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Editorial

Terrace landscapes. Editorial to the special issue

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Found worldwide, terraced landscapes are a hallmark of intensive agriculture with deep historical, anthropological and archaeological roots (Acabado, 2012; Amborn, 1989). With their geometric lineout, terraced landscapes also represent one of the most obvious expressions of human transformation of the environment and of human environmental management. Seen from the ground, they impress for the intricacy of their interconnected walls, channels (when irrigated) and passages. Seen from above, they strike for their coherence and integration on top of underlying landforms. But terraced landscapes are far from barely affecting the topography of a region. The implementation of terraced fields is paired with significant environmental transformations, e.g. in land cover, soil properties, microclimate, insolation and/or geomorphology (Arnáez et al., 2015; Evans and Winterhalder, 2000; Ramos et al., 2007; Treacy and Denevan, 1994). In fact, environmental changes linked to terraced agriculture have been claimed to provide some of the earliest evidence of large-scale human impact on the Earth system (Kaplan et al., 2011; Ruddiman et al., 2011). For instance, together with animal farming, the spread of wet rice cultivation in SE Asia, often paired with the development of terraced paddy fields, has been claimed to have perceptibly contributed to modifying the composition of the atmosphere starting c. 5 ka BP, well before the beginning of the industrial revolution (Ellis et al., 2013; Fuller et al., 2011; Ruddiman, 2003; Ruddiman, 2013; Ruddiman et al., 2015).

Terraced landscapes have the potential to convert sloped terrains into productive agricultural land by increasing humidity retention in soils and by reducing surface erosion, thus allowing long-term cultivation (Donkin, 1979; Hudson, 1995). However, when mismanaged or abandoned, terraced landscapes are more prone to erosion than woodland, with landslides posing a serious hazard to agrarian fields and urbanized areas downslope (Crosta et al., 2003). Understanding historical sustainability pathways in terraced systems in the face of existing social and environmental challenges is important to warrant human wellbeing in rural areas and develop viable agrarian strategies. In fact, from a socio-economical standpoint, terraced landscapes can contribute to the integration of small-sized communities into the global market through the pathways of sustainable growth (Balbo et al., 2016; UN, 2015).

The main aim of this volume is to provide an overview of research on terraced systems that have been in use over the long period (decades, centuries and millennia). The approach is interdisciplinary, with contributions from the environmental (agronomy and ecology) and social (archaeology and anthropology) sciences. Authors explore the impact of terracing on pre-existing environments and ecosystems but also its social implications in terms of technological innovation, management and governance strategies. Given that the agricultural food-production system is globally increasingly affected by environmental and social pressure, the long-term study of terraced system provides an essential contribution. Such systems integrate tradition and innovation, but also environmental and social know-how, in the constant redefinition of new ways to supply the food needs of an ever-growing human population. Works collected in this volume contribute to deepening our knowledge on how different societies have been able to successfully maintain through time social-ecological systems based on terraced agriculture (see Table 1).

1. Contributions

1.1. *When is a terrace not a terrace? The importance of understanding landscape evolution in studies of terraced agriculture (Ferro-Velasquez et al.)*

Previous studies have focused on the origin and impact of slope agriculture developments in Ethiopia during and after the Aksumite period, starting c. 100 CE (Sulas et al., 2009; French et al., 2009). Here, Ferro-Velasquez et al. looks at the extensive terraced landscape at Konso, southwest Ethiopia (UNESCO World Heritage Site since 2011), possibly originated 500 years ago (Amborn, 1989) and currently covering an estimated surface of c. 200 km^2. Within Konso, the Sahayto area has been chosen as representative of the historic heartland of the Konso settlement. Konso is used as a point in case to demonstrate the gradual and adaptive development of traditional terrace systems. Gradual development in traditional terraced landscapes is presented as an intrinsic feature in opposition with modern terrace developments, which may be built over broad areas in a single construction phase. Following the proposed approach, the evolution of terraced landscapes becomes a proxy of changes in farming practices, as well as in social, economic and climatic conditions.

