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Short communication

A spatiotemporal gradient in the anthropization of Pyrenean landscapes. Preliminary report

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ABSTRACT

A preliminary analysis of the timing of landscape anthropization in the southern-central Pyrenees shows the occurrence of an elevational gradient from the Bronze Age (basal belts) to the Middle Ages (alpine belts). This relationship is statistically significant and suggests an average anthropization rate of 40 m in elevation per century. The elevational gradient is most clear between the Bronze Age and the Roman occupation, suggesting a progressive upward anthropization trend from the south with the likely involvement of Iberian cultures. During the Middle Ages, a massive anthropization pattern of subalpine/alpine areas is observed; this pattern is chronologically consistent with the incursion of northern cultures crossing the Pyrenees and the development of extensive high-mountain pastoralism and horizontal transhumance. In general, the progression of upward anthropization has occurred during warm climatic phases. Further work is needed to confirm these observations, especially in areas with few available paleoecological studies, notably the basal and montane belts. It could be interesting to develop similar studies of other Pyrenean regions and other mountain ranges.

1. Introduction

This brief communication explores the possibility of the progressive landscape anthropization with elevation (basimontane to alpine belts) and time (from the Bronze Age to the Middle Ages) in the central Pyrenees (Fig. 1). The study region is located on the southern slopes of the highest part of the Pyrenees, including areas of Spain and Andorra; however, the possibility of similar patterns in other Pyrenean areas and in other mountain ranges is suggested. It should be emphasized that this is not a study about the progress of human settlement on mountain environments, as deduced from archaeological studies. This paper deals with landscape anthropozation, that is, human-induced large and irreversible transformations of original landscapes leading to present-day configuration of the different mountain vegetation belts. Sometimes, landscape anthropization may coincide with human settlement while in other cases it may occur much latter. Landscape anthropization trends are commonly derived from paleoecological studies, mainly palynological analysis of lake sediments and peat bogs. In these palynological studies landscape anthropization is manifested mainly in total or parcial deforestation and meadow expansion (landscape opening), treeline lowering, unexpected changes in forest composition, increases of fire incidence and intensification and/or expansion of cropping and grazing practices (Table 1). This paper briefly introduces previous reviews on the human settlement and landscape anthropization of the Pyrenees to finalize with the already mentioned hypothesis of a potential chrono-elevational anthropization gradient and the dataset on which this possibility is based. The possible influence of climate change is also discussed, and some potential cultural implications of the recorded gradient are advanced.

2. Previous studies

Gassiot Ballbè et al. (2017) summarized the available archaeological evidence on the human settlement of the Pyrenees. According to these authors, human presence was very scarce during Late Glacial and Early Holocene times (19,000-8000 BCE), and most human populations lived in low-to mid-elevation peripheral Pyrenean areas and in lower valleys within the mountain range. However, some human activity has been detected in subalpine and alpine areas during the Younger Dryas period. High-mountain environments began to be settled occasionally and/or temporarily in

