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Essay

Anticipation, discovery and serendipity in Quaternary paleoecology: personal experiences from the Iberian Pyrenees

Valentí Rull[1,2]

[1]Botanic Institute of Barcelona, Spanish National Research Council (CSIC), Pg. Midgia s/n, 08038 Barcelona Spain. Email: vrull@csic.es
[2]Catalan Institute of Paleontology Miquel Crusafont, Universitat Autònoma de Barcelona, ICTA-ICP Bld., C. Columnes s/n, 08193 Cerdanyola del Vallès, Barcelona, Spain

Abstract: This essay is a personal insight based on my own experience in the Iberian Pyrenees, which addresses three situations common in paleoecological research, such as the verification of previously devised hypotheses (anticipation), the finding on unknown events in unstudied sites (discovery) and the finding of unexpected outputs in already known areas (serendipity). The account is concentrated on the value of the coring sites by themselves as generators of paleoecological knowledge, rather than on the actual findings, which are presented and discussed in the corresponding data papers. The main aim is to show that there is still much room for new findings, even in areas that have been surveyed for long time and are supposed to be well known, from a paleoecological perspective. Finally, some general lessons are derived and conceptualized.

Keywords: Pyrenees; paleoecology; hypothesis testing; discovery; serendipity; Quaternary; Lateglacial; Holocene; last millennia

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1. Introduction

A fundamental conceptual difference between experimental and observational research is that the former uses controlled experiments to test previously defined hypotheses, whereas the latter relies on the finding of empirical evidence from the observation natural phenomena. Quaternary paleoecology has part of both, although the observational component is of paramount importance. In Quaternary study, the initial hypotheses help define the location, type and age of past records to be retrieved, along with the proxies to be analyzed. In this case, researchers choose a given coring site and a particular set of variables able to address particular questions to be answered. When paleoecological research is aimed at testing previously proposed hypotheses, we can consider that the results obtained were, in some way, anticipated. Sometimes, however, Quaternary paleoecologists study previously uncored localities without any definite expectations, simply to obtain samples and see what happens. Usually, yet not always, this is performed using a wide arrangement of multidisciplinary analyses to acquire as much information as possible on the condition and functioning of past natural systems. This "blind" approach requires more investment but is more prone to produce new discoveries and suggest previously unexpected research prospects and directions [1].

In this paper, I show some examples of new discoveries from blind paleoecological research, anticipated prospects from planned surveys and serendipitous findings, or unexpected outputs that emerged from planned research. These examples come from my own research on my homeland, the Pyrenees (Figure 1), and are aimed at explaining how the coring sites were found and why they became important, rather than displaying the results obtained, which are already well documented in the cited publications. It is important to stress that the paper presents my own personal view on the subject and I am the only responsible for the content. During the investigations described, many colleagues have collaborated in my projects and I in have participated in theirs, and it would be impossible to remember, even to know, all the researchers involved in all of them. I have emphasized the main project leaders, their affiliations and the institutions that funded the research. The reader is referred to the cited literature for more details on project participants and funding sources.