The provocative title proposed by Ferro-Velasquez et al.,

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Table 1
List of contributions with location and chronology of presented case studies.

	Authors	Case study	Topography	Climate	Period
1	Ferro-Velasquez et al.	Konso, SW Ethiopia, Africa	Mountain c. 1400–2100 m asl	Dry/cold to sub-humid	Possibly Aksumite (c. 100–940 CE) to present
2	Ridder at al.	Politiko-*Troullia*, Cyprus	Hill c. 400 m asl	Semi-arid	Cyprus Bronze Age (c. 2700 BCE) to Medieval period (1571 CE)
3	Jiang et al.	Longji, Guangxi, China	Hill and mountain c. 400–900 m asl	Mid-subtropical monsoon	Late Yuan Dynasty (c. 1300 CE) to present
4	Londoño et al.	Wari, Cerro Baul, S Peru	Mountain up to c. 2000–2500 m asl	Dry	Wari (c. 600–1000 CE) to present
5	Fukamachi	Kamiseya and Moriyama, satoyama landscapes, Japan	Hill c. 100–600 m asl	Humid sub-tropical	Historical and modern (1900s with focus on 1970s transition) to present-day
6	Puy et al.	Ricote, Murcia, Spain	Hill c.	Semi-arid Mediterranean	Medieval (c. 900 CE) to present (focus on 2000s transition)

questions the very definition of agricultural terrace, a generic term encompassing a range of different structures built in different contexts to solve different problems, including e.g. improving soil quality, mitigating soil erosion or fostering water retention. So much so that within the same terrace system, sectors developed in different periods may have responded to different needs. Archaeobotanical characterisation, archaeological stratigraphy and soil formation analysis are used in Konso to define the function, efficacy, construction sequence and environmental consequences of terraces from different construction phases. Overall, the authors argue for the necessity to understanding the historical context to assess the efficacy, sustainability or resilience of any terrace system from an environmental management perspective. Their approach is interdisciplinary and based on the comparison of data from historical archives with modern field observations. Specifically, soil descriptions (micromorphology), geochemistry, molecular composition of the soil organic matter and stratigraphy are used to achieve a long-term perspective.

Besides demonstrating the potentially important role of slash and burn clearance in the early phases of land appropriation (accounted for in the oral tradition of the *poqualla* dynasties), a key result of Ferro-Velasquez et al.'s work is the revelation of the importance of *yela* terraces in the early stages of development of the Konso terrace system. *Yela* terraces consist of irrigable riverside plots obtained through the construction of inclined drystone walls acting as traps for sediments of alluvial and colluvial origin. Alluvial sediment input was regulated through a system of artificial offtakes (*dotatta*) and channels (*kava*), and upslope terraces were constructed to protect the *yelas* by regulating runoff and soil erosion and favouring the creation of new high-quality soil. Primarily built to regulate runoff, upslope terraces were eventually farmed. The novel perspective provided by this work indicates that the Konso terrace system was built to regulate rather than prevent soil erosion. In this context, *yela* fields, mostly overlooked in previous land management programmes, are put back into perspective as the core agronomic resource, and slope terraces, previously considered central, are interpreted as a secondary regulatory element within the system.

1.2. Economic and social activities on ancient Cypriot terraced landscapes (Ridder et al.)

Ridder et al. analyse the distribution of archaeological potsherds on the surface of the Politiko-*Koloiokremmos* terrace system, near the archaeological site of Politiko-*Troullia* in central Cyprus, as a proxy to understand off-site behaviour during the Bronze Age period. The Politiko-*Troullia* Bronze Age settlement was occupied around 2000 BCE (Falconer and Fall 2013). Previous excavations suggest that its inhabitants relied on a mixed subsistence economy, involving agriculture (olives, grapes and figs), husbandry (sheep and goat), hunting (deer) and metal smelting (copper) for which wood from olive tree, pine and oak were used as fuel.