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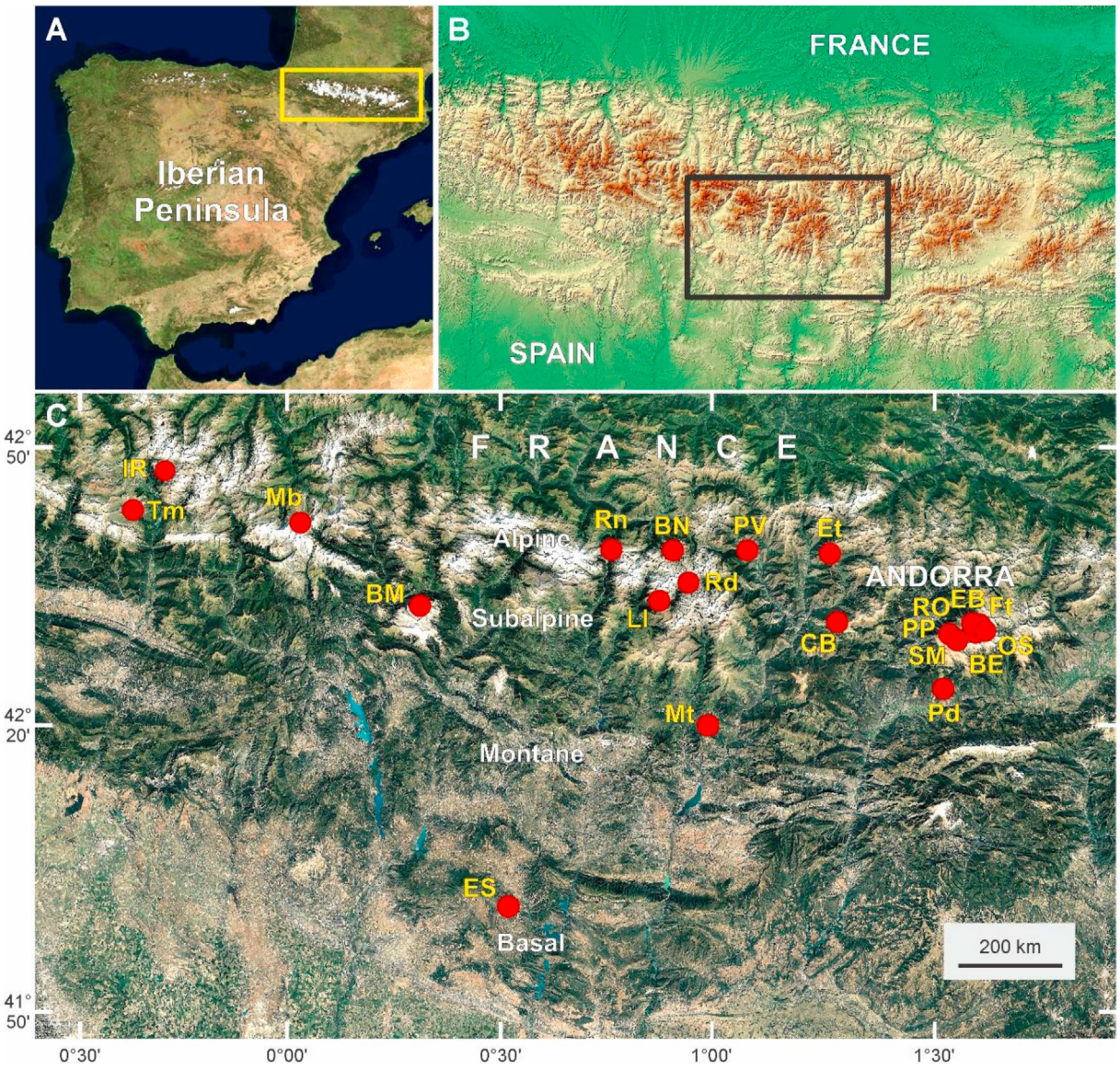

Fig. 1. General map. A) Location of the Pyrenees (yellow box) with respect to the Iberian Peninsula. B) Closer view of the Pyrenees showing the study area (black box). C) Google Earth close-up of the study area showing the lakes and peat bogs considered in this work (red dots). The abbreviations correspond to those described in Table 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the Early-Mid Holocene (8000-6000 BCE) by groups of Mesolithic hunter-gatherers. Neolithization had started by 5600–3000 BCE, leading to the establishment of more stable settlements and the development of farming and pastoralism at low, middle and high elevations. A significant increase in the occupation of the area occurred between 3500 and 2500 BCE, especially in areas above the present treeline, probably due to an increase in mobile herding practices. In some areas, a further decline in known settlements took place between 2000 BCE and the Roman period, whose causes still remain unknown.

