; Pires and Prance, 1985), covering an area of more than 7.000 km^2 along the main course of the middle Rio Negro. Hess *et al*. (2003) estimated a total area of more than 100.000 km^2 of igapó forests across the entire central Amazon. Igapós sustain a great biodiversity, both terrestrial and aquatic. Many endemic fish populations depend on the igapó as a nursery, guaranteeing recruitment, and for feeding, since most of the energy supporting the aquatic food chain comes from the forest. The growth period of trees is mainly restricted to the low water months, producing annual rings during the cambial dormancy induced by submergence (Junk *et al*., 1989; Worbes, 1995; Parolin *et al*., 2004; Schongart *et al*., 2004). In this nutrient-poor environment, adaptations for seedling establishment include large seed mass (Parolin, 2000), allowing rapid initial growth before the flood and association with ectomycorrhizae to reduce nutrient loss from leaching (Singer and Araujo-Aguiar, 1986). Most igapó tree species are evergreen and continuously produce new leaves. In addition, floodplain forests extend far away from the turbulent water of river channels. Therefore, it is possible that during the flood, anoxic conditions in the hypolimnion limit soil respiration and litter decomposition, favoring accumulation of litter and humus. After the flood, soil respiration recovers (Furch and Junk et al., 1997; Richey et al., 2002; Jauhiainen et al., 2005).

Recently Lahteenoja *et al*. (2009) demonstrated the existence of thick peat deposits in the Peruvian Amazon, with accumulation rates similar to the Indonesian tropical peatlands. Schulman *et al*. (1999) and Ruokolainen *et al*. (2001) estimated an area of 150.000 km^2 for Amazonian peatlands. Independently of considering the organic soil of igapós and campinaranas as peat or not, these forests may be storing huge amounts of carbon in the humus layer. Considering these environments are inundated for most of the year and not normally exposed to lengthy drought, that along most of the main stem of the Rio Negro all months exceed an average rainfall 100 mm (Sombroek, 2001) and that logging and deforestation pressures are minor in the middle Rio Negro, ground fire in standing forest should not be a common problem. Nevertheless, extensive forest fires do occur. Therefore, a large but as yet unquantified amount of carbon in the peat-like layer and vegetation of these forests may be at risk of being emitted to the atmosphere. Predictions of reduction in rainfall for the entire Amazon point the middle Rio Negro region as the strongest negative anomalies for this century (Marengo, 2007). Longer drought seasons could reduce fire return intervals and increase fire frequency. Considering the slow re-growth of these forests, the floodplain landscape could suffer and ecosystem shift towards open vegetation (Scheffer *et al*., 2001). Consequently, even larger amounts of green-house gases could be emitted and populations of endemic species could suffer local extinctions.

In order to better understand the relationship between these ecosystems and fire, the first objective of this study was to compare fine fuel loads between the *igapó* forests at the middle Rio Negro, the common *campinarana* forest present in many parts the Rio Negro basin and the typical well-drained latosol upland forest in central Amazonia. The second was to relate percentage of sand in the superficial soil to variations in fuel load across the floodplain forests. The third was to relate mean annual length of inundation to variations in fuel load across the floodplain forests. The fourth was to measure forest structure recovery within 15 years after fire in the floodplain landscape.

Materials and Methods

Site description:

At 2°36'S, 60°13'W, in the lower Rio Negro basin, we sampled well-drained clay-soil upland forest and *campinarana* forest. The mean annual temperature of 26.7°C varies little (Leopoldo *et al*. 1987) and the total annual rainfall is 2200 mm. Dry season (< 100 mm per month) runs from July to September and the rainiest month is April. The topographic plateaus are typically well-drained clay-rich Latosols, covered with upland evergreen forests. Tall closed-canopy *campinarana* forest is found on sandy podzols, generally near streams on the lower portion of broad valley slopes (Lucas and Chauvel, 1992), with a deep (>10cm) layer of humus above the sandy soil. *Campinarana* was also sampled 60 km north of this point near the town of Presidente Figueiredo.

Igapó forests and additional clay-soil upland forests were investigated within 80 km away from the town of Barcelos (0° 58'S, 62° 55'W) on the middle Rio Negro (Fig. 1a.). The *igapó* is on a floodplain inundated by acid (pH 3.5-4.0) nutrient-poor black waters and exposed to a mean 5 m amplitude flood pulse (Fig. 2**)**, with highest level in July and lowest in January. The catchment area for this course of the river is large and receives high rainfall (2400-4000 mm yr^{-1}), making for a stable flood pulse (Sombroek 2001). There is a two-month lag between the beginning of the rainy season and the beginning of rising water. Near Barcelos, annual mean rainfall is 2100 mm, with over 100 mm of rain during the three lowest water months (Fig. 2**)**. The soil texture of the alluvial islands and river margin floodplains is either silty (Goulding *et al*. 1988) or follows the flood level gradient, from clay-rich on the upper, to sandy in the lower parts of the river margins (Irion *et al*. 1997). Forest structure and tree species diversity vary with flood level (Ferreira 2000; Parolin *et al.* 2004). More floristic diversity and taller canopies are found in the upper part of the flood zone (Ferreira 1997). Small motorized canoes are ubiquitous, the main form of travel through the many river channels. Forest fires are ignited accidentally from camp fires made in the shade of the igapó forest while travelling or fishing in the dry season. This type of ignition source is not easily mapped as it is unrelated to slash-and-burn agriculture or pasture management by fire.

Fuel load by forest type

We sampled ten igapó forests in the middle Rio Negro (Fig. 1a.), four upland forests: two in the middle Rio Negro and two in the lower Rio Negro and five campinarana forests in the lower Rio Negro. Humus + litter layer depth and fine fuel loads were compared between forest types using the Mann-Whitney (U) test.

We modified the planar intersect technique of Brown *et al.* (1971, 1982) to quantify fuel load. We measured the depth of litter + humus at ten places along each 250 m transect. Depth was estimated by inserting a smooth metal rod of 2mm thickness, until increased resistance to penetration indicated the bottom of the humus layer. Each piece of fine woody debris (FWD) was counted if it crossed or touched an imaginary 2 m vertical sampling plane above the ground surface. FWD with 1-10 hr dry-down times (0.1-2.5 cm diameter) was counted along ten 3 m sections of the same transect. FWD with 10-100 hr dry-down times (2.6-8.0 cm) was tallied along ten 9 m segments. Five soil samples, taken from below the humus and litter, were mixed into a single composite sample per transect. Transects followed level ground. Length of mean annual inundation was derived from the average flood depth of each transect in the *igapó* forest, estimated from the height of the water mark on tree trunks. The effect of inundation on fine fuel load was examined by linear regression.

Satellite-derived-vegetation indices

The Moderate-resolution Imaging Spectroradiometer (MODIS) product MOD13Q1 (Vegetation Indices) was used to infer the stage of post-fire floodplain forest regeneration. We used the Enhanced Vegetation Index (EVI) from April, 2000 to February, 2009. Unlike other vegetation indices, EVI does not saturate at leaf area index values typically found in mature Amazon forests (Huete *et al.* 2002). A single large burn scar of ~2600 ha was used for this study (Fig. 1b). This entire area burned in the dry season of 1998. Tree mortality in that year was presumed to be near 100% as is typically the case for igapó forest fires. MODIS, NOAA and GOES hot pixel data available at the *Instituto Nacional de Pesquisas Espaciais* (INPE) website, indicate that between 1998 and 2010 the large burn scar did not re-burn. Four separate MODIS EVI pixels within the burn scar were followed over time. Four control pixels were chosen in the adjacent unburned igapó forest. Nominal pixel size is 250 x 250 m at nadir view. Temporal resolution is eight days.

Due to the wide scan angle, broadly overlapping scans on different orbits and the inclusion of morning and afternoon orbits, MODIS reflectance data obtained for the same site on different dates will have different reflectance values. These effects are known as the bi-directional reflectance distribution function (BRDF) and are not removed in EVI data. BRDF is most problematic for textured surfaces, such as a forest canopy. However, if a burned pixel is cloud free, a nearby forested control pixel is also likely to be cloud free, and they will usually be from the same day and orbit. Thus, pairs of burned and unburned pixels close in space will have almost identical view and illumination geometries. Therefore, to partially remove BRDF effects we used a simple ratio, normalizing each burned pixel's EVI to the EVI of a nearby pixel of intact igapó forest captured on the same date.

In addition to reducing BRDF effects, this ratio indicates the stage and rate of secondary forest growth in the burn scars. For example, on Amazon upland, bare soil of a slash-and-burn site or of a site with 100% felled tree trunks, will have EVI lower than surrounding primary forest (ratio <1.0). If left fallow within three years, EVI will exceed that of neighboring primary forest (ratio >1.0), as a smooth dense canopy of secondary forest covers the soil and felled trunks (Steininger, 1996). EVI then gradually drops to the level of surrounding primary forest over the following 10-20 years as the secondary forest canopy surface becomes more irregular (ratio declines toward 1.0).

We also examined the behavior of raw EVI values in the burn scar, i.e., not normalized by EVI of neighboring control pixels in unburned forest. To reduce noise in graphs of the MODIS data, we applied a running mean of ten consecutive observations.

