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Human-environment interactions; landscape archaeology; raised fields; Amazonia; Late Holocene; landscape evolution; Pre-Columbian agriculture.

Introduction

The Llanos de Moxos (LM) covers an area of 150,000km^2 in north-eastern Bolivia. The landscape is characterized by savannahs crisscrossed by rivers and paleorivers. The forest-savannah boundary is controlled by the repeated cycles of seasonal floods that impede tree growth through anoxic conditions and severe drought.[1] The LM hosts extensive pre-Columbian earthworks: canals, causeways, fish weirs, raised fields and monumental earth mounds.[2] These earthworks are unevenly distributed in the LM (Fig. 1); some types of earthworks are present in some areas, whilst absent in others.[3] Therefore, the LM offers an excellent opportunity to compare different kinds of archaeological landscapes and the links between environmental settings and the development of complex societies. Social complexity is understood as the combination of subsistence intensification, political integration and social stratification following population growth.[4] Here, two regions from within the LM are compared: the platform fields region (PFR) in the north-western LM and the monumental mounds region (MMR) in the south-east.

The Platform Fields Region

The platform fields region, in the north-western LM (PFR in Fig. 1) is uplifting[5] and modern rivers flow in the deeper parts of paleo valleys.[6] Therefore, in the PFR, seasonal inundations are due exclusively to rainfall and rivers do not deposit sediments onto the floodplain. Topographic profiles show that the PFR has a general concave topography with an average gradient of about 0.15cm Km^{-1} (Fig. 2a). Forested fluvial levees are almost absent here. Even on slightly elevated relict levees, forested areas are very rare. Soil profiles show high hydromorphism and a thin A horizon. The combination of severe water-logging and old weathered soils creates highly unfavorable conditions for agriculture, as indicated by the presence of cerrado-like vegetation.[7]

No lakes or other water sources are available for irrigation during the dry season in the area.

1 Mayle et al. 2007.
2 Erickson 2008.
3 Denevan 1966; Lombardo, Canal-Beeby, and Veit 2011.
4 Johnson and Earle 2000.
5 Dumont and Fournier 1994.
6 Hanagarth 1993.
7 Langstroth 2011.

