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Analysis of carbon pools and human impacts in the Yala Swamp (Western Kenya): A landscape approach

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This work is dedicated to my daughter Tswelelo Mfundisi for her support, understanding and patience

ABSTRACT

Soil and biomass carbon pools in the Yala Swamp of Western Kenya are analyzed using principles of landscape ecology through remote sensing techniques and geographic information system (GIS) tools. Two LANDSAT images are used to estimate land-use and land-cover change over the swamp between 1984 and 2001. It is found that 6 333 ha of the swamp have been drained for agricultural production. The time span of drainage of the areas varies from historic (20 to 40 years ago) to recent times (less than 20 years ago).

The impact of human activities on the carbon pools are assessed and carbon dioxide emissions in the area estimated based on the results obtained from processing satellite images and field data (during the annual cycle of 2002/2003). Soil samples collected from relatively undisturbed wetland and drained wetland areas are analyzed for SOC and total N. It is found that natural wetland areas contain higher SOC and total N than adjacent drained areas. The average SOC content in natural wetland topsoil (0-20 cm) is 5.63 ± 4.9%, while that for drained areas is 2.31± 1.61%. The total-N values for the two areas are 0.40 ± 0.3% and 0.22 ± 0.1%, respectively. Correlations between SOC and total N for the natural wetland and drained areas are 0.96 and 0.98, respectively. The SOC content for pairs covering natural wetland and recently drained areas (between 1984 and 2001) is 3.94 ± 1% and 2.29 ± 1%, respectively, i.e., a change in the SOC stock of 1.65 ± 1 kg C/m^2 in this part of the landscape. A comparison with the Nyando Swamp shows that the carbon stocks found in the two swamps are similar. Covering 15 267 ha, the Yala Swamp stores 1.2 Million tons of carbon in the top 20 cm alone. For the sum of all swamps around Lake Victoria, this amounts to 1.8 Million tons of carbon.

In addition to its effect on climate change, destruction of the carbon pools affects ecosystem productivity, the various functions of wetlands for biodiversity, and the regional carbon cycle. For the 6 333 ha converted to date, 104 494.5 tons of carbon have been lost from the top 20 cm of the soil. Unlimited access by farmers to the swamps around Lake Victoria for drainage and conversion to agricultural land could release 1.87 Million tons of carbon to the atmosphere. Meeting the human need for food in the area while sustaining the integrity of its biogeochemical cycles and swamp ecosystems is a challenge to farmers and policy makers alike.

KURZFASSUNG

Die Kohlenstoffsenken in Boden und Biomasse im Yala Sumpf von Western Kenya werden mit den Instrumenten der Landschaftsökologie Fernerkundung und geographische Informationssysteme (GIS) analysiert. Zur Ermittlung von Veränderungen in der Landnutzung und -bedeckung zwischen 1984 und 2001 werden zwei LANDSAT Satellitenbilder verwendet. Es wird festgestellt, dass 6.333 ha des Sumpfes für landwirtschaftliche Zwecke entwässert worden sind. Die Entwässerungsmaßnahmen wurden in den letzen 40 Jahren durchgeführt.

Die Wirkung von menschlichen Aktivitäten auf die Stickstoffsenken werden ermittelt und die Kohlendioxidemissionen im Untersuchungsgebiet auf der Grundlage der Ergebnisse der Satellitenbildauswertung und der Felderhebungen (während eines Jahres 2002/2003) ermittelt. Bodenproben aus relativ ungestörten bzw. entwässerten Feuchtlandgebieten werden auf bodenorganischem Material (SOC) und Gesamtstickstoff (N) analysiert. Die Ergebnisse zeigen, dass die natürlichen Feuchtgebiete einen höheren SOC-Anteil und Gesamt-N als danebenliegende entwässerte Bereiche enthalten. Der durchschnittliche SOC-Gehalt im Oberboden (0-20 cm) in natürlichen Feuchtgebieten beträgt 5.63 ± 4.9%, in entwässerten Bereichen beträgt dieser Wert 2.31± 1.61%. Die Gesamt-N-Werte für die beiden Bereiche betragen 0.40 ± 0.3% bzw. 0.22 ± 0.1%. Die Korrelation zwischen SOC und Gesamt-N für die natürlichen bzw. entwässerten Feuchtgebiete ist 0,96 bzw. 0,98. Der SOC-Gehalt für Wertepaare für natürliche Feuchtgebiete und Gebiete, die in den letzen 20 Jahren (von 1984 bis 2001) entwässert wurden, beträgt 3.94 ± 1% bzw. 2.29 ± 1%, d.h. eine Veränderung im SOC-Gehalt von 1.65 ± 1 kg C/m^2. Ein Vergleich mit dem Nyando Sumpf zeigt, dass die Kohlenstoffmengen in den beiden Sümpfen etwa gleich sind. Mit einer Fläche von 15.267 ha speichert der Yala Sumpf 1,2 Mio. Tonnen Kohlenstoff allein in den oberen 20 cm Boden. In Bezug auf alle Sümpfe um den Viktoria See beträgt die Summe 1,8 Mio. Tonnen.