Another problem with measuring forest succession in seasonally flooded environments is the varying percentage of water in each pixel over the year. Water has low EVI and occludes both bare soil (low EVI) and low green secondary forest or shrubs (high EVI). The effect is much more pronounced in the burned pixels, since water is mostly hidden year-round beneath the dense emergent canopy of intact *igapó* forest. To account for the water fraction in each recovering burn pixel, we obtained daily water level records from the *Agencia Nacional de Aguas* (ANA) for Barcelos, 80 km downstream from the burn scar.

Field inventories

Two inventories of secondary forest basal area in the middle Rio Negro were made at fire scars, 11 and 15 years old (Fig. 1b). The younger fire scar covered 100 ha and the older 15 ha. Fire dates were determined from a time series of Landsat images. Each fire had caused 100% tree mortality along both plots, so all measured stems were presumed to have germinated or sprouted after the fire. All trees and vines with diameter at breast height (DBH) ≥ 5.0cm were inventoried in one 4 m x 250 m plot per site.

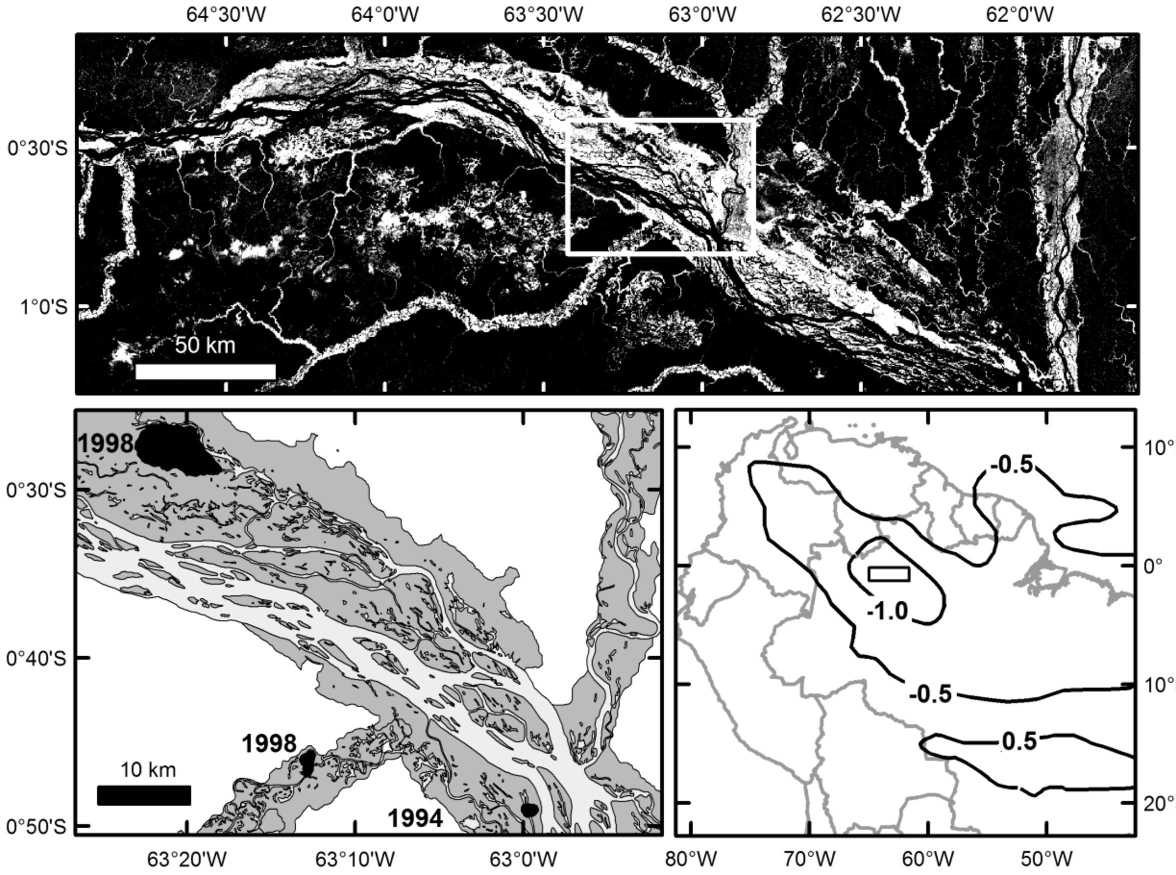

Figure 1: Middle Rio Negro flooded forest extent, burn scars and modeled future rainfall. (a) JERS SAR L-band radar image at high water stage of May 1996; white tones indicate seasonally flooded emergent vegetation, black is open water or upland. (b) Map of white rectangle in the radar image, showing in black locations and fire dates of three burn scars examined in this study; seasonally flooded vegetation shown grey. (c) Hadley CM3 climate model under IPCC emissions scenario B2, of predicted reduction in rainfall in northern South America by ~2055, relative to the average rainfall of 1961-90, difference in mm day^{-1}; small rectangle is location of middle Rio Negro radar image. Credits: (a) courtesy of Global Rainforest Mapping Project, copyright NASDA/MITI ; (b) base map from IBGE, 2007; (c) modified from Marengo (2007).

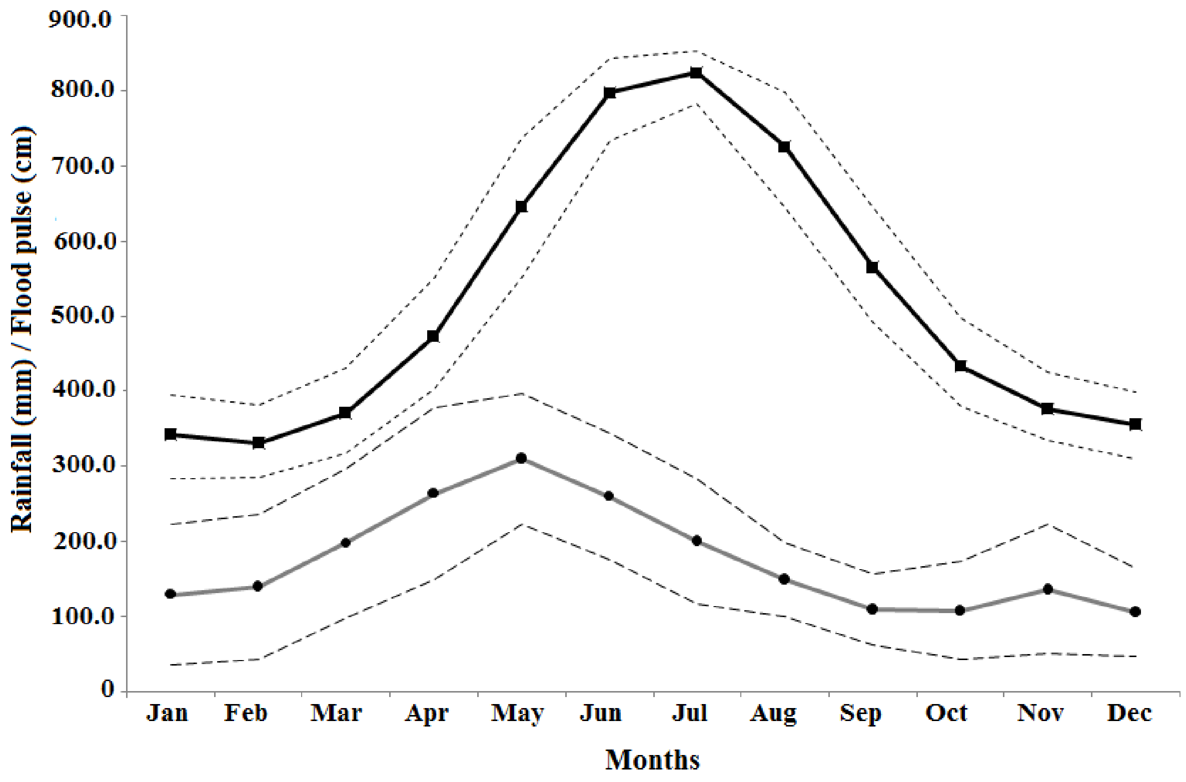

Figure 2: Grey line - Average of the total monthly Rainfall from 1977 to 2009, measured daily in Cumaru station 70 km north the town of Barcelos. Black line – Average of the Rio Negro water level in Barcelos for each month since 1968. Confidence intervals are +/- 1 standard deviation. Data from: *Agência Nacional de Águas*.

Results

Forest flammability

Fuel load: For both size classes of FWD fuel loads were higher in *igapó* forest than in sandy-soil *campinarana* and upland forest (table 1). The fuel load comprised of humus + litter layer was not different between *igapó* and *campinarana* forests. However, both had more of this fuel than upland forests.

Soil texture: The surface mineral soil showed an unexpected variation in the fractions of sand, silt and clay among transects on igapó sites. Except for one transect with 83% of sand, surface soils were composed mostly of silt (33-63%) and clay (26-66%). This one sandy site was not an alluvial deposit, but an area of eroded *terra firme*, now 2.5 m below the high water mark. This site also had a low fuel load. *Campinarana* forest soil texture varied little, with more than 90% of sand and less than 2% of clay in all cases. Upland forests on well-drained clay soil had the same variation of fractions we found in igapó forests, with sand never above 35%, and with silt and clay varying as the dominant fractions.

