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Paleoecology helps optimize restoration efforts by identifying unrealistic pre-anthropic targets

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Paleoecological records are useful in that they inform ecological restoration efforts by not only providing the most suitable pre-anthropic baselines, but also identifying unrealistic and unfeasible restoration targets due to climatic, cultural, and economic constraints.

Paleoecology can inform ecological restoration efforts, as it may help set the expected/desired pre-anthropic ecosystem targets and baselines (Willard and Cronin 2007; Willis et al. 2010). However, past reconstructions have also identified unexpected changes in community composition, with no modern analogs, in response to environmental shifts (Williams and Jackson 2007). It has been recommended that conservation and restoration efforts focus on viable strategies and consider the possibility that novel and unexpected ecosystems will emerge in the near future as a response to ongoing global change (Jackson and Hobbs 2009; Hobbs et al. 2014). Another source of uncertainty in the definition of restoration targets is the feasibility of rebuilding pre-anthropic conditions, especially in cases where ecosystems have already crossed a tipping point leading to irreversible regime changes. Paleoecology is also able to identify unrealistic restoration targets, which may help optimize conservation efforts by helping to shape more realistic targets for restoration. This paper shows some of these situations using case studies selected according to the experience of the author, but similar situations exist elsewhere. The main past and present features of the selected areas are described (also see Fig. 1). The main paleoecological trends in each area are shown in Figure 2.

1. Gran Sabana (Venezuela)

Type locality: Several lakes and bogs from the southwestern sector of the Gran Sabana region (Rull et al. 2013).

Pre-anthropic vegetation: Dense and diverse rainforests (*Catostemma* and *Dimorphandra*) and shrublands (*Bonyunia*), possibly with scattered savanna patches.

Present-day vegetation: Treeless savannas with gallery forests along rivers and palm stands of *Mauritia flexuosa* (morichales) on flooded terrains.

Current anthropic pressures: Extensive burning, surface mining, and international tourism.

Main paleoecological trends: Pre-anthropic woodlands occurred during the Younger Dryas (YD) and the Early Holocene (EH), when the climate was significantly colder and drier than that of today (13 to 10 cal kyr BP). Further burning, possibly by nomadic hunter gatherers, transformed the region into extensive treeless savannas with gallery forests along rivers. This persisted until ~2 cal kyr BP, when the indigenous Pemon people settled the region and favored the establishment of *Mauritia* palm stands using selective burning.

Main restoration challenges: Climatic and cultural. Past YD and EH climates suitable for the occurrence of pre-anthropic vegetation are impossible to reproduce in the present conditions. In addition, rebuilding pre-anthropic landscapes would imply the removal of savannas and *Mauritia* palm stands, as well as the eradication of fire practices, which constitute key resources and traditions for the Pemon people.

2. Pyrenees (Spain)

Type locality: Lake Montcortès (Rull et al. 2021).

Pre-anthropic vegetation: Lower montane forests (*Pinus* and *Quercus*) and gallery forests (*Alnus* and *Corylus*) surrounding rivers and lakes.

Present-day vegetation: Croplands, pastures, badlands, and remains of low-montane forest.

Current anthropic pressures: Intensive and extensive agriculture, forestry, and regional tourism.

Main paleoecological trends: Pre-anthropic montane and gallery forests were affected by anthropogenic fires at ~300 BCE (Iron Age) but were resilient until a second deforestation event occurred at ~300 CE (Roman Period), when croplands significantly expanded. Fires stopped at the beginning of the Middle Ages (~500 CE), but deforestation events (selective felling) continued until the Modern Age (~1800 CE). During the last century, massive depopulation of montane areas due to population emigration to industrialized cities led to the expansion of montane forests (Trapote et al. 2018).