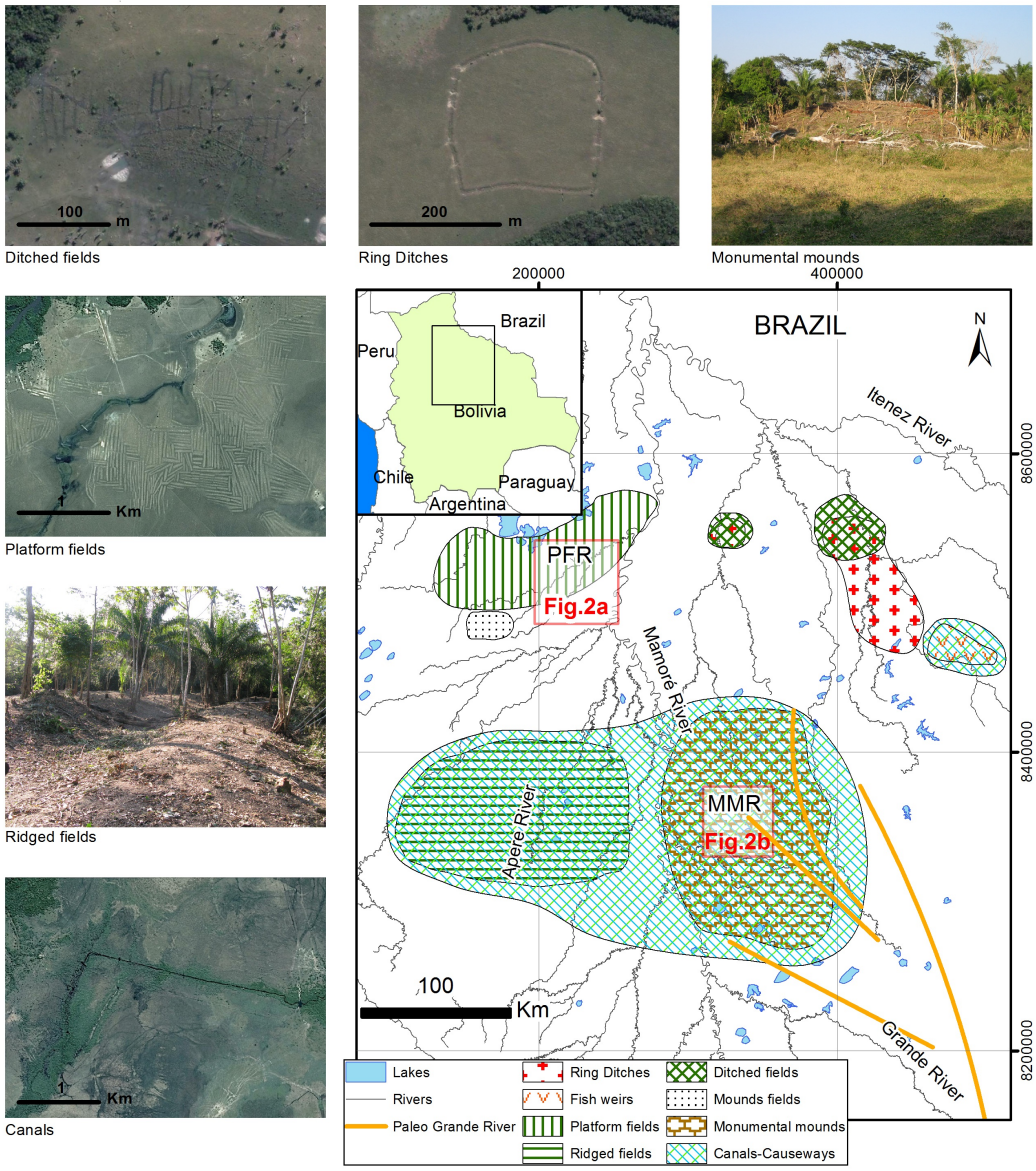

Fig. 1 | The different pre-Columbian earthworks found in the Llanos de Moxos and their spatial distribution based on Lombardo, Canal-Beeby, and Veit 2011. Platform, ridged and ditched fields are different types of raised fields, which are pre-Columbian agricultural fields. Ditched fields are a special case because they are actually not elevated. Ring ditches are ditches that limit pre-Columbian settlements.

In the PFR there are about 50,000 hectares of platform fields[8] accounting for 6.4% of the whole landscape. Platform fields are a type of raised field that are particularly wide but only slightly elevated. The PFR is probably the region in the LM where the greatest amount of earth was moved by pre-Columbian people. Raised fields have been described by several authors as being highly productive, managed following a *Chinampas*-like model, where standing water between fields provided green manure for fertilization.[9] However, field morphology and spatial distribution indicate that in the PFR this model cannot be applied and fields were built with the sole purpose of maximizing drainage.[10]