Fuel load in igapó as a function of flooding time

Fuel load varied within the igapós in the study area. The length of inundation time did not explain the accumulation of humus. All sites flooded for more than five months per year, however, had deep humus and litter layers. Other sites showed a large variation in the amount of humus + litter (table 1). On the other hand, submergence explained 40% of the variation in the smaller size class of FWD. The longer time submerged, the more woody debris were found. For the larger category of FWD, no relationship was found ($r^2 = 0.16$; $p = 0.24$).

Another result of the surface soil analysis was found when plotting each soil fraction against submergence time. One transect was excluded for being an outlier with 83% sand and derived from erosion rather than alluvial floodplain deposit. Silt fraction, which ranged from 33 to 63%, decreased with increasing length of submergence ($r^2 = 0.541$, $p = 0.024$). Sand and clay fractions, however, could not be explained by the length of flood period.

Post-fire regeneration

Annual peaks of EVI (Fig. 3a) and of the EVI ratio (Figure 3b), correspond to the time of year when the surface of the burn scar had little or no water. At these peaks, spectral response is attributable almost exclusively to the regenerating secondary vegetation. The peaks are progressively higher each year for both indicators. Succession, however, was much slower than is typically found on upland sites. After 11 years of recovery the annual peaks in the smoothed EVI ratio did not reach 1.0. The lowest EVI found each year represents the time when water dominates the burn scar. These annual minimums also became higher each year, suggesting that one or more of the four burned pixels had secondary forest emerging from the water surface even at the high water stage.

The variance of each set of four EVI ratios (each set being a single date) increased with time (Fig. 4). The effect is more pronounced in the last three years of the study, when high values of spatial variance are found year-round. The spatial variance of EVI in the unburned igapó forest showed no tendency over the nine years of MODIS data. Absence of low spatial variance for any dates in the years after 2006, however, suggests a difference in the stages of forest regeneration between the four MODIS pixel locations inside the burn scar. Before 2006 at high water level, low spatial variance was caused by submersion of the secondary vegetation (low EVI), with similar EVI values being produced by the four burned pixels. After 2006, those sites with emergent secondary forest have higher EVI, while others lack such advanced recovery and are covered with water (low EVI). At low water, the taller secondary forest sites have higher EVI, while bare soil in the sites with less advanced succession keeps EVI low. This interpretation is borne out by a sequence of Landsat Thematic Mapper images from the low water seasons of 1 year before and 2 and 11 years after the fire, showing large spatial variation in the ”greenness” within the burn scar in the most recent image (Fig. 5).

In the field, the basal area inventories (≥5.0cm of DBH) found only 2.7 m^2/ha and $0m^2$/ha in the 15 and 11 years old burn scars respectively, corroborating the remote sensing evidence for slow secondary succession. Within the 0.1 ha plots, there were no trees that survived the fire, confirming the high mortality.

Table 1 Fuel loads by forest type

Forest type	n	1+10h fuel count	100h fuel count	Depth
Low igapó	4	75.0a ± 8.9	7.3a ± 1.6	24.0a ± 2.4
Middle igapó	6	62.6a ± 20.1	6.8a ± 2.7	17.3a ± 8.8
Campinarana	5	36.3b ± 12.3	3.3b ± 1.3	19.0a ± 3.6
Terra firme	4	31.1b ± 9.3	3.2b ± 2.3	9.01b ± 4.8

Values are means and standard deviations of n samples in each forest type. Means within a column followed by the same letter are not significantly different from each other (Mann-Whitney (U) test, $P \leq 0.05$).

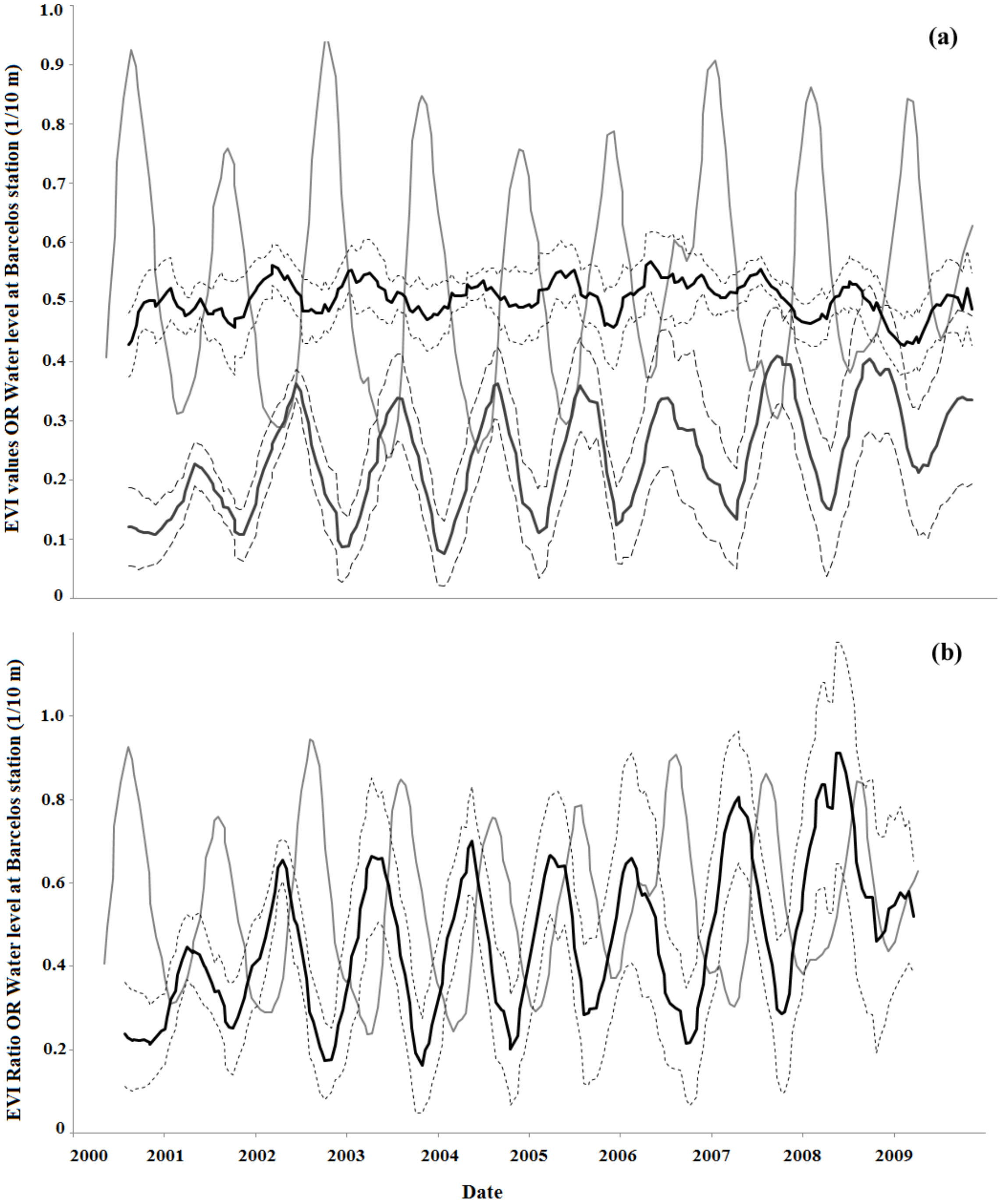

Figure 3: (a) EVI time-series from 2000 to 2009 of forest recovery in four MODIS pixels after the 1998 fire. Black line: running-mean of averaged EVI values of four unburned igapó forest pixels. Dark grey line: running-mean of averaged EVI values of the four burned pixels. (b) Regeneration Ratio time-series from 2000 to 2009. Black line: running-mean of averaged four Regeneration Ratio pairs. Confidence intervals are +/- 1 standard deviation of the averaged four pixels values in the burned, control igapós and Regeneration Ratios. Light grey line: the 10-day running mean of daily water levels.