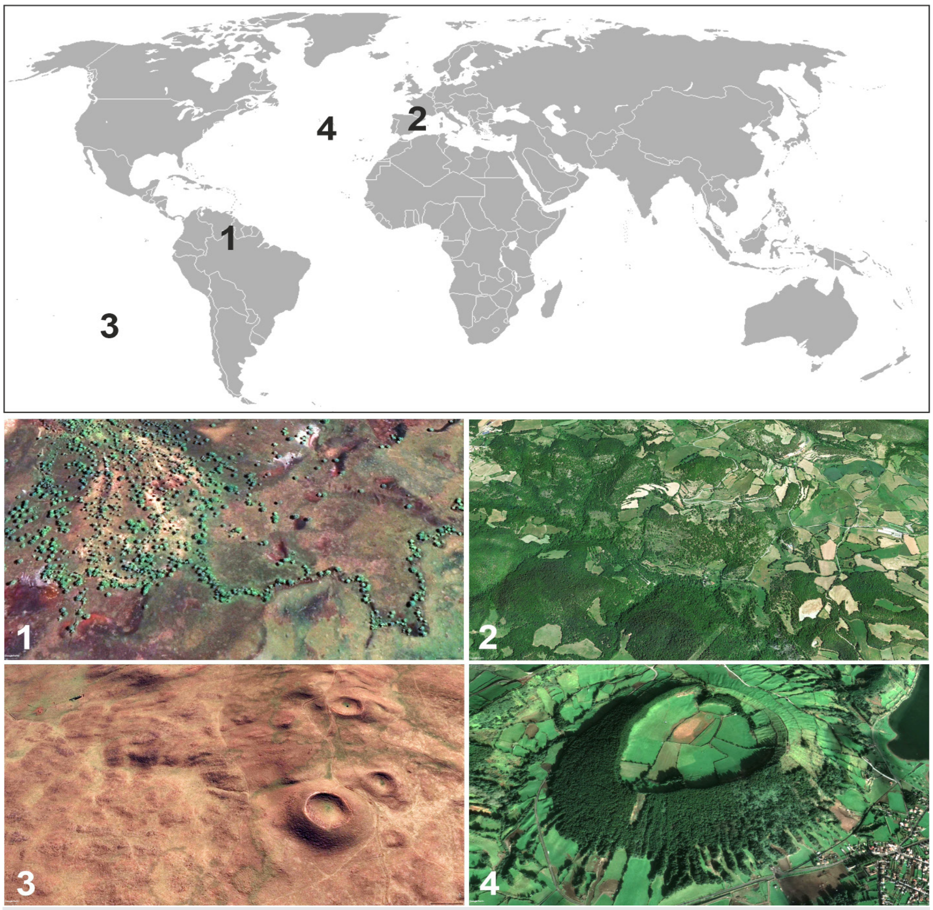

Figure 1: Location of case studies and examples of their current landscapes. (1) Typical landscape of the southern Gran Sabana (Venezuela) with palm stands growing on flooded savannas. (2) Landscape around Lake Montcortès (Iberian Pyrenees, Spain) with intensive cultivation and some montane forest patches. (3) Badlands of the Maunga Terevaka volcano (Easter Island, Chile) partially covered by grasslands. (4) Volcanic crater on São Miguel Island (Azores, Portugal) with extensive croplands and planted forests of exotic species. Images from Google Earth.

Main restoration challenges: Cultural and economic. The full large-scale recovery of pre-anthropic forests would require the abandonment of private agricultural and forestry practices at regional scales. This would necessitate a radical change in the local culture and/or in the land property regime, a situation that would be highly unpopular and likely unviable under the present socioeconomic conditions.

3. Easter Island (Chile)

Type locality: Two lakes (Kao and Raraku) and a bog (Aroi) (Rull 2020).

Pre-anthropic vegetation: Dense forests dominated by an extinct palm that covered ~80% of the island.

Present-day vegetation: Grasslands, badlands, and scattered plantations of exotic trees (*Eucalyptus*).

Current anthropic pressures: Substantial international tourism.

Main paleoecological trends: The original palm woodlands, as old as ~40 cal kyr BP, began to be removed by Polynesian colonizers around 1200 CE using fire. This deforestation was a spatiotemporally heterogeneous process across the island ending by 1600 CE, when the entire island was transformed into grasslands and badlands. During forest clearing, the islanders (Rapanui) developed gardening cultivation techniques that facilitated their subsistence until European contact (1722 CE), which signified the beginning of the demise of the ancient Rapanui culture. Landscape degradation was greatest in the 19th century, when the island was transformed into a sheep ranch.

Main restoration challenges: Cultural and evolutionary. The small island (>150 km^2) has approximately 20,000 exposed sites and manifestations of the ancient Rapanui culture, still preserved in their original places, which were built up on a mostly deforested island. Rebuilding the original palm woodlands is not realistic under these conditions. In addition, the palm species that grew on the island are already extinct; therefore, their identity and ecological requirements are unknown.

