ESTIMATING CARBON STOCK SIZES AND DISTRIBUTION OF METHANE SOURCES FOR UPPER AMAZON PALM SWAMP ECOSYSTEMS USING IN SITU MEASUREMENTS, OPTICAL IMAGERY AND AND MULTI-TEMPORAL MAPPING WITH PASSIVE UND ACTIVE MICROWAVES

Zimmermann R[1], Horna V[2], McDonald KC[3], Schröder R[3,1], Podest E[3], Flessa H[2], Behling H[2], Vasquez P[4], Dietz J[5,1], Heckmann M[6,1], Börner A[7,1].

1) University of Hohenheim, Forest Ecology and Remote Sensing Group, Stuttgart D-70599, Germany
2) University of Göttingen, Department of Biology and Forestry, Göttingen, Germany
3) Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA, USA
4) Universidad Agraria La Molina, Centro de Datos para la Conservacion, Lima, Peru
5) World Agroforestry Center, ICRAF, Nairobi, Kenia
6) University of York, Department. of Archeology, U.K.
7) Max-Planck-Institute of Biogeochemistry, Jena, Germany

Corresponding author: Reiner Zimmermann, rzimmerm@uni-hohenheim.de

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Abstract:

Large areas of western Amazonia are covered by *Mauritia* palm swamps. They may contain enormous amounts of carbon, which accumulated during the Holocene. Current remote sensing and atmospheric studies show high atmospheric methane concentrations in this region, indicating a significant terrestrial source of this greenhouse gas. We suspect the *Mauritia* palm swamps to dominate this source. Future climate change will have a significant impact on carbon storage and greenhouse gas release of these tropical wetlands. This study intends to understand the role of palm swamps as carbon sink or source of greenhouse gases. We use pollen records and geochemical analysis to analyse the development and carbon sequestration of palm swamps during the late Quaternary. Gas exchange, biometric measurements and biomass analysis are used to determine plant carbon and nutrient stocks and dynamics. Methane emissions were measured. Soil organic matter stocks were characterized to determine current and potential release of greenhouse gases from palm swamp ecosystems. *Mauritia* swamps (Aguajales) occur in areas with stagnant water and show distinct changes in palm density, understory vegetation and peat accumulation. Aguajal vegetation units can be separated by palm density, adult palm height and accompanying understory composition. Our study area is the upper Amazon watershed in Peru. Field ecophysiology studies were conducted at a large palm swamp formed around an infilled oxbow lake on the recent floodplain of the Rio Madre de Dios and a high elevation swamp of the Rio Alto Mayo, both in Eastern Peru.

The Madre de Dios palm swamp has a dated cut-off age of >5000 BP. Peat coring shows a high variability of peat accumulation from more than 7m to less than 1m. A 6m long sediment core showed very good pollen content and preservation and an excellent record on the holocene development of the palm swamp. *Mauritia flexuosa* stands in the Madre de Dios are dynamically growing and do have apical growth rates comparable to temperate forest trees. Their aboveground biomass stocks are similar or higher than those of adjacent Terra firme forests, while their belowground carbon stocks exceed the aboveground standing stocks up to a factor of ten or more. Aboveground biomasses of palm swamps of the Alto Mayo are in the lower range for tropical lowland and montane forests. Biomass in the inundation forests was 206.5 (± 60.1) t ha^{-1}, in forest stands of the hill region 190.4 (± 56.2) t/ha. Physical and chemical soil parameters showed a clear distinction between the soils of the inundation forests and soils on well-drained upland forests. The soils of the inundation forests have a clay texture, high proportions of undecomposed organic matter and thus high carbon (22.1%) and nitrogen (2.1%) contents, moderately acid pH of 4.7 in upper and 5.0 in the lower horizons, and low Al^{3+} saturation of 2.6%. In small depressions prolonged water logging occurs due to impeded drainage on the clayey substrate and mineralization seems to be reduced due to the anoxic conditions. Therefore, the very high P- and N-content of the soils can not be used efficiently by plant roots for tree growth. Aguajal soils of the Madre de Dios showed up to more than 7m of pure undecomposed carbon peat before mineral soil components are encountered.