Zusätzlich zu den Auswirkungen auf den Klimawandel beeinflusst die Vernichtung der Kohlenstoffsenken die Ökosystemproduktivität, die verschiedenen Funktionen der Feuchtgebiete hinsichtlich Biodiversität sowie den regionalen Kohlenstoffzyklus. Für die bisher umgewandelten 6.333 ha sind 104.494,5 Tonnen Kohlenstoff aus der oberen 20-cm Bodenschicht verloren gegangen. Durch einen unbeschränkten Zugang der Bauern zu den Sümpfen um den Viktoria See für Entwässerung und Umwandlung in landwirtschaftliche Flächen könnten 1,87 Mio. Tonnen Kohlenstoffe in die Atmosphäre entweichen. Den Bedarf der Menschen an Nahrungsmitteln zu erfüllen und gleichzeitig die Integrität der biogeochemischen Kreisläufe und Sumpfökosysteme zu erhalten, ist eine Herausforderung sowohl für die Bauern als auch für Entscheidungsträger und Politiker.

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1 GENERAL INTRODUCTION

1.1 Wetland ecosystems

Wetlands comprise 6% of the Earth's surface (Williams, 1990). They are transitional between terrestrial and aquatic systems, and predominantly support hydrophytes, at least periodically. They occur in areas where soils are naturally or artificially inundated or saturated by water due to high groundwater or surface water during a part of or throughout the year. Wetlands are common in river deltas and estuaries, floodplains, tidal areas, and are widespread in riverbeds, depressions, foot slopes, and terraces of undulating landscapes. Wetland ecosystems may be discriminated on the basis of hydrology, soils, and vegetation and include swamps, marshes, bogs, fens, floodplains, and shallow lakes (Mitsch and Gosselink, 1993; Neue et al., 1997).

The Ramsar Convention defines wetland as marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceeds six meters (UNESCO, 1994). In agricultural ecosystems, wetlands may be defined as having free water at or near the surface for at least the majority of the growing season of arable crops, or for at least 2 months of the growing season of perennial crops, grassland, forest, or other vegetation. The water is shallow enough to allow growth of a crop or natural vegetation rooted in the soil. Free water may occur naturally or may be retained by: field bunds, puddled plow layers, traffic pans from rainfall run-off, or irrigation sources (Neue et al., 1997).

Tropical wetlands have at least one wet growing season per year but may be dry, moist or without water in other seasons. Wetland soils may therefore alternately support wetland and dryland plant species. Therefore, wetlands are ecotones. The boundary between wetland and dryland is often gradual, and may fluctuate from year to year depending on variations in precipitation. If water (drainage and irrigation) can be fully controlled it is within the farmer's discretion to establish either wet- or drylands. Despite that, the drainage capacities of most tropical wetlands are insufficient to prevent periodic soil submergence during the rainy season (Neue et al., 1997). This is due to lack of resources and understanding of the functioning of the wetland ecosystem.

Wetland aerial estimate is uncertain given the broad definition of wetlands (Mitra et al., 2003). Each country should formulate its definition based on the international definition. The Ramsar Convention requires all its parties to adopt and adapt the definition as is relevant to their territory. Each party is also required to make an inventory of wetlands within its territory and ensure the wise use of such wetlands. The contracting parties shall encourage research and the exchange of data and publications regarding wetlands and their flora and fauna. They shall also promote the training of personnel competent in the fields of wetland research, management and wardening (UNESCO, 1994).

1.1.1 Wetland types of Africa

The largest wetlands of Africa are the Sudd Swamp of Sudan, the Okavango Delta of Botswana, the Kafue/Bangweulu floodplains of Zambia, and the swamp forests of Zaire (Figure 1.1). East Africa contains wetlands that are smaller in size but nevertheless important in their ecological structure and functioning such as lowland valley swamps on the fringes of Lake Victoria (mostly in Uganda but a few on the eastern shores of Kenya) (Haper and Mavuti, 1996). Although wetlands of many types are found in Tropical Africa, the most distinct is perhaps the papyrus marsh (Williams, 1990). Papyrus (*Cyperus papyrus*) is a large sedge 3-5m in height but sometimes 10m (Jones and Humphries, 2002). It grows in dense stands along lake edges, most commonly in the vicinity of Lake Victoria. Papyrus marshes are absent in West Africa and the great riverine swamps of the Congo Basin.

Papyrus has a C4 photosynthetic pathway, an efficient mechanism found in most tropical grasses for fixing derivatives of atmospheric carbon-dioxide. Concentrations of nitrogen, phosphorus and other minerals are low in papyrus and other emergent macrophytes (Williams, 1990). However, papyrus concentrations of these elements are low within the macrophyte group, suggesting great efficiency in achieving growth under low nutrient conditions.

Papyrus also shares with other macrophytes the ability to extract minerals from infertile waters and sediments and to release, through decay and exudation, organic compounds that serve as energy sources for a variety of diverse consumer food chains, which in many places include humans.