Using paleoecological evidence—i.e., pollen-based vegetation reconstructions—from some sites in the eastern area of the central Pyrenees, Pèlachs et al. (2017) concluded that the starting point of modern farming and livestock-raising practices occurred at approximately 4250 cal yr BP and that the maximum human pressure, as manifested in the maximum magnitude of landscape opening by forest clearing, started in the Roman Period and persisted throughout the last two millennia. González-Sampériz et al. (2017) extended the dataset to the entire central Pyrenean area and included available paleoecological records from basimontane and montane belts. These authors concluded that although early signs of human impact were already visible in some sites by 4000 cal yr BP (Bronze Age), it was not until Medieval times that human activities became especially important in terms of landscape anthropization, regardless of the elevations or the geographical locations of the sites considered. A general conclusion was that the development of the Pyrenean landscapes was mainly controlled by the climate until Medieval times, when humans took the lead (González-Sampériz et al., 2017). It is also noteworthy that, according to these authors, the environmental history of the central Pyrenees shows a relatively high degree of internal coherence across space and elevation. Using a similar dataset, with the addition of some archaeological sites and dated paleofire records, González-Sampériz et al. (2019) attempted to define the shaping of cultural landscapes—i.e., anthropogenic deforestation and the expansion of open vegetation—in the central Pyrenees in

Table 1
Raw data used in this paper to analyze the relationship between elevation and anthropization time, as depicted in Fig. 1. The anthropization time and the corresponding palynological evidence were taken directly from the original references. Abbreviations: L = Lake, P = Pond, B = Bog. AT = anthropization time.

Site	Code	Elevation (m)	Latitude	Longitude	AT (cal yr BP)	AT (CE/BCE)	Palynological evidence	References
Marboré (L)	Mb	2612	42.695631	0.040019	1300	650	Forest (especially deciduous) reduction, alpine meadows expansion	Leunda et al. (2017)
Forcat (L)	Ft	2531	42.493889	1.639167	1150	800	Generalized landscape opening and grazing	Ejarque (2009)
Estany Blau (L)	EB	2471	42.496389	1.620833	1150	800	Generalized landscape opening and grazing	Ejarque (2009)
Serra Mitjana (B)	SM	2406	42.4645	1.582778	850	1100	Woodland clearance (fire) and grassland expansion, grazing	Miras et al. (2015)
Riu dels Orris (B)	RO	2390	42.488889	1.637222	1100	850	Woodland retreat and extension of alpine grasslands, grazing	Ejarque et al. (2010)
Orris de Setut (B)	OS	2300	42.4825	1.650278	1100	850	Woodland retreat and extension of alpine grasslands, grazing	Ejarque et al. (2010)
Estanilles (B)	Et	2247	42.626149	1.29625	550	1400	Treeline lowering (fire), pasture development	Cunill et al. (2013)
Redon (L)	Rn	2240	42.640483	0.778297	1000	950	Forest retreat, agropastoralism increase	Pla and Catalan (2004); Catalan et al. (2014)
Planells de Perafita (B)	PP	2240	42.479167	1.566944	1150	800	Generalized landscape opening and grazing	Ejarque (2009)
Bosc del Estanyons (B)	BE	2180	42.480278	1.619167	2050	−100	Large-scale forest opening, agropastoralism, metallurgy (?)	Miras et al. (2007); Ejarque et al. (2010)
Redó (L)	Rd	2116	42.580039	0.958333	850	1100	General deforestation, grazing and cereal croppping	Catalan et al. (2000, 2013)
Ibón de las Ranas (L)	IR	2092	42.794075	−0.291636	700	1250	Subalpine deforestation, pasture expansion	Montserrat Martí (1992)
Pradell (B)	Pd	1975	42.288889	1.547778	1100	850	Woodland management (fire), cropping, grazing	Ejarque et al. (2009)
Basa de la Mora (L)	BM	1914	42.546111	0.325	700	1250	Deforestation and expansion of grazing lands	Pérez-Sanz et al. (2013)
Bassa Nera (P)	BN	1891	42.638472	0.924333	3150	−1200	Forest clearing (fires) and intensification of agropastoral activities	Garcés-Pastor et al. (2016, 2017)
Coma de Burg (L)	CB	1821	42.505	1.306111	2800	−850	Replacement of fir by pine forests	Pèlachs et al. (2007)
Tramacastilla (L)	Tm	1668	42.724517	−0.367869	1000	950	Forest clearing with no recovery	Montserrat-Martí (1992)
Llebreta (L)	Ll	1619	42.594444	0.888611	2100	−150	Treeline lowering, expansion of alpine meadows, cereal cultivation	Catalan et al. (2013)
Prats de Vila (B)	PV	1150	42.638056	1.103611	2000	−50	*Abies-Fagus* replacement, grazing and agriculture expansion	Pèlachs et al. (2009)
Montcortès (L)	Mt	1027	42.330556	0.994722	2700	−750	Deforestation (fire), grazing and cropping	Rull et al. (2011, 2021), Rull and Vegas-Vilarrúbia (2015)
Estanya (L)	Es	670	42.029706	0.527314	3700	−1750	Deforestation, cereal cultivation	Riera et al. (2004); González-Sampériz et al. (2017)