4. Azores (Portugal)

Type locality: Lake Azul, São Miguel Island (Rull et al. 2017).

Pre-anthropic vegetation: Dense *laurisilvas* dominated by *Morella faya* and *Juniperus brevifolia*.

Present-day vegetation: Croplands, pastures, and extensive forest of exotic species, mainly *Cryptomeria japonica* (Japan) and *Pinus pinaster* (Mediterranean).

Present anthropic pressures: Intensive and extensive agriculture, forestry, and incipient tourism.

Main paleoecological trends: Pre-anthropic *laurisilvas* were abruptly removed using fire by the first European colonizers around 1400 CE, and the landscape was transformed into a mosaic of shrublands and grasslands. This persisted until ~1800 CE, when extensive reforestation with exotic tree species began to shape present-day landscapes.

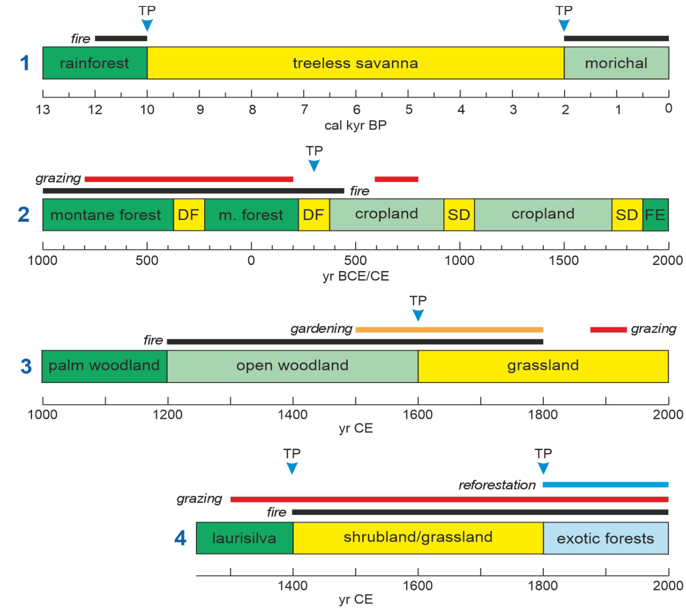

Figure 2: Vegetation changes in the areas considered in this work at three different temporal scales: The Holocene (1: Gran Sabana), the last 3000 years (2: Iberian Pyrenees), and the last millennium (3: Easter Island; 4: Azores Islands). Summarized from Rull (2020) and Rull et al. (2013, 2017, 2021). DF: deforestation using fire; SD: selective deforestation (mechanical); TP: tipping points; FE: forest expansion.

Main restoration challenges: Cultural and economic. As in the case of the Iberian Pyrenees, the eventual large-scale restoration of the original forests would require socioeconomic changes that would be difficult, or impossible, to implement under present conditions.

Restoration alternatives

The restoration impediments highlighted in the case studies above relate to large-scale or island-wide rebuilding of pre-anthropic ecosystems and landscapes, but other smaller-scale options are possible using the available paleoecological information. The possibility of restoring stands or patches representative of past plant communities outside (*quasi in situ*) or inside (*inter situ*) their natural distribution areas, either past or present, has been proposed (Burney and Burney 2007; Volis and Belcher 2010). Restoring past communities in protected areas such as national or regional parks, may also be feasible if current environmental conditions permit. Where landscapes are used for food production and other cultural purposes, a combination of these approaches would be the restoration of a series of communities that reproduce the different natural vegetation and landscape stages represented in paleoecological records to provide a historical account of the shaping of present-day landscapes.

Because paleo-inferred restoration targets can include communities that existed under warmer and/or drier climates or under different disturbance regimes, they may contribute to mitigate ecological global-change impacts. Specifically, these landscape mosaics may help to maintain biodiversity and, thus, important ecosystem properties and services. Ultimately, when large-scale restoration to pre-anthropic conditions is impossible, the paleodata can be used in framing realistic restoration targets at small to medium scales in multi-functional landscape mosaics. In cases such as Gran Sabana and Easter Island, where indigenous cultures are still present, the contribution of their traditional knowledge would be very useful for providing a holistic socioecological perspective that contributes to the conservation of cultural landscapes (Uprety et al. 2012; Wehi and Lord 2017).

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