Mauritia swamps must be at times areas where plant production exceeds decomposition, resulting in the accumulation of partially decomposed organic matter. Tree growth measurements and tree apical growth

estimates by leaf scar counts indicate that primary productivity, tissue respiration and mortality of palm swamp trees are higher than in adjacent upland forests. Assimilation rates in *Mauritia* plants under good light conditions reach values expected in non flooded plants. We measured in the Aguajal in Madre de Dios maximum apparent assimilation rates of 6µmol CO_2 m^{-2} s^{-1} in mature *Mauritia* leaves at around 1000µmol Photons m^{-2} s^{-1}. Leaf dark respiration rates were moderate at 0.4µmol CO_2 m^{-2} s^{-1} indicating a high primary productivity. .Adaptation of this plant to soil water logging is evident in the high density of pneumathophorous roots.

While recent remote sensing studies with focus on river flooding and wetlands of the central and lower Amazon exist, spatial information on the upper Amazon is lacking. Retrospective time series backscatter data for forest wetland assessment are available from the JERS synthetic aperture radar (SAR) as well as from brightness temperature measurements taken by SSM/I or, more recently, by ALOS PALSAR and AMSR-E providing L and C-Band capabilities, respectively. Unlike high resolution SAR measurements, passive microwave observations from AMSR-E offer the unique opportunity to track day-to-day changes in inundation extent for large, flooded and densely vegetated upper Amazon swamp complexes. We investigate the relationship between forest floor flooding and overlaying vegetation to determine sub-pixel inundation fraction by using a linear mixture model. Changes in vegetation density are monitored by daily scatterometer measurements available from QuikSCAT. To account for seasonal changes in temperature and inundation fraction, time series of daily AMSR-E polarization ratios are being explored. Swamp flooding and physiological activity of palm trees was determined from *in situ* xylem sap flux measurements and photosynthetic measurement campaigns. Site conditions were monitored by meteorologic stations at site including water level monitoring. Methane exhalation was determined by timed surface sampling and mass spectrometric analysis in the lab. Analysis of historic aerial photography from 1962 on, Landsat and ASTER imagery allowed the identification of palm swamp vegetation units. SAR imagery (wet season/dry season temporal change analysis) showed a good correlation between the distribution of Aguajales and other wetlands and the extent of flooding. The radar signal penetrates open canopies more easily and the reflected signal is stronger for wet soil surfaces and water relative to dense forest canopies with underlying dry soils. The areas with heavy flooding remain waterlogged throughout most time of the year and typically carry Aguajales. Classification of forests in the study area was successfully achieved by combining the remote sensing data with ground data of structural vegetational features, the distribution of above ground biomass within the stands and site soil parameters. The temporal flooding analysis with SAR correlates well with the distribution patterns of amphibiome types, the duration and intensity of flooding and soil chemical conditions.

Current carbon stocks and methan exhalation rates of the entire upper Amazon palm swamp areas are still unknown. Frankenberg et al. [1] compared the results of the global atmospheric methane transport models TM3 with globally measured atmospheric methane concentrations. Disagreement occurred between the methane transport model and atmospheric data over central tropical areas with the highest discrepancy found for the upper Amazon region. This area is treated by all global models as “terra firme perhumid rainforest” which is known to have no methane net release to the atmosphere. However, if the 5 to 8% palm swamps found in the Western Amazon may constitute a significant methane source, and if this methane release persists most of the year, the paradox of the global methane model vs. atmospheric concentration measurements might become resolved. Our first measurements suggest significant methane release from *Mauritia* swamps. Enhanced methane concentrations of 2 to 4µlL^{-1} in air samples collected 10cm above the soil surface indicate a significant methane emission from the swamp area. They also indicated a high spatial variability of methane emission within the swamp area. The current knowledge suggest that palm swamps in western Amazonia are a tropical hotspot for soil C sequestration and they may also act as a significant source of atmospheric methane at the local, regional and perhaps global perspective.

[1] C. Frankenberg, J. F. Meirink, M. van Weele, U. Platt. and T. Wagner, “Assessing methane emissions from global space-borne observations,” Science, vol. 308, pp. 1010-1014, 2005

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