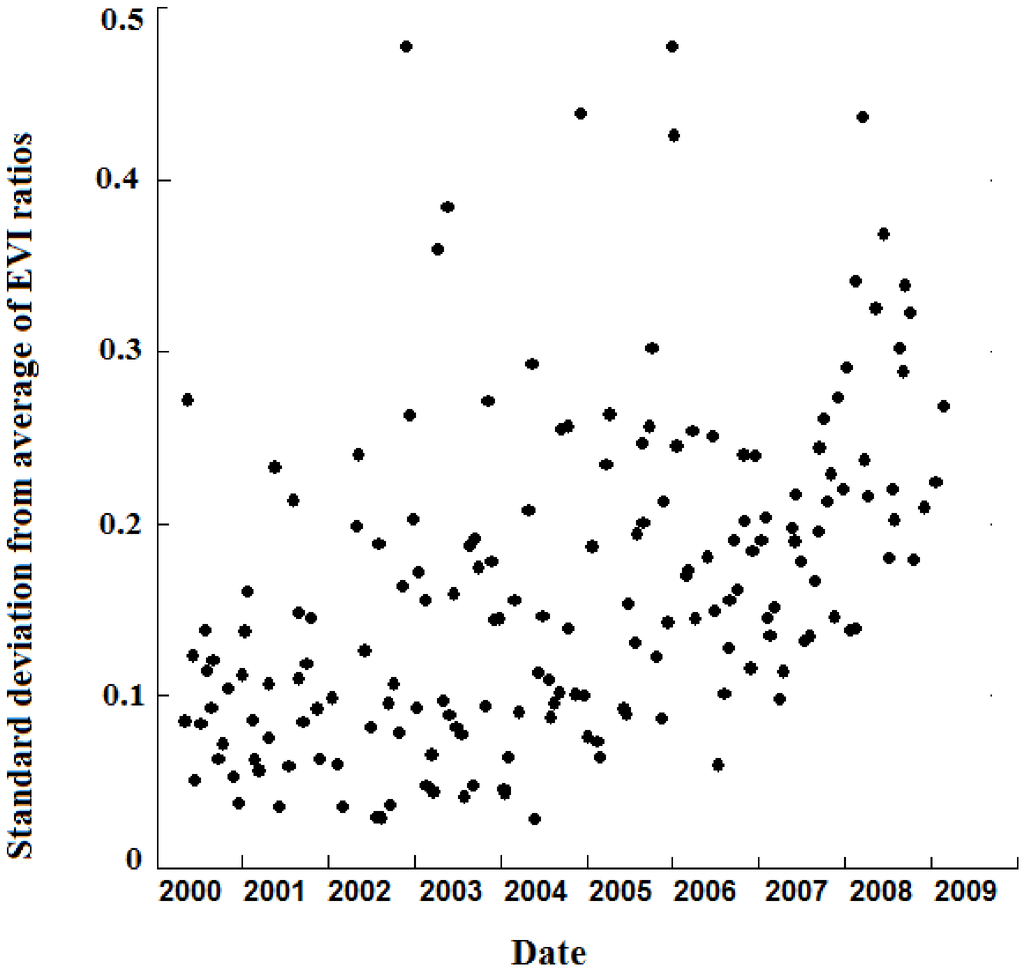

Figure 4: Standard deviation from the average of the four Regeneration Ratios from 2000 to 2009. Note the absence of low values after 2007 (r^2=0.21, p<0.001).

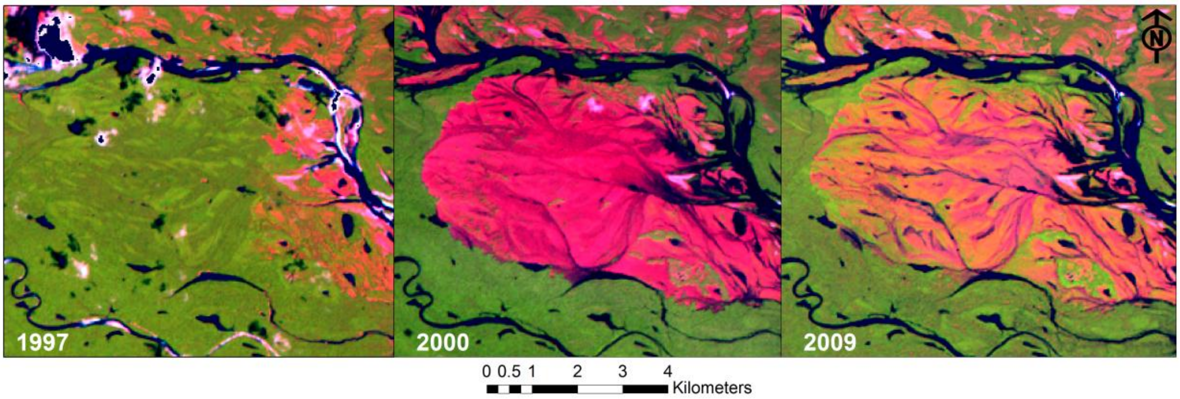

Figure 5: Landsat 5 Thematic Mapper false-color composites (bands 5, 4, 3; rgb) one year before, two years after and 11 years after the 1998 fire. Reddish tones indicate bare soil or dry herbaceous vegetation, green indicates closed forest canopy, bright green is low secondary forest. All three images were converted to atmosphere-free surface reflectance using the 6S model implemented in Claslite v.2.3.1 (Asner *et al* 2009). Images from USGS and INPE.

Discussion

Our results point to the available fuel load as the main cause of the flammability of seasonally flooded forests in the Rio Negro basin. The humus + litter layer, penetrated by a living root mat, was considerably thicker in both *campinarana* and *igapó* forests, compared to the clay-soil upland forests we studied. In Kalimantan, Indonesia, Yeager *et al*. (2003) noticed that after the 1997-98 El Niño, peat swamp forests had been more affected by fire than nearby lowland forests. Page *et al*. (2002) found that 91.5% of the area burned in the same fire event were peatlands and estimated a release of 0.19–0.23 Gt C to the atmosphere. Therefore, we would like to point out that what all these flammable wetlands have in common is an organic layer with superficial fine roots as a spatially consistent fuel load. This supports a basic principle of fire ecology described by Whelan (1995); when there are constant sources of ignition, the spread of fire is firstly dependent on the availability of fuel.

Yeager *et al*. (2003) observed that the peat fuel load in the burned area they studied had provided a slow fire spread, increasing the fire residence time and heat transfer to the trees. Most tropical rainforest trees are not adapted to fire, being severely damaged when exposed for too long (Uhl and Kauffman, 1990; Cochrane *et al*., 1999; Cochrane, 2003). According to Whelan (1995), the ultimate determinant of the fire intensity is the quantity of fuel load available. The dry weight of fuel per surface area is directly related to the amount of energy that will be released with combustion. Kauffman *et al*., (1988) found more than 90% that the fuel in the low igapós of the Upper Rio Negro was in the humus, litter and root mat layer, with 96% of the forest floor covered by litter. Similarly, the root mat layer observed in our study is definitely a load of fuel capable of generating large amounts of energy during combustion, causing high tree mortality.

Apparently, processes acting not on the litter production, but on the decomposition are related to the accumulation of the humus layer in *igapó* and *campinarana* forests. Litter production in *igapó* forests is not different from upland forests (Adis *et al*. 1979; Luizão 1989). As a strategy for nutrient preservation, most igapó tree species are perennial and often keep their leaves even when waterlogged. Therefore, a low rate of decomposition is more likely to explain the formation of the humus layer. The root mat, however, may be the cause or consequence of the organic matter accumulation.

Yule and Gomez (2009) found that most of the dissolved organic carbon from the fresh litter, in Malaysian peat swamp forests, was rapidly leached and cycled, explaining the presence of fine roots in the superficial peat layer. Not coincidently, a fine root layer is also present in the humus found in both igapó and campinarana forests, establishing a structure full of spaces for oxygen to penetrate. Aware of this fact, locals report that the fire commonly spreads beneath the peat across dozens of meters. Singer and Araujo (1979), studying campinarana forests in the lower Rio Negro basin, suggested that the presence of fine roots in association with ectomycorrhizal fungi increased the efficiency in nutrient cycling in such nutrient-poor soils. They described a suppression of the leaf-inhabiting fungi by the dominant ectomycorrhizae associated with the dominant tree species. In upland forests on well-drained clay soil, these authors observed more rapid decomposition of litter by higher species diversity and dominance of the leaf-inhabiting fungi, restricting humus accumulation. In 1986, Singer and Araujo-Aguiar found this same association in an igapó forest in the lower Rio Negro. In these forests, the authors estimated that the leaf-inhabiting fungi were reduced to as little as one-fifth of their density in the upland forests. The ectomycorrhizal dominance was again, responsible for the presence of a humus layer over the soil, guaranteeing the availability of nutrients for the fungi and the trees through the root system. Later, other studies discussed the importance of this symbiotic association to the existence of these igapó forests in an environment with scarcity of nutrients (Singer, 1988; Goulding *et al*., 1988).

Another explanation for humus accumulation is associated to the harsh environmental conditions for microbial activity in nutrient-poor blackwater ecosystems. Most of the waters of the Rio Negro and its tributaries drain from basins dominated by white-sand soils, such as campinarana forests, where the rain water is colored by fulvic and humic acids from the incomplete decomposition of the organic matter, lowering the water pH to 3.5 – 4 (Sioli, 1983; Junk, 1997). Qualls and Haines (1990), studying the effects of fulvic and humic substances on the decomposition of submerged leaf litter, found that their influence was indirect. By lowering the water pH from 5 or 7 to 4, carbon respiration was reduced. Furthermore, microbial activity may be affected by the absence or reduced concentration of dissolved oxygen below a thermocline (Reiss, 1977). Most igapó forests are situated in backwaters away from turbulent flow. The constant heating from absorbing sun radiation can form a thermocline, restricting the mixture of the superficial and lower water layers, where the oxygen is produced and consumed by microorganisms, respectively. In anaerobic conditions, decomposition by bacteria or fungi becomes slower than the input of new organic matter, containing litter and woody debris from the forest.

A third possible cause of fuel accumulation is the presence of secondary compounds in the leaves and wood of many igapó species (Furch and Junk, 1997; Parolin, 2002). According to Janzen (1974) nutrient-poor blackwater forest species tend to have high concentrations of secondary compounds in their leaves in order to reduce herbivory. Yule and Gomez (2009) attributed the low rate of decomposition in peat swamp forests, to the physical and chemical properties of the litter produced by species endemic to this environment. As a result of a long evolutionary process in this nutrient poor environment, a peat layer is maintained over the years guaranteeing the availability of nutrients. As an indirect consequence, more lignin and toxic substances such as latex, resins, oils, phenols and tannins in the litter may act as chemical fuel increasing these forests' flammability during dry periods.