8 Lombardo 2010.
9 See Erickson 2008.
10 Lombardo et al. 2011.

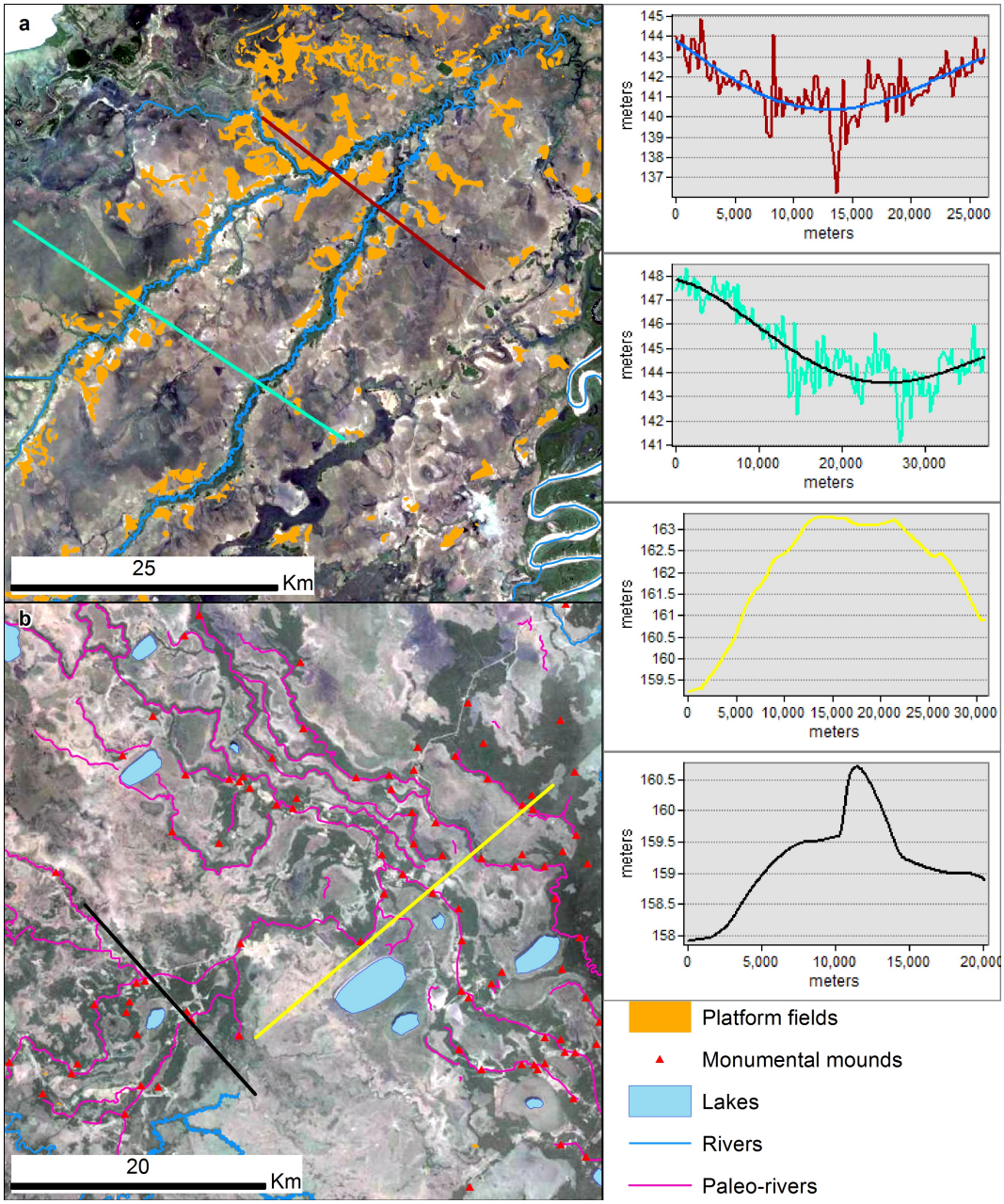

Fig. 2 | Satellite images of the PFR (a) and the MMR (b) with topographic profiles. Locations of the PFR and the MMR are shown in Fig. 1. Source of the images: Google earth; topographic profiles based on the original Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) for the PFR and on a resampled SRTM DEM for the MMR. See Lombardo, May, and Veit 2012 for the resampling method.

The fields in this area are only 40cm higher than their surroundings and depressions between fields are not embanked. Moreover, fields were built on the naturally better drained sites. Therefore, water could not be retained between the fields. No monumental earthworks or other evidence for complex social activity has been found in the PFR.

The Monumental Mounds Region

In the MMR (Fig. 1 and Fig. 2b), the landscape is characterized by the presence of savannahs closely interwoven with forested levees of paleo-rivers. Our research shows that, in the MMR, mid-Holocene fluvial activity associated with the paleo Grande River (Fig. 1)

created relief on a local scale by depositing many fluvial levees, accounting for approximately 25% of the MMR, and on a regional scale by depositing a sedimentary lobe that created a topographic high.[11] The topography of this lobe accounts for the relatively good drainage conditions in the MMR (Fig. 2b). Thanks to the fertile sediments deposited by the Grande River and the relatively good drainage, soils here have thicker organic epidedons and far less hydromorphism than in the PFR. However, the MMR was not immediately suitable for agriculture. When people built the monumental mounds in this area, the Grande River had left behind a landscape where patches of floodplain remained completely enclosed by the fluvial levees. This phenomenon greatly reduced natural drainage as rainwater remained trapped in these enclosed savannahs. Thus, in order to make full use of the MMR's agricultural potential, pre-Columbian people had to transform the landscape through the construction of a drainage system. Remote sensing imagery and extensive field work provide evidence of a dense network of pre-Columbian canals in the MMR. Canals improved the drainage by cutting through the paleo-levees or by taking water from the flat savannahs to the rivers. Pre-Columbians also used some of the numerous lakes present here as water reservoirs, allowing irrigation and agricultural activities during the dry season. In the MMR, between AD 400 and 1400,[12] pre-Columbians built dozens of networked monumental earth mounds along the paleo-river channels. Monumental mounds, called locally "*lomas,*" are earth buildings that follow structural patterns and geometric rules. The average mound covers 5.5 hectares and consists of a 3–5m elevated earthen platform that hosts one or more pyramidal structures on its top. Monumental mounds can be up to 21 meters high and can cover up to 20 hectares. Monumental mounds are by far the most labor-consuming earthwork that has been documented in the LM. They probably played an important political and ritual role.[13]