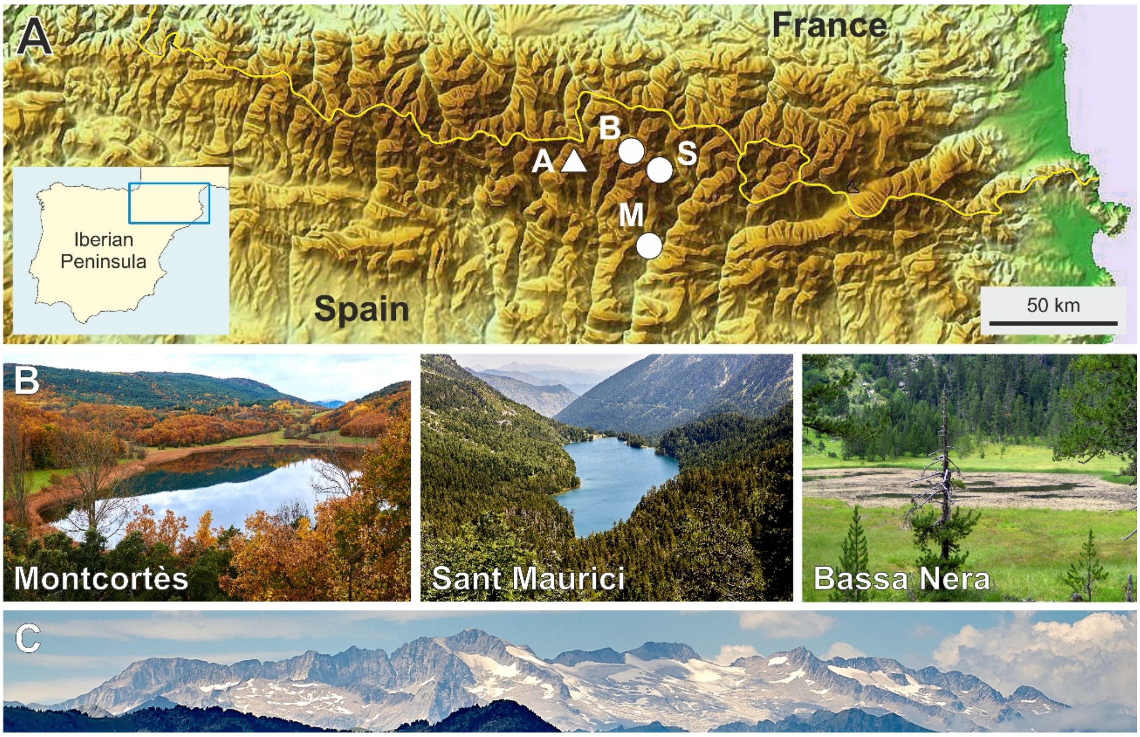

Figure 1. The Pyrenean range and the coring sites. A) Topographic map of the Pyrenees showing the coring sites discussed in the text (white dots) and the Pyrenean summit (white triangle). B) Coring sites. C) The Maladeta massif, with the highest Pyrenean summit (Aneto; 3404 m) in the center. A, Aneto peak; B, Bassa Nera; M, Lake Montcortès; S, Lake Sant Maurici. Photos: V. Rull.

2. Antecedents

The story begins in tropical America a couple of decades ago. After a long stay (1981-2002) in the Caribbean region (Venezuela), I decided to return to Spain, and this was possible thanks to a fellowship from the Spanish Ministry of Science and Technology, the precursor of the present Ministry of Science and Innovation. This fellowship included a research proposal, and the topic that I chose for this was a comparative paleoecological study between the northern Andes (where I worked since the 1980s) and the Pyrenees, where I had initiated my paleoecological research before leaving Spain. Finding new coring sites on the Pyrenees was not easy. Indeed, paleoecological studies were a tradition on this mountain range and many, if not most, suitable sites had already been surveyed – or, at least, this was that local paleoecologists told me. In addition, almost all Pyrenean lakes were of glacial origin and situated at high elevations. This would not be particularly bad, but most of these lakes had been dammed and/or drilled below for electricity generation since the beginning of the 20th century. Damming was not a major disturbance, as the sediments remained in the bottom, but underground drilling and deep water extraction had removed or deeply disturbed most lake sediments. In the local scientific environment, the feeling that everything that could be done was already done prevailed, and my project was met with skepticism. Some colleagues even told me that I would be unable to find anything new but only to confirm what is already known, at best. This is what I call the "all-done" paradigm. However, this did not discourage me.