Independently of which processes favor the accumulation of humus, most of these forests contain a spatially consistent layer of rapidly dried and aerated fuel load. However, our results have show that some high igapós, annually flooded for a mean period of less than 5 months had no root mat. It is possible that this variation is a consequence of physical removal by currents or accelerated decomposition by aerated turbulent water. Such hydro-dynamism is generally associated with meanders. The outer margin of every meander has much stronger and faster currents than the opposite, consequently removing most of the litter that falls from the trees above (Walker, 1985). However, in some cases, such as in long meanders, the inner margin may act as an alternative passage for the river flow, with the same consequences for the litter.

Our findings also suggest that FWD, with higher amounts in *igapó* and than in upland and *campinarana* forests, contribute to the flammability of these forests. Flammability of woody debris is associated with the time it takes for a flaming front to move across a fuel complex, with the finer pieces reaching ignition temperature more rapidly than larger pieces (Fosberg 1970; Whelan 1995). Hence, FWD may be crucial for generating sufficient energy to ignite and combust larger pieces of woody debris. Balch *et al*. (2008) studied the effects of fine fuel addition on the rate of fire spread, flame height and width, and total burned area. They found a two to fivefold increase in these effects, as a response to the fine fuel input. Since, most igapó forests of the middle Rio Negro are inundated 3-8 months every year and receive a total average of 380 mm of rain during the three lowest water-level months (Fig. 2), the rapid dry-down time of FWD above the root mat, may play a critical role in these forests flammability.

Post-fire regeneration

In the large 11 year old burn scar of ~2600 ha, we used a new approach to access the secondary forest succession and resilience of these environments after wildfire disturbance. The higher inverse correlation of the water level with the raw EVI of burned sites (Pearson: -0.70) and with the EVI Ratio (-0.65), compared to unburned sites (-0.22), indicates the seasonal contamination of the pixels by water in these wetlands. This "noise" needs to be considered when analyzing the signal of long-term regeneration. The tall primary igapó forest covers most of the water throughout the entire year, independent of the flood level, greatly reducing the effect of water-contaminated pixels. This explains the much smaller amplitude of the annual variation in EVI from unburned igapós.

Leaf shedding of igapó tree species during rising water levels, making the under-canopy water surface more visible is also a possible cause of "noise". Schongart *et al*. (2002) have shown that many species in the fertile Amazon floodplain forest are deciduous as a response to the floodpulse, with the peak of leaf shedding during rising water levels and flushing with lowering water levels. Evergreen tree species in the Amazon floodplain have a shorter interval between peak of leaf shedding and flushing (2 mo. delay), both occurring close to the highest water level. Using EVI, Huete *et al*. (2006) demonstrated the large-scale green-up and brown-down of Central Amazon *terra firme* forests as a response of leaf flushing and shedding in dry and rainy seasons respectively.

Despite our general results suggest an extremely low resilience of this ecosystem to fire disturbance, the spatial variation between EVI ratios indicate that there are local processes affecting the speed of forest re-growth inside the burn scar. We thought of four possible alternative explanations for our findings. First, the mean floodpulse in the region oscillates 5 m, restricting the growth period in the lower parts of the floodplain to the low water-level months (Worbes 1985; 1995; Junk *et al*. 1989; Parolin 2002; Parolin *et al*. 2004; Schongart *et al*. 2004). Second, the extremely low nutrient content of the Rio Negro waters, that flood these forests every year also influence plant growth at the floodplain (Furch, 1997). Third, disruption of the symbiotic association between ectomycorrhizal fungi and dominant host plants (Singer & Araujo-Aguiar 1986), by the combustion of the root mat layer, may strongly affect seedling survival. The fourth possible cause is re-burning feedback, since burned areas remain with open canopy, thus flammable for a long time. These processes, described more deeply in the following paragraphs, may not act independently, but synergistically against forest recovery.

The reduced growth period in Amazonian floodplains, caused by annual flooding of the major rivers, is a well known characteristic of the region`s seasonally flooded forests (Worbes 1985; 1995; Junk *et al*. 1989; Parolin 2002; Parolin *et al.* 2004; Schongart *et al*. 2004). Inundations that can last for more than 8 months and rise in average 5 meters at the middle Rio Negro create anoxic conditions at the root system, reducing its activity, which results in water deficit at the crown of most tree species. The adaptation of these trees to survive waterlogging is cambial dormancy which produces annual growth rings (Worbes 1985; 1995). Consequently, a reduced growth period limits secondary forest succession in burned blackwater floodplains.

Another characteristic of the waters carried by the Rio Negro and most of its tributaries is the low nutrient content, responsible for a low potential for primary production (Sioli 1984; Furch 1997; Furch & Junk 1997). Rainfall water leaches the basin sediments formed during the Tertiary, which contain mostly kaolinite with low cation exchange capacity. Soils of igapó forests particularly lack phosphorous and calcium. Soluble portion of phosphorous can be even higher than in fertile várzea forests but are mostly lost by leaching. Soluble portion of calcium, however, are extremely low in igapó forest soils (Furch 1997).

As previously mentioned, a possible cause of humus accumulation in igapó forest soils is the dominance of ectomycorrhizal fungi in the decomposing community, in a symbiotic association with the dominant trees through their root system. The main conclusion of Singer (1988) and Singer & Araujo-Aguiar (1986) was that this symbiosis was vital for the existence of this forest in such a nutrient-poor environment. Dominance of ectomycorrhizae in the soil biota provides direct cycling and maintains the humus layer, constantly supplying nutrients for both the trees and fungus with the minimal leaching. The species *Aldina latifolia* and *Swartzia polyphylla* were described as hosts to this fungus and are the most abundant tree species in the lower Rio Negro region (Singer & Araujo-Aguiar 1986). Ferreira (2000) found these same two species together contributing 23% of the basal area in igapó forests of the middle Rio Negro. ter Steege *et al*. (2006) observed that the Amazon poorest soils had more abundance of Leguminosae which are known for the association with ectomycorrhizae. Thus, only small areas in Guyana and the upper Rio Negro region were expected to have this association for having high abundances of the genus *Aldina*. Therefore, it is possible that the extremely low resilience observed in the igapós of the middle Rio Negro is related to the difficulty in re-establishing this symbiosis after severe fires. Basically, the survival of new seedlings depends on the presence of trees, supplying litter, associated with ectomycorrhizae, providing direct cycling before leaching from heavy rainfall or seasonal flooding occurs (Uhl *et al*. 1988). Both requirements are not available in the middle of the scar. Furthermore, Parolin (2000) showed that seed mass in igapó species is high (average 7.08 g) to compensate the low availability of nutrients in the soil and provide more chances for seedling survival. If there is no nutrient available after seed reserves extinguish, the plant cannot survive.

The last but possibly the most important cause of slow secondary succession in burned igapós is the positive feedback in the flammability of these ecosystems after wildfires. Cochrane *et al*. (1999) described the increase in Amazon upland forests flammability after having burned by ground fire. In the case of igapó forests of the middle Rio Negro, no forest is left after the passage of ground fires. Many dead trunks, however, are left standing or fallen and the growth of floating herbaceous plants during high water months results in dry organic matter covering many burned sites. For at least ten years, no canopy if formed, meaning that, if dry enough, any source of ignition can produce a new wildfire. We observed with Landsat 5 TM and Quickbird images, second burnings at the boarder of burn scars, sometimes expanding the previously burned area. Hot pixel data centered at old fire scars at the middle Rio Negro floodplain also suggest higher flammability. With unlimited ignition sources throughout this flooded landscape, every drought season can delay a bit more secondary succession.

The blackwater forests and campinarana forests in the Rio Negro may be facing higher fire frequency during future El Niño years as climate becomes drier (Marengo 2007). Differences in fire severity have being shown to strongly influence the rate of forest regeneration, thus creating a mosaic of different successional stages across the landscape (Diaz-Delgado *et al*. 2003). Medium levels of disturbance would promote higher species diversity at the landscape scale. Forest regeneration in the middle Rio Negro floodplain, however, may be too slow to maintain such a patchwork in the future. The basal areas we measured in the field correspond to at least 20 times less the ones found by Ferreira (2000) at the middle Rio Negro, even after 15 years of recovery.

We have shown that extensive forests in the Rio Negro basin are naturally flammable for having large amounts of fuel load, specifically leaf litter and humus in a well-aerated root mat, and fine woody debris on the litter surface. Temporary cooking fires made by people travelling by canoes are ubiquitous sources of ignition across the floodplain florests. Considering that forest wildfires are restricted to the low rain and water level months, climate-model predictions of prolonged and more severe droughts, as a consequence of increased frequency in El Niño Southern Oscilation (ENSO) and the Atlantic Multidecadal Oscillation (AMO) events, should lead to more forest fires in the future (Marengo 2007). Our data also indicate an extremely low rate of forest recovery after burning, increasing the susceptibility to re-burning. Therefore, if fire return-intervals increase as a response to longer droughts, huge amounts of carbon stocks in the trees and soil of these forests, may be lost to the atmosphere. In addition, the risk of this forested landscape being converted to open vegetation is a truly disturbing possibility, putting endemic species to this environment at risk of becoming locally extinct. The only option to avoid this process is to convince local people to properly use and manage fire.