chronological terms. According to these authors, this method could be considered the most reliable procedure for determining the beginning of the Anthropocene in the study area. The conclusion was that in the central Pyrenees, general landscape anthropization did not begin some millennia ago but instead took place during recent centuries, starting in early Medieval times, at approximately 700 cal yr BP (1300 CE).

3. The gradient hypothesis

The idea of assumed geographical and elevational homogeneity in the ultimate anthropization of the Pyrenean landscapes is evident in the paleoecological reviews dealing with this topic discussed above, and the preferred time intervals during which these transformations are assumed to have happened are Late Roman and early Medieval times. However, a more detailed analysis of the chronological inferences of each original paper regarding the anthropization of each particular site reveals the occurrence of higher variability than was previously expected. The question here is whether this variability may have an elevational pattern, a possibility that has recently been suggested (Rull et al., 2021) but remains unexplored. This paper uses chronological data from the original references to preliminarily test this chrono-elevational hypothesis.

The dataset used in this study is similar to those provided by Pèlachs et al. (2017) and González-Sampériz et al. (2017, 2019); altogether, these datasets account for all paleoecological works developed to date in the southern-central Pyrenees. In this paper, however, only sites with reliable dating and continuous palynological records, including data of the last 3–4 millennia (since the Bronze Age), were considered. These sites are depicted in Fig. 1, and the raw data utilized are provided in Table 1. A biplot of elevation versus anthropization time, as given in the original references, is displayed in Fig. 2. In one case (Rn), the anthropization date was not explicitly mentioned and was deduced from the dated pollen diagrams, indicating general deforestation coeval with significant increases in cereal cultivation and grazing activities (Pla and Catalan, 2004). In the other cases, ranges were provided for the anthropization time, and these ranges usually corresponded to the upper and lower boundaries of the pollen zone representing landscape anthropization. In these cases, the lower value of each range was considered.

Using this dataset, the obtained correlation between anthropization and elevation was evident and statistically significant