3. Anticipation

In a previous geographical survey carried out when I still was in Veenezuela, I had identified two lakes with potentially undisturbed sediments: Montcortès and Sant Maurici. One of them, Lake Montcortès (42º 19′ 50″ N – 0º 59′ 41″ E; 1027 m elevation) (Figure 1) is a unique karstic lake that is rare in the Pyrenees. My interest on this lake was sparked by some exploratory limnological studies discussing about the potential meromictic character of the lake [2,3]. If this was true, then the lake would have varved (annually-laminated) sediments but, for my surprise, it had never been cored, despite its easy access by route. Upon my return to Spain, I started working at the Autonomous University of Barcelona (UAB) and founded a research team called PATAM (Tropical and High-Mountain Paleoecology) but still lacked the necessary equipment to core the lake. Therefore, I did a proposal for this to the research team on Quaternary Paleoenvironments and Global Change from the Pyrenean Institute of Ecology (IPE), belonging to the Spanish National Research Council (CSIC), led by Blas Valero-Garcés. He welcomed the idea and included the task in a peninsula-wide campaign of lake coring in collaboration with the Limnological Research Center (LRC) of the University of Minnesota (USA) [4]. We finally cored the lake in April 2004 (Figure 2) and obtained ~6 m of (varved!) sediments, which now we know that are an interrupted annually-resolved sequence encompassing the last 3000 years. With time, Montcortès sediments have been intensively cored and studied – with the funding of research projects led by the IPE and the Department of Ecology of the University of Barcelona (UB), under the leadership of Teresa Vegas-Vilarrúbia (TVV) – using a wide arrangement of proxies of diverse nature, and this varved record has become a type sequence that is unparalleled across the whole circum-Mediterranean region [5-16]. The finding of Lake Montcortès varved sediments was the result of a planned strategy based on incipient limnological knowledge, and hence, most – although not all, as we will see later – ensuing paleoecological and paleoenvironmental records obtained were further preceded by an anticipated idea.

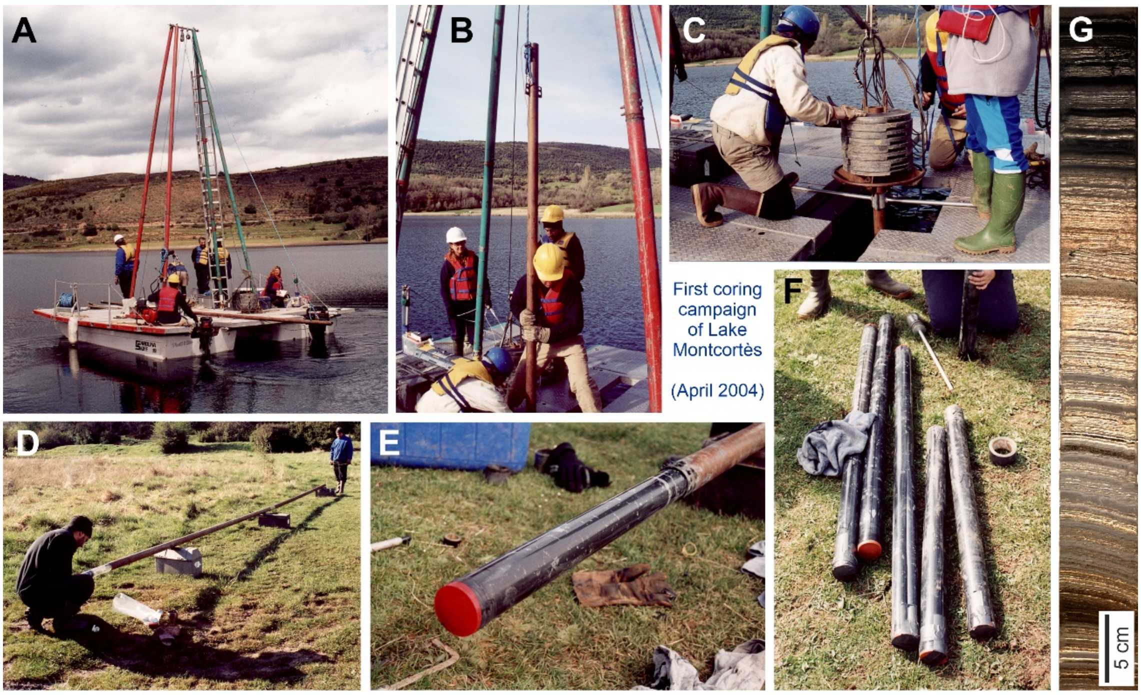

Figure 2. First coring campaign of Lake Montcortès in April 2004 using a Kullenberg platform and gravity corer. A) General view of the coring platform. B) Placing the corer in position. C) Loading the corer for maximum penetration. D) The corer with the sediment recovered inside. E) Extruding the core. F) The core once split for transportation. G) Image of core MON04-1 A-1K showing the seasonal laminations.