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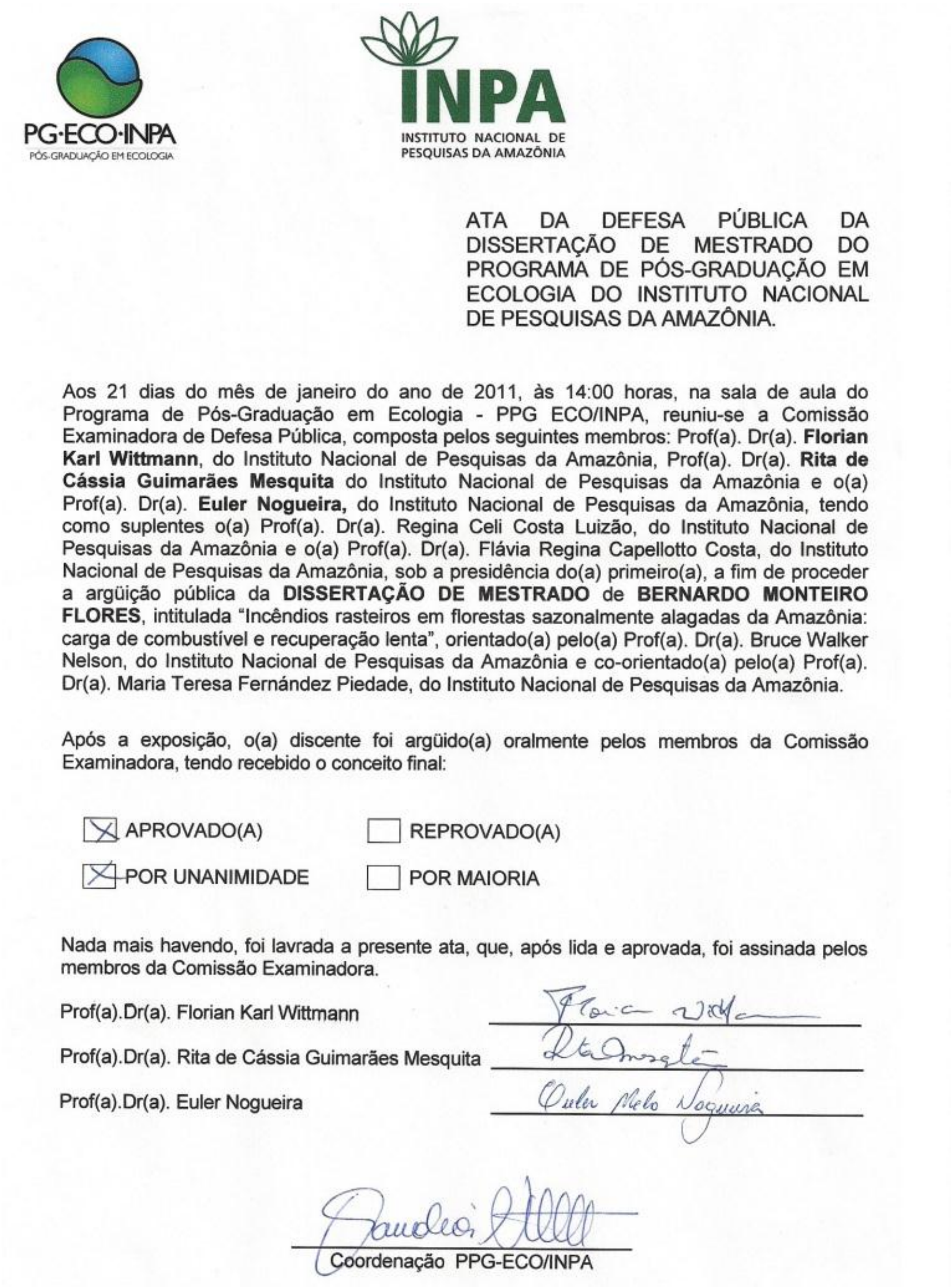
Conclusão

Demonstramos que extensas florestas na planície de inundação do médio Rio Negro (~7.0 mil km^2) e florestas sobre areia branca na mesma bacia são naturalmente suscetíveis ao fogo por possuírem grandes quantidades de combustível sobre o solo, principalmente húmus, raízes finas e liteira fina. Fogueiras usadas para a alimentação de ribeirinhos viajando pelos diversos canais na região do médio Rio Negro são abundantes fontes de ignição. Considerando que esses incêndios florestais são restritos aos meses com baixo nível das águas do rio, previsões de secas mais intensas e prolongadas no futuro (Marengo, 2007) podem também estar anunciando um aumento na freqüência de incêndios. Nossos dados indicam uma resiliência extremamente baixa dessas florestas após pegarem fogo. Se o tempo de retorno dos incêndios aumentar diante de secas mais freqüentes, com uma regeneração muito lenta, o risco de essa paisagem florestal ser convertido à vegetação aberta é uma possibilidade perturbadora. Isto poderia levar a extinções locais de espécies endêmicas ao ecossistema e a emissão de enormes quantidades de carbono, estocados no solo e biomassa dessas florestas. A única opção para evitar esse desastre esta na conscientização da população local sobre os cuidados básicos ao utilizar e manejar o fogo.

Apêndices

APÊNDICE A – Ata da Defesa presencial



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

Aos 21 dias do mês de janeiro do ano de 2011, às 14:00 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: Prof(a). Dr(a). **Florian Karl Wittmann**, do Instituto Nacional de Pesquisas da Amazônia, Prof(a). Dr(a). **Rita de Cássia Guimarães Mesquita** do Instituto Nacional de Pesquisas da Amazônia e o(a) Prof(a). Dr(a). **Euler Nogueira,** do Instituto Nacional de Pesquisas da Amazônia, tendo como suplentes o(a) Prof(a). Dr(a). Regina Celi Costa Luizão, do Instituto Nacional de Pesquisas da Amazônia e o(a) Prof(a). Dr(a). Flávia Regina Capellotto Costa, 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 **BERNARDO MONTEIRO FLORES**, intitulada "Incêndios rasteiros em florestas sazonalmente alagadas da Amazônia: carga de combustível e recuperação lenta", orientado(a) pelo(a) Prof(a). Dr(a). Bruce Walker Nelson, do Instituto Nacional de Pesquisas da Amazônia e co-orientado(a) pelo(a) Prof(a). Dr(a). Maria Teresa Fernández Piedade, 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:

☒ APROVADO(A)	☐ REPROVADO(A)
☒ POR UNANIMIDADE	☐ POR MAIORIA

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

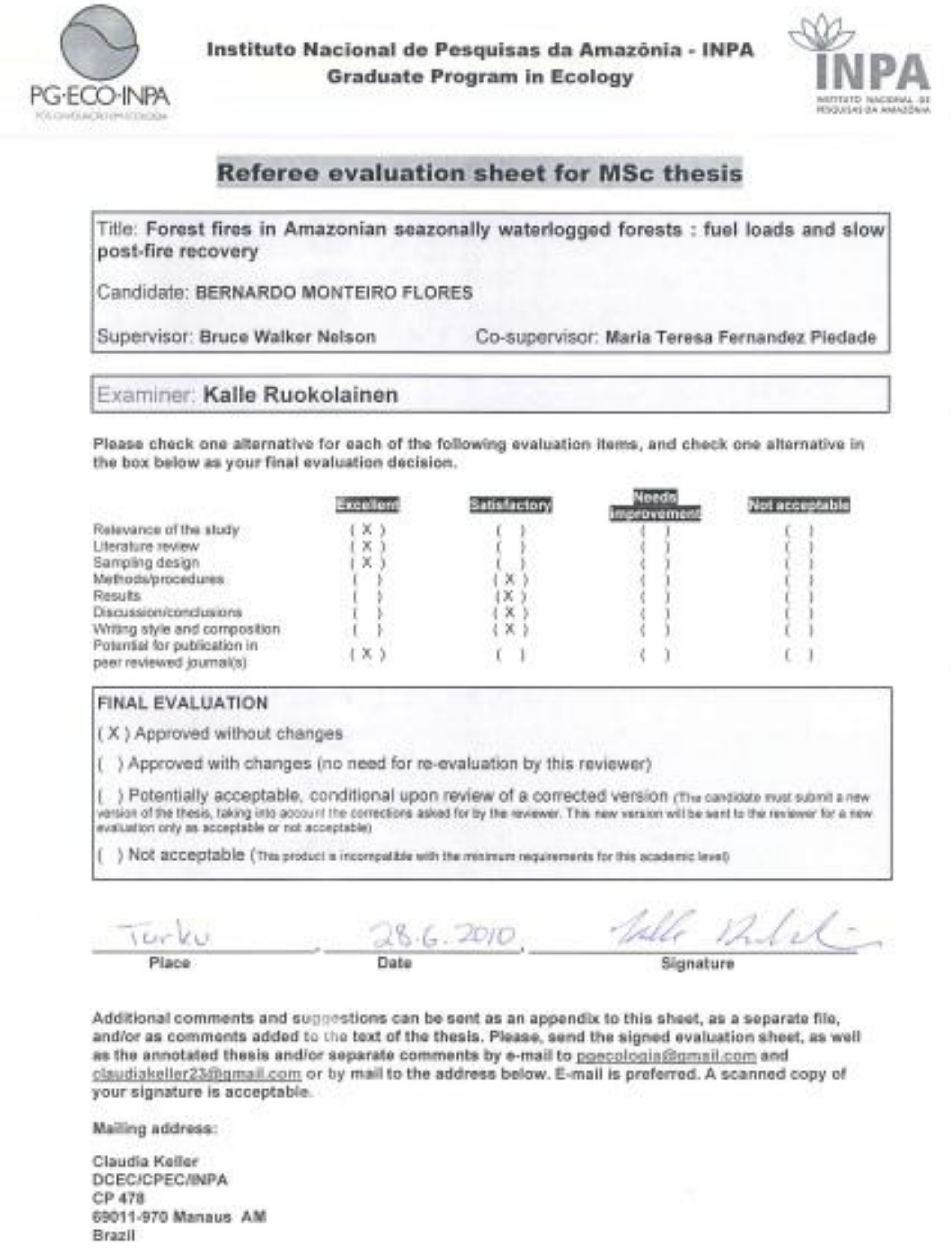
Prof(a).Dr(a). Florian Karl Wittmann ____________________