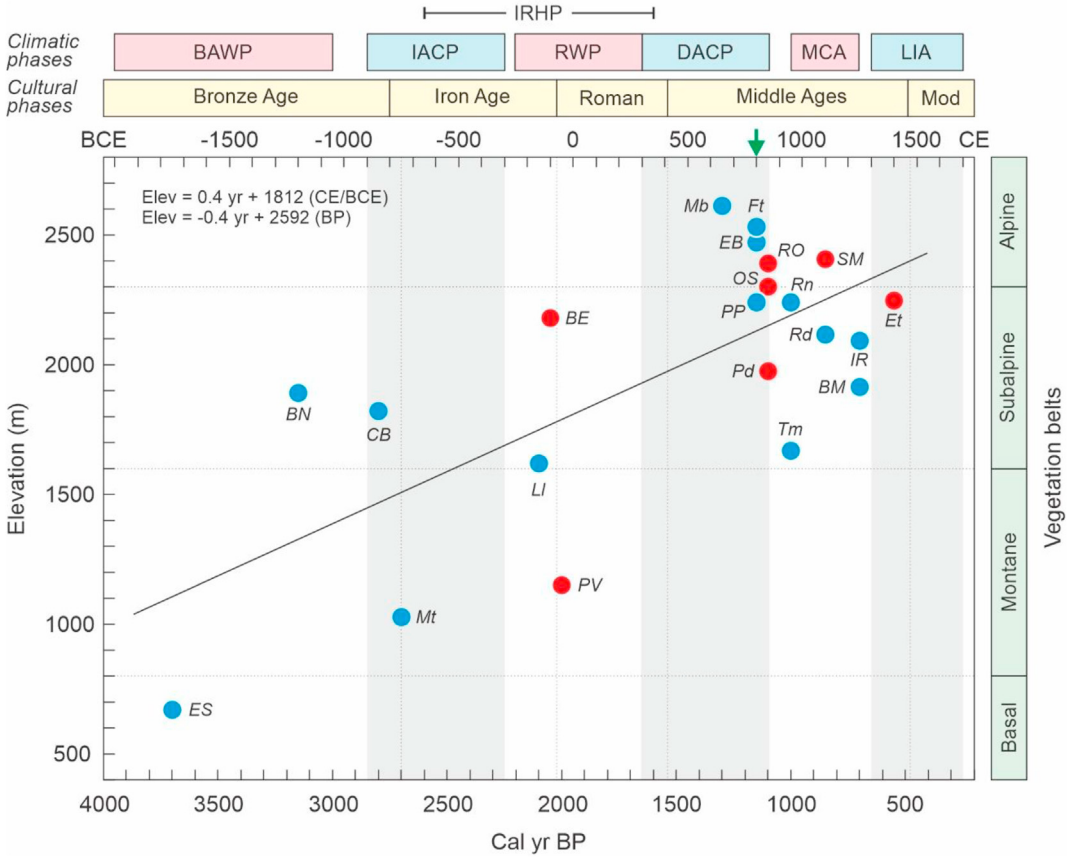

Fig. 2. Relationship between time and landscape anthropization in the studied region according to the original information from the literature provided in Table 1. Blue dots represent lakes, and red dots are peat bogs (see also Table 1). The green arrow indicates the Pyrenean penetration by and further establishment of the Carolingian Empire on the Iberian Peninsula. Gray bands indicate cold climatic phases. Abbreviations: BAWP = Bronze Age Warm Period, IACP = Iron Age Cold Period, RWP = Roman Warm Period, DACP = Dark Ages Cold Period, MCA = Medieval Climate Anomaly, LIA = Little Ice Age, IRHP = Iberian-Roman Humid Period. The climatic phases correspond to those described by Gribbin and Lamb (1978), Mann et al. (2009), Martín-Puertas et al. (2009), Martín-Chivelet et al. (2011), Büntgen et al. (2016) and Helama et al. (2017). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

($r = 0.698$; $p < 0.001$). The linear regression equation had a slope of 0.4 (Fig. 2), which may be interpreted as an average anthropization rate of 0.4 m in elevation per year (or 40 m per century). Whereas some cultural phases are relatively well represented, especially the Middle Ages, others show relevant information gaps; this is the case, for example, for the Roman period. Regarding the ecological belts, there is also a clear difference between the subalpine/alpine belts, which contain most of the available data, and the basal/montane belts, which have only 3–4 sites. The trend is clear for the basal (Bronze Age), montane (Iron Age to Roman Period) and alpine (Middle Ages) belts, but the subalpine belt shows significant anthropization dispersion encompassing the whole temporal range, from the Bronze Age to the Middle Ages. This high dispersion is mainly due to three locations (BN, CB and BE) that were anthropized during the Bronze Age and the Iron Age, whereas the majority of the subalpine sites were anthropized in Medieval times. Without these three sites, the general correlation increases to $r = -0.820$ ($p < 0.001$). The case of the early anthropization of the BE site, in comparison with other sites from the same valley situated at similar elevations (RO and OS), was discussed by Ejarque et al. (2010), who emphasized that the spatial fragmentation of the human use of mountain resources led to microscale variability in land use patterns. It is also possible that some locations were anthropized earlier than expected by the gradient model due to the occurrence of special resources available for exploitation that could have been absent at other sites. Examples could be water availability, mining or the exploitation of some subalpine forests for wood and/or charcoal.