Archaeological artefacts (potsherds, grinding and gaming stones) collected from the surface of the Politiko-*Troullia* and Politiko-*Koloiokremmos* terrace systems, were grouped by Ridder et al. into four chronological groups: (1) Prehistoric Bronze Age (2700–1650 BCE), (2) Protohistoric Bronze Age (1650–1050 BCE), (3) Iron Age-Hellenistic (1050–50 BCE), (4) Roman-Medieval (50 BCE–1571 CE) (Smith, 2014). The authors combined ground and aerial mapping of existing terraces with the use of commercial GIS software to analyse emerging distribution patterns. In addition, soil resistivity and excavation were deployed to identify Bronze Age stone structures buried under the surface of the analysed terraces.

The survey revealed dense concentrations of potsherds, grinding stones (used for ore processing) and gaming stones (associated elsewhere with ritual, communal and living activities) well beyond the vicinity of the Politiko-*Troullia* Bronze Age settlement, and as far as the eastern edge of the Politiko-*Koloiokremmos* terrace system. Ridder et al. argue that, beside agriculture, terraces surrounding the Bronze Age site of Politiko-*Troullia* were frequented for metallurgy and other social and economical activities. In conclusion, the authors claim that copper ore reduction and primary smelting in some of the easternmost terraces surrounding Politiko-*Troullia* was probably favoured by the combination of a predominantly flat topography, the availability of fuel from the nearby woodland, the proximity to water (for processing and transportation) and a favourable wind exposure. The same elements would have contributed to making the terraced area attractive for other socio-economical activities.

1.3. A record of palaeoenvironmental change inferred from organic geochemical characteristics of soil in Longji ancient Terrace, Guangx, China (Jiang et al.)

In spite of increasing scientific efforts, and mostly due to the sheer size of the subject matter, the agricultural history and archaeology of China remain largely unexplored. While important discoveries have been made in recent years on the origins of agriculture, and specifically rice agriculture in China (Cohen, 2011; Zhang et al., 2012; Zhao, 2011), Jiang et al. open a window on a more recent but significantly less known period, exploring the past 600 years of terrace agriculture development in the Longji Terrace system (800 m asl, Guangxi, South China).

The Longji Terrace system reveals at least four distinct phases of transformation, associated to different climate phases and agricultural strategies (crop type, farming intensity). Jiang et al. propose a multi-proxy study of organic geochemical proxies (TOC, organic carbon stable isotope and n-alkanes) preserved within a terrace soil profile combined with grain size analysis, magnetic susceptibility and AMS radiocarbon dating to reconstruct climatic and anthropogenic trends in Longji. On these bases, the authors propose a four-stage subdivision (A-D, A being the deepest level) for the Longji Terrace system, following its genesis in the late Yuan Dynasty (14th century CE).

Each stage is characterized in terms of anthropic activity intensity and climatic context. Stage A (late 14th - late 15th centuries) sees incipient anthropic activity with weak development of wet farming in the context of increasingly dry climate trends. Stage B (late 15th - late 19th centuries) reveals an overall enhancement in farmed activity in the late 15th century, weakening progressively towards the 19th century. This period is associated with overall cooler and wetter conditions characterizing the Little Ice Age, peaking after the 17th century. In stage C (late 19th century to c. 1950) farming, and wet farming in particular, intensifies again in correspondence with the establishment of warmer but wetter climatic conditions. During stage D (c. 1950s – present) farming is further intensified in the current context of climate warming and in association with the introduction of modern fertilisers.

1.4. A change in landscape: lessons learned from abandonment of ancient Wari agricultural Terraces in Southern Peru (Londoño et al.)

Londoño et al. present the study of three abandoned Wari terrace systems in the Moquegua Valley, on the western slopes of Cerro Baul, within a mountain arid region of South Peru, where the pre-Incan Wari empire flourished between c. 600 and 1000 CE. . The Wari agricultural system presented by Londoño et al. was abandoned around 1000 CE, possibly due to converging climatic and socio-political factors (Williams, 2002). Previous to abandonment, the Wari had developed an irrigation system diverting water from the streams of Cerro Baul into terrace agricultural fields constructed in the lowlands and in the high sierra (up to 2000–2500 m a.s.l.).