Lake Sant Maurici (42º 34′ 55″ N – 1º 00′ 16″ E; 1924 m elevation) (Figure 1) was also included in the same campaign, also to my request, but when we visited the lake in April 2004, it was unexpectedly frozen, which was unusual for the time. Therefore, we were unable to "unravel the secrets of the lake", as Doug Schnurrenberger, a member of the LRC coring crew said. This lake was dammed in 1953 and this raised the water level by ~15 m, which is the height of the dam [17], but it was not drilled underground, which suggested that its sediments could have remained intact (I should say that I had privileged first-hand information on this fact because my grandfather had been

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working on damming and drilling of Pyrenean lakes when I was a kid). Some local paleocologists told me that this was very unlikely, as most high-elevation lakes had been disturbed, and Sant Maurici was not an exception. This is why it remained uncored, despite its easy access – which was even more amazing than the case of Montcortès, which is less known – because Sant Maurici is the most iconic lake of a highly visited national park, called "Aigüestortes i Estany de Sant Maurici" (PNAESM). Roughly a decade after the first trial, we obtained a new research project, that time from the Autonomous Organization of National Parks (OAPN) and led by Jesús Julio Camarero (also from the IPE), and came back to Sant Maurici, together with the IPE and the PATAM-UB teams, for coring [18]. By that time, I was already in the Botanical Institute of Barcelona, also of the CSIC, where the PATAM headquarters was moved. After an initial (2013) fruitless trial, a second campaign (2014) was designed after identifying the deepest part of the lake, where the original smaller lake and its sediments must have remained "hidden" after damming (Figure 3). That time, the campaign was successful, and we retrieved a couple of cores containing a chronologically coherent Holocene sequence [19]. The occurrence of a large Middle-Holocene sedimentary gap, however, suggested that these cores would have been taken on a marginal position, where the sedimentation might have been interrupted by a prolonged water-level fall [20]. Now – with the funding of another OANP project led by TVV [21] – we are analyzing this possibility by locating the original lake using aerial photographs from before 1953 and modern pictures of the lake when it is periodically dried up for maintenance purposes. Indeed, when the dam is fully opened, the water level drops by approximately 15 m, and a modern version of what once was the original ~3-m deep lake comes to light (Figure 3). This can also be considered a case of anticipated paleoecological findings.