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

Prof(a).Dr(a). Euler Nogueira Euler Melo Nogueira

____
Coordenação PPG-ECO/INPA

APÊNDICE B – Parecer do revisor Kalle Ruokolainen



Instituto Nacional de Pesquisas da Amazônia - INPA
Graduate Program in Ecology

Referee evaluation sheet for MSc thesis

Title: **Forest fires in Amazonian seazonally waterlogged forests : fuel loads and slow post-fire recovery**

Candidate: **BERNARDO MONTEIRO FLORES**

Supervisor: **Bruce Walker Nelson** Co-supervisor: **Maria Teresa Fernandez Piedade**

Examiner: **Kalle Ruokolainen**

Please check one alternative for each of the following evaluation items, and check one alternative in the box below as your final evaluation decision.

	Excellent	Satisfactory	Needs improvement	Not acceptable
Relevance of the study	(X)	( )	( )	( )
Literature review	(X)	( )	( )	( )
Sampling design	(X)	( )	( )	( )
Methods/procedures	( )	(X)	( )	( )
Results	( )	(X)	( )	( )
Discussion/conclusions	( )	(X)	( )	( )
Writing style and composition	( )	(X)	( )	( )
Potential for publication in peer reviewed journal(s)	(X)	( )	( )	( )

FINAL EVALUATION

(X) Approved without changes

( ) Approved with changes (no need for re-evaluation by this reviewer)

( ) Potentially acceptable, conditional upon review of a corrected version (The candidate must submit a new version of the thesis, taking into account the corrections asked for by the reviewer. This new version will be sent to the reviewer for a new evaluation only as acceptable or not acceptable)

( ) Not acceptable (This product is incompatible with the minimum requirements for this academic level)

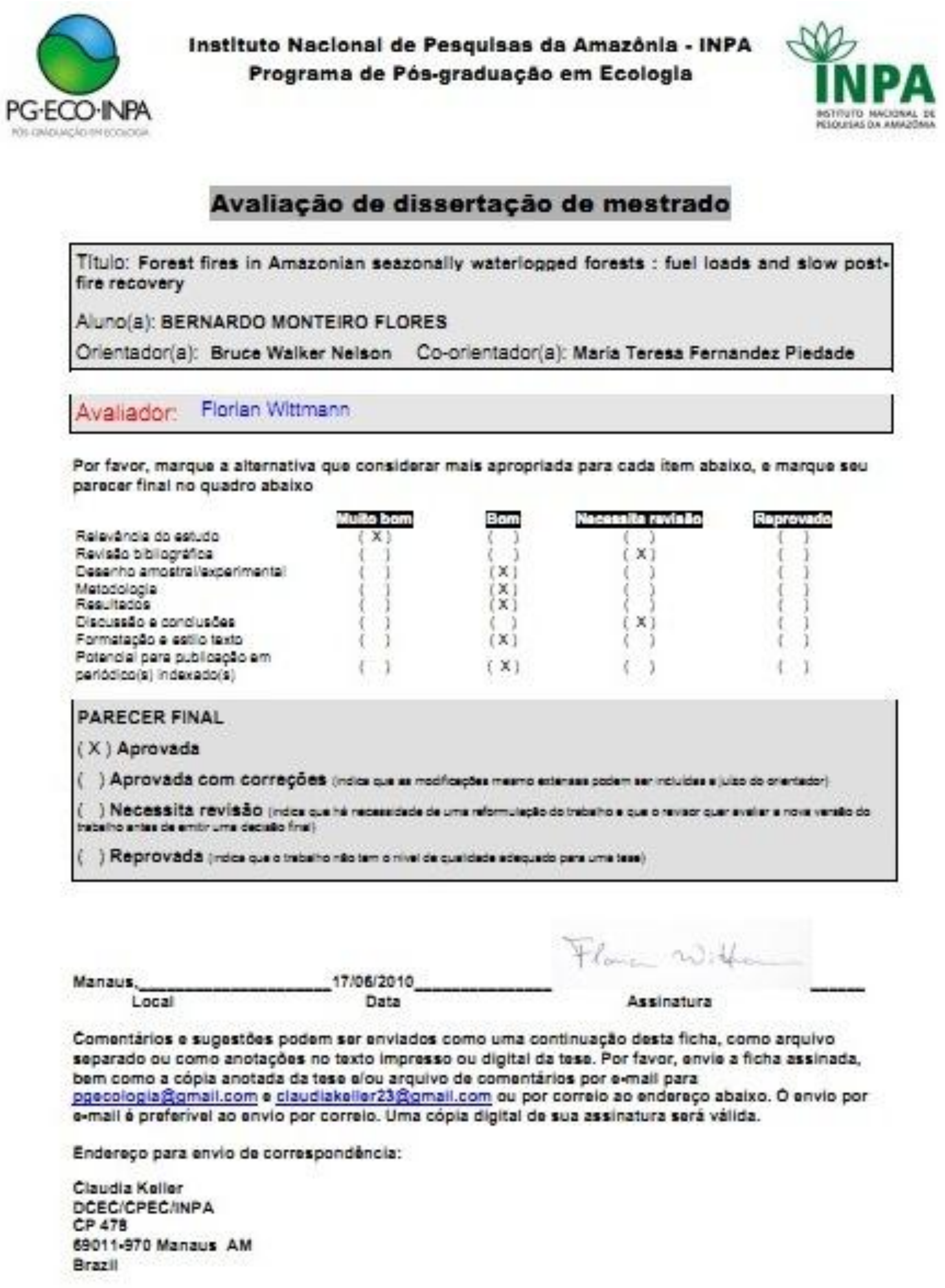
Turku, 28.6.2010,
Place Date Signature

Additional comments and suggestions can be sent as an appendix to this sheet, as a separate file, and/or as comments added to the text of the thesis. Please, send the signed evaluation sheet, as well as the annotated thesis and/or separate comments by e-mail to pgecologia@gmail.com and claudiakeller23@gmail.com or by mail to the address below. E-mail is preferred. A scanned copy of your signature is acceptable.

Mailing address:

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

APÊNDICE C – Parecer do revisor Florian Wittmann



Instituto Nacional de Pesquisas da Amazônia - INPA
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Avaliação de dissertação de mestrado

Título: **Forest fires in Amazonian seazonally waterlogged forests : fuel loads and slow post-fire recovery**

Aluno(a): **BERNARDO MONTEIRO FLORES**

Orientador(a): **Bruce Walker Nelson** Co-orientador(a): **Maria Teresa Fernandez Piedade**