Systematic field survey supported with hand-held surveying equipment and terrestrial laser scanning were deployed, together with laboratory soil characterisation, to assess the degree of degradation of the Wari terrace system since abandonment, while reconstructing its original outline, thus providing an insight into Wari land management strategies. Micro-topographic mapping was used to understand erosion patterns and preservation of the ancient Wari terrace systems, which design was then compared to modern terracing in the nearby Moquegua Valley. The comparison between ancient and modern terrace designs is used to discuss the integration of traditional knowledge and techniques in modern developments, the resilience of local communities to desertification as well as the value, preservation and management of cultural heritage. Overall, Wari terraces show intense degradation since abandonment in 1000 CE, especially when compared to later Incan terraces, which are generally well maintained and in a good state of preservation. Starting from the study of erosional scars, the authors defined different runoff and erosional patterns for sample study areas located in different geomorphological settings along the slope. They found that microtopography and changing climatic settings affect differently the preservation of existing terraces. Terraces found in concave settings are more vulnerable due to the development of channel incision, bifurcation and stream piracy, while terraces found in convex settings (divides) are less affected, being prone to less aggressive sheet flow. In contrast, soil composition (in terms of grain size distribution and organic matter content) seems irrelevant in the definition of different erosional patterns.

The loss of ancient mountainside terraced land, together with the deterioration by lack of maintenance of the associated irrigation system, contributes to decreasing agricultural productivity in the Moquegua Valley. This is happening in spite of the construction of modern concrete lined irrigation channels for the production of water-intensive annual row crops for animal feeding. The loss of arable land due to the abandonment of ancient terraces and traditional subsistence farming techniques is estimated to amount to c. 1000 ha (Williams, 2006), and is combined with an overall loss in soil quality. Authors argue that, within the South Peruvian socio-economical and climatic contexts, the reclamation and rehabilitation of ancient terraces and irrigated agricultural systems and farming techniques can help mitigating the effects of desertification and climate change (CEPES, 2011). After suggesting a number of empirical ways to integrate traditional and modern solutions in the rehabilitation of ancient terrace systems in Cerro Baul (e.g. designed and maintained irrigation, polyculture, crop rotation and ancient cultigen propagation) the authors reckon that such rehabilitation should be accompanied by extensive research on ancient agricultural infrastructure to reduce the loss of archaeological information encoded in abandoned terrace structures and connected remains.

1.5. Sustainability of terraced paddy fields in traditional satoyama landscapes of Japan (Fukamachi)

Fukamachi revises policies currently implemented in Japan for the conservation and governance of satoyama landscapes. The term satoyama, from *sato* (里) arable land or homeland, and *yama* (山) hill or mountain, defines most rural areas in Japan, which are found between the edge of the cities and the high mountains. Extending over two thirds of the country, satoyama landscapes offer a myriad of examples of site-specific socio-ecological solutions based on fishing, agriculture, woodland management and other resources. Fukamachi focuses here on terrace paddy fields and related irrigation infrastructures. While representing some of the most rooted traditions in Japan, traditional rice cultivation in paddy fields has undergone radical changes through modernisation since the 1970s. The author analyses the role of state policy in the modernisation process and the challenges for the sustainable conservation and governance of terrace paddy fields and satoyama landscapes, including among others loss of biodiversity, loss of traditional knowledge and depopulation.

Fukamachi approach combines the review of national government policy with interviews to government officials and participant observation among locals and citizen groups in two traditional paddy field communities: (1) Kamiseya, a remote and severely depopulated hill area in the Seya district of Miyazu City, and (2) Moriyama, a sub-urban area with fast-growing population in the Hachiyado district of Otsu City. In both contexts, contracting population and economical trends challenge the functioning of traditional paddy fields and associated traditions.