Intriguing anthropogenic earthworks can be found in other parts of the LM (Fig. 1), but the MMR is the only area where the existence of a complex pre-Columbian society has been clearly documented to date. The spatial distribution of the mounds and their associated infrastructure of canals and causeways provide good evidence for the existence of political structures.[14] Archaeological excavations have unearthed elaborately decorated pottery and different burial traditions,[15] indicating specialized craftsmen and social distinction. Monumental mounds were occupied continuously and simultaneously for 1000 years.[16] Archaeobotanical evidence suggests that Maize (*Zea mays* L.) was a major contributor to the diet along with manioc (*Manihot esculenta* Crantz).[17] Other cultigens found include chili pepper, sweet potato, jack bean, peanuts, squash, and cotton. Nevertheless, no raised fields have been reported in the MMR.

Discussion

The PFR and MMR present some similarities and important differences. Both regions are crossed by paleorivers and both regions are free from river overflows. However, the two differ in soils and relief. In the PFR, hydromorphic soils with thin organic layers are associated with a low gradient, a concave profile and limited local relief. On the other hand, in the MMR, more fertile soils with thicker organic epidedons are associated with

11 Lombardo, May, and Veit 2012.
12 Jaimes-Betancourt 2010.
13 Erickson 2008; Lombardo and Prümers 2010.
14 Lombardo and Prümers 2010.
15 Prümers 2009.
16 Jaimes-Betancourt 2010.
17 Bruno 2010; Dickau et al. 2012.

a convex topography at regional scale and abundance of elevated paleo-levees at the local scale. Moreover, in the MMR there are abundant lakes located in elevated areas that can be used for irrigation (Fig. 2b). These differences are essential to understand the different landscape engineering strategies developed by pre-Columbians and, ultimately, the levels of social complexity achieved. The absence of local relief and the low gradient in the PFR made this area unfit for agriculture. Local relief had to be artificially created by the construction of raised fields. Raised fields per se cannot be assumed to be the product of a large complex society, because their construction and maintenance do not require the coordination of large groups of people[18] and because estimates of their carrying capacity are far from reliable.[19] The lack of evidence of social complexity suggests that the PFR was sparsely populated. The anthropogenic landscape that can be seen today is likely to be the accumulated result of repeated phases of construction and abandonment of raised fields. However, archaeological data are still too limited to estimate pre-Columbian population density and settlement dynamics. Our hypothesis is that people in the PFR had to work hard to try and ameliorate agricultural conditions through building raised fields, but the general edaphology did not permit surplus production or high population density.

On the other hand, the construction of the monumental mounds and the level of cultural evolution reached in the MMR would have been impossible without the availability of large areas of good agricultural land provided by the Grande River. Nevertheless, without the pre-Columbians' drainage infrastructure, the positive water balance would probably have created permanent/semi-permanent wetlands, greatly reducing the area suitable for agriculture. Pre-Columbians drained the MMR and in doing so they increased the area of flood-free agricultural land. The absence of raised fields in the MMR suggests that the canals fulfilled the drainage function that was provided by raised fields in other parts of the LM.

Conclusions

People in the LM adopted different strategies and built different earthworks to adapt to different environments. Raised fields were not able to sustain a large population in the PFR; they just allowed agriculture in a small part of the landscape. People transformed the PFR on a very local scale, whilst in the MMR pre-Columbians changed the regional hydrology building a network of drainage and irrigation canals. The availability of flood free agricultural land in the PFR was four times smaller than the available land on paleo levees in the MMR. The comparison between PFR and MMR suggest that the level of social complexity reached in the different regions was influenced by the local geo-ecology.

18 Walker 2004.
19 Lombardo et al. 2011; Renard et al. (in press).

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