Avaliador: Florian Wittmann

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

(X) **Aprovada**

( ) **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,______________________17/06/2010________________ ______
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Comentários e sugestões podem ser enviados como uma continuação desta ficha, como arquivo separado ou como anotações no texto impresso ou digital da tese. Por favor, envie a ficha assinada, bem como a cópia anotada da tese 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
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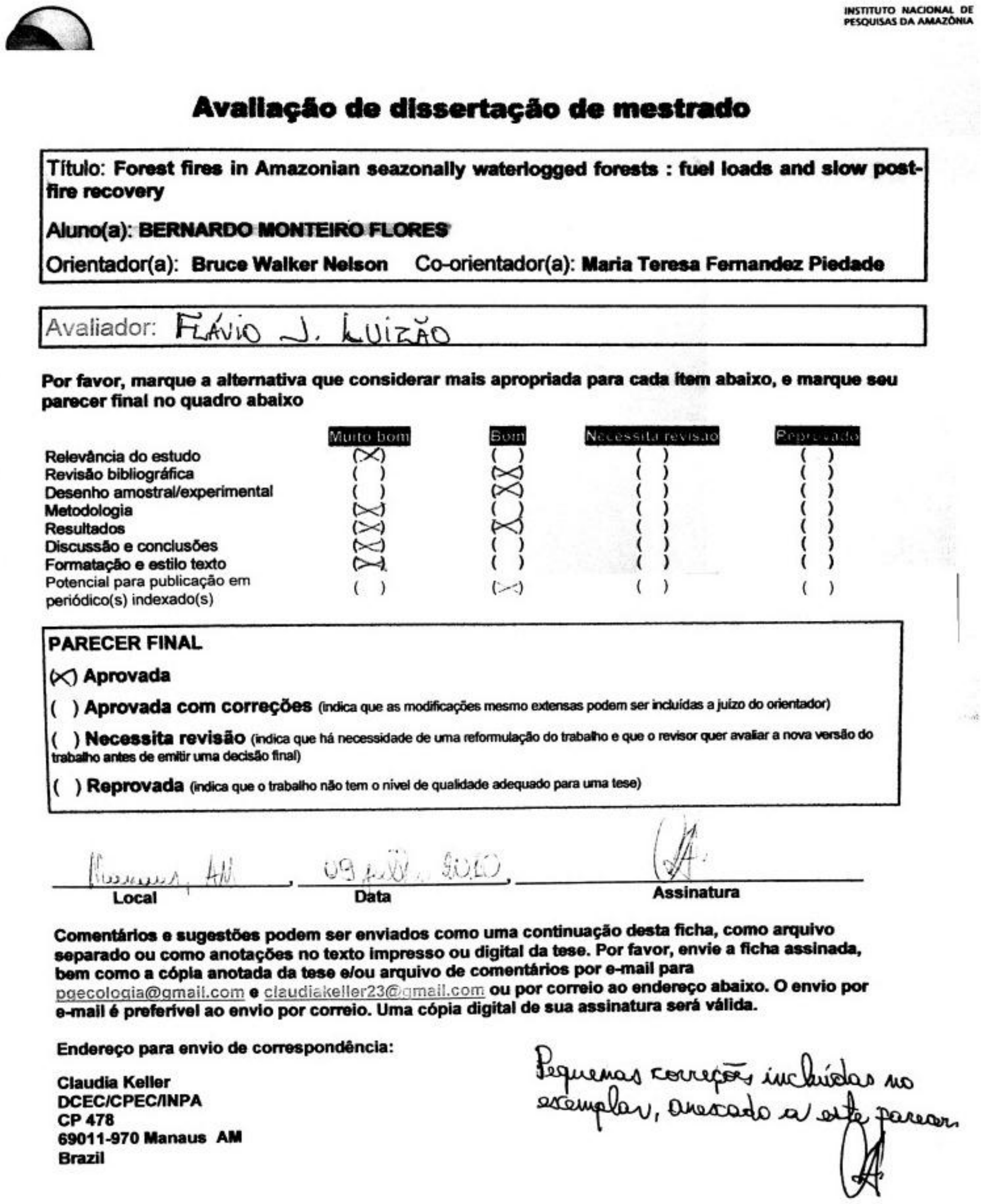
69011-970 Manaus AM
Brazil

APÊNDICE D – Parecer do revisor Flavio J. Luizão



INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA

Avaliação de dissertação de mestrado

Título: **Forest fires in Amazonian seazonally waterlogged forests : fuel loads and slow post-fire recovery**

Aluno(a): **BERNARDO MONTEIRO FLORES**

Orientador(a): **Bruce Walker Nelson** Co-orientador(a): **Maria Teresa Fernandez Piedade**

Avaliador: FLÁVIO J. LUIZÃO

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	☒	☐	☐	☐
Revisão bibliográfica	☐	☒	☐	☐
Desenho amostral/experimental	☐	☒	☐	☐
Metodologia	☒	☐	☐	☐
Resultados	☒	☒	☐	☐
Discussão e conclusões	☒	☐	☐	☐
Formatação e estilo texto	☒	☐	☐	☐
Potencial para publicação em periódico(s) indexado(s)	☐	☒	☐	☐

PARECER FINAL

☒ **Aprovada**

☐ **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, AM, 09 abril 2010,

Local **Data** **Assinatura**

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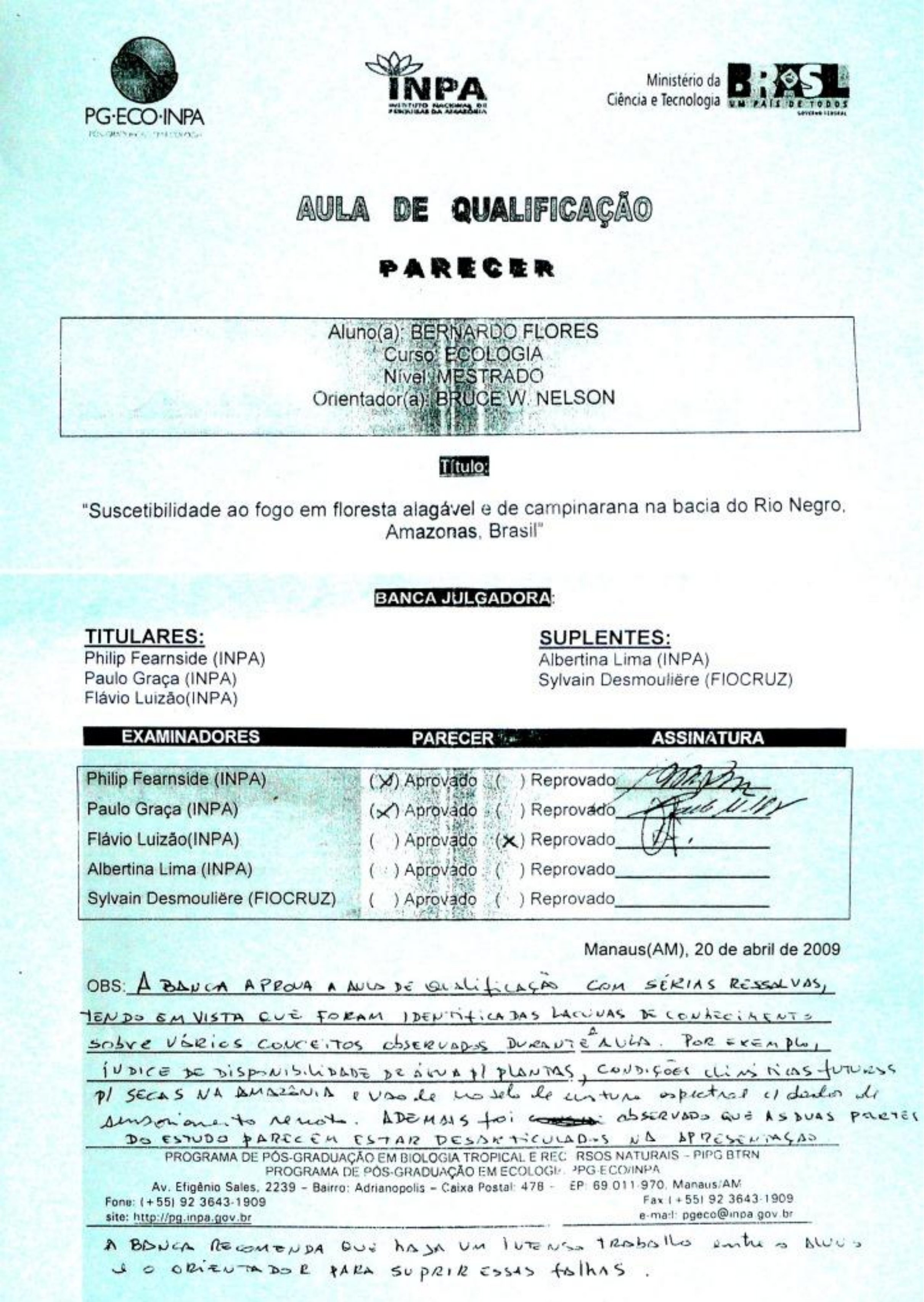
Pequenas correções incluídas no exemplar, anexado a este parecer.

APÊNDICE E – Pareceres da Aula de Qualificação



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PARECER

Aluno(a): BERNARDO FLORES
Curso: ECOLOGIA
Nível: MESTRADO
Orientador(a): BRUCE W. NELSON

Título:

"Suscetibilidade ao fogo em floresta alagável e de campinarana na bacia do Rio Negro, Amazonas, Brasil"

BANCA JULGADORA:

TITULARES:	SUPLENTES:
Philip Fearnside (INPA)	Albertina Lima (INPA)
Paulo Graça (INPA)	Sylvain Desmoulière (FIOCRUZ)
Flávio Luizão(INPA)	

EXAMINADORES	PARECER		ASSINATURA
Philip Fearnside (INPA)	☒ Aprovado	☐ Reprovado	
Paulo Graça (INPA)	☒ Aprovado	☐ Reprovado	
Flávio Luizão(INPA)	☐ Aprovado	☒ Reprovado	
Albertina Lima (INPA)	☐ Aprovado	☐ Reprovado	
Sylvain Desmoulière (FIOCRUZ)	☐ Aprovado	☐ Reprovado	

Manaus(AM), 20 de abril de 2009

OBS: A BANCA APROVA A AULA DE QUALIFICAÇÃO COM SÉRIAS RESSALVAS, TENDO EM VISTA QUE FORAM IDENTIFICADAS LACUNAS DE CONHECIMENTO sobre VÁRIOS CONCEITOS OBSERVADOS DURANTE A AULA. POR EXEMPLO, ÍNDICE DE DISPONIBILIDADE DE ÁGUA P/ PLANTAS, CONDIÇÕES CLIMÁTICAS FUTURAS P/ SECAS NA AMAZÔNIA E USO de modelo de mistura espectral c/ dados de sensoriamento remoto. ADEMAIS foi OBSERVADO QUE AS DUAS PARTES DO ESTUDO PARECEM ESTAR DESARTICULADOS NA APRESENTAÇÃO

PROGRAMA DE PÓS-GRADUAÇÃO EM BIOLOGIA TROPICAL E RECURSOS NATURAIS - PIPG BTRN
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA - PPG-ECO/INPA
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A BANCA RECOMENDA QUE HAJA UM INTENSO TRABALHO entre o ALUNO E O ORIENTADOR PARA SUPRIR ESSAS falhas.