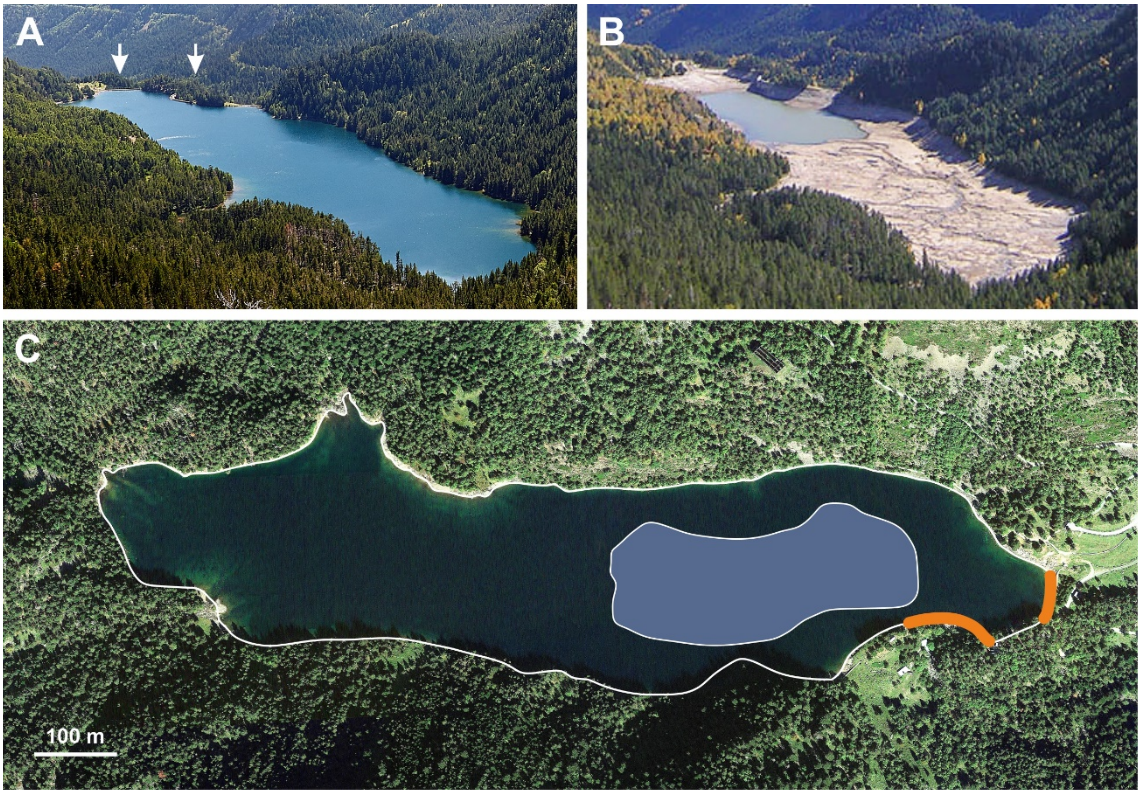

Figure 3. Lake Sant Maurici before and after damming. A) The lake in summer 2018, close to its full capacity. B) The lake in autumn 2011, when it was emptied for maintenance purposes. C) Google-Earth image of the lake indicating the location of the original glacial lake (blue area), as inferred from old aerial photographs [22]. The damming areas are marked by orange lines. Photos: V. Rull.

4. Discovery

The third case is from a pond called Bassa Nera (42º 38′ 05″ – 0º 55′ 27″ E; 1891 m elevation) (Figure 1), not far from Lake Sant Maurici, where blind research led to a discovery. We found this

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pond during an exploratory survey of the group PATAM, in 2007, funded by the Institute of Catalan Studies (IEC), in the search for uncored localities on the Pyrenean highlands. The site seemed particularly well suited to record past treeline fluctuations, as it was situated slightly below the present upper forest boundary (2200-2300 m). However, we have no previous expectations regarding the age and other specific features of the sediments. The site had already been visited in a former UAB fieldwork campaign [23] but, as in the cases of Montcortès and Sant Maurici, it remained uncored, despite a mountain track route where heavy vehicles can circulate is just ~150 m away. By that time, we had already acquired a Russian borer (which we used to call Natasha) and performed a first coring in the peat bog situated at the margin of the pond (Figure 4). As mentioned above, we have no particular hypothesis or research target. We obtained ~7 m of lake sediments and peat typical from an infilling lake sequence in its later stages [24,25]. The oldest radiocarbon date obtained was ~7000 yr BP, but the basement rock was not reached, which suggested the presence of older sediments. We decided to analyze the obtained sediments and come back to the site in the future with a piston corer to drill the central part of the pond, which was the deepest part of the basin. In the meantime, another team, encouraged by our findings, obtained an older record encompassing the last 10,000 years, also in the marginal peat bog [25]. We came back to Bassa Nera in 2014, together with researchers from the Open University (UK) and the funding of the OAPN and the IEC and, using a Livingstone corer, we obtained an 11-m depth sequence in the center of the pond, encompassing the last 15,000 years. To our surprise, this record contained the only complete and continuous high-resolution Lateglacial sequence available for the Iberian Pyrenees. This sequence is now under study – with the funding of the abovementioned OAPN research project led by TVV – and is potentially a standard stratigraphic sequence that could be useful for correlation and dating purposes at a regional Pyrenean level [26]. This finding came from blind coring and may thus be considered an unexpected discovery.