Fukamachi argues that the international recognition of the value of human-natural landscapes (e.g. by UNESCO), stimulated the creation in Japan of groups and commissions dedicated to the study and preservation of terraced paddy fields, such as the Japan Rice Terrace Association (Zenkoku Tanada Renraku Kyogikai) and the Academic Society on Rice Terraces (Tanada Gakkai), as well as the implementation of landscape restoration policies (Watanabe et al., 2012). Within this international framework, the terraced paddy fields of the Noto Peninsula were recognized by FAO in 2011 as one of the world's Globally Important Agricultural Heritage Systems (GIAHS). Besides top-down initiatives and recognition, Fukamachi analyses the value of bottom-up initiatives by local communities and stakeholders. In Kamiseya, such initiatives have led to its recognition as one of the Top 100 Japanese Rural Landscapes (Nihon no Sato 100 sen) in a public survey by Asahi Shimbun Newspaper Company in cooperation with Forests Culture

Association (Iwata et al., 2011). The author observed similar initiatives in sub-urban Moriyama, where citizens are increasingly involved in the revitalization and conservation of paddy field agricultural and related traditions. The combination of top-down and bottom-up governance approaches has increased awareness of the social-ecological value of traditional paddy field landscapes and satoyama (Takeuchi et al., 2016). As a result, although further work is needed, an inflection is observed in historical trends of depopulation and/or sharp decrease in farmer communities and actively cultivated farmland in traditional rice terraces.

1.6. Drip irrigation uptake in traditional irrigated-terraced fields: the edaphological impact (Puy et al.)

Puy et al. focus on changes in soil physico-chemical properties caused by the introduction of drip irrigation (DI) in traditional flood/furrow irrigation (FI) terraced fields, which represents one of the main pathways for the modernisation of traditional irrigated systems. The introduction of DI implies radical changes in FI fields, including the abandonment of pre-existing hydraulic infrastructures and practices. Instead of being intentionally flooded at broad time intervals, under DI the largest portion of parcels remain dry throughout the year, while small amounts of fertiliser-enriched water are allocated in proximity of the plant-roots on an almost daily basis.

Puy et al. study the impact of such recent changes on soil health and structure in the context of the historical irrigated-terraced system of Ricote, Murcia, Southeast Spain, which origin dates back to the 9th-10th centuries CE. Irrigated for centuries with FI, c. 90% of the fields in Ricote are now included in a DI scheme initiated in 2007. To compare edaphological characteristics in FI and DI plots, authors analyse pH, electrical conductivity, available P, carbon, C/N, bulk density, soil water content and particle size distribution using a robust statistic approach, including opening of compositional data (CoDa) using an isometric logratio (*ilr*) transformation (Egozcue et al., 2003). In addition, Electrical Resistivity (ERT) was deployed to assess water infiltration rates and distribution through the soil profile in FI and DI conditions.

The proposed approach allows Puy et al. to show how soil is transformed in less than a decade following the introduction of DI in a traditionally FI terraced agricultural system. After highlighting some clear advantages, authors are able to identify a number of potential edaphological drawbacks derived from DI introduction. (1) In DI plots, soils found in proximity of water emitters have higher mean water contents than in FI schemes. DI thus diminishes the effects of locational impairment by providing steady water inputs across the irrigated scheme. However, soils not directly found under the water emitters are impoverished in organic matter, P and N contents compared to FI plots. (2) DI strongly reduces the amount of water leaching into the groundwater system under FI conditions. While reducing water loss, such reduction implies that most of the carbonates precipitated under DI could constitute a relevant source of CO_2, increasing the amount of CO_2 released from the soil (Hannam et al., 2016). (3) While DI successfully reduces and homogenises salt contents, FI offers a more homogeneous distribution of coarse and fine particles in the soil. In other words, DI might contribute to coarsen the topsoil, a symptom of soil degradation potentially leading to desertification (Geeson et al., 2002).

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