The possibility of other geographical gradients was also tested. There was no significant correlation between anthropization age and longitude ($R = 0.008$; $p = 0.927$), which rules out a possible E-W or W-E component in the anthropization of the central Pyrenees. In contrast, the correlation with latitude was significant ($r = -0.485$; $p = 0.025$), which was likely due to the positive correlation between latitude and elevation ($r = 0.436$; $p = 0.048$). Therefore, we can conclude that, with the available information, the most influential geographical parameter in the anthropization of the southern-central Pyrenees was elevation, and for this reason, anthropization progressed from south to north between the Bronze Age and the Middle Ages, when massive anthropization of the subalpine and alpine belts occurred. The elevational S–N trend suggests that before Medieval times, human pressures on Pyrenean landscapes were progressive and came mainly from the south, likely involving autochthonous Iberian cultures until Roman occupation occurred shortly before 2000 cal yr BP. During the Middle Ages, the development of extensive pastoralism and horizontal transhumance in the highlands (Gassiot, 2016; García-Ruiz et al., 2020), as well as the Pyrenean penetration by and further establishment of the northern Carolingian Empire in the Iberian Peninsula in 800 CE (Rull and Vegas-Vilarrúbia, 2015), may have changed the temporal and spatial anthropization trends, thus facilitating the almost-simultaneous anthropization of the

subalpine and alpine belts (Fig. 2).

4. Climatic influence

To properly characterize the possible influence of climatic changes on anthropization, it would be necessary to know the detailed anthropization rates and their eventual variations over time in relation to known climatic phases. At the present stage, this is not possible due to insufficient data, and the analysis should instead proceed on a site-by-site basis. Overall, two-thirds (14) of the studied sites were anthropized during warm climatic phases, and only one-third (seven) of the sites were anthropized during cold climatic phases. From the Bronze Age to Roman occupation, when the chrono-elevational gradient became more evident, most sites (five out of seven) were anthropized during warm phases (Fig. 2). During the Middle Ages, when the gradient was disrupted, ten of 14 sites were anthropized during warm periods. The whole picture suggests that, regardless of the particular trends of each cultural phase, relatively warmer climates facilitated the progressive occupation and anthropization of higher landscapes. These observations seem unsurprising, as a warming climate favors the upward displacement and settlement of human populations, but the progression of upward anthropization during cold phases, although more minor than that during warm phases, deserves some explanation. Interestingly, all sites that were anthropized during cold climates were lake catchments except one, which suggests that water availability favored human settlement despite the occurrence of cold climates. However, these are preliminary observations that should be confirmed with future studies that consider the local conditions of each particular site.

5. Final remarks

In addition to the well-known general intensification of human pressures on Pyrenean landscapes during the Middle Ages (Pèlachs et al., 2017; González-Sampériz et al., 2017, 2019; García Ruíz et al., 2020; Rull et al., 2021), the previous impressions of the general Pyrenean anthropization during Medieval times may be influenced by a sampling bias created by the dominance of subalpine and alpine localities whose landscapes were indeed irreversibly anthropized in the Middle Ages (Fig. 2). This is likely a consequence of the greater abundances of sedimentary archives (from glacial lakes and peat bogs) at high elevations, the occurrences of which are favored by fluvioglacial geomorphology and relatively colder climates in comparison with basal and montane belts, where these types of sedimentary bodies are scarcer. However, when the available quantitative data are combined, a different picture emerges in the form of a spatiotemporal pattern. The potential occurrence of a chrono-elevational gradient in the anthropization of the southern-central Pyrenees is consistent with the currently available evidence but should still be considered a hypothesis to be confirmed with future studies, especially in the basal and montane belts where few studies are currently available. It is worth focusing efforts in this sense to test whether the proposed gradient is confirmed and, if so, to estimate its magnitude and potential cultural implications. It would also be interesting to verify the occurrence of the same or other geographical patterns in the anthropization of the northern slopes of the Pyrenees, where the elevational gradient is inversed, and on other mountain ranges, where the relationships between elevation and latitude/longitude are different from those of the Pyrenees. An analysis of this type would help clarify when and how (and, hopefully, by whom) mountain landscapes have been irreversibly anthropized until giving rise to the present situation.

Author statement

Both authors made substantial contributions and have approved the final version of the manuscript. VR conceived the work, developed the analysis and wrote the manuscript. TVV provided ideas during the development of the work and contributed to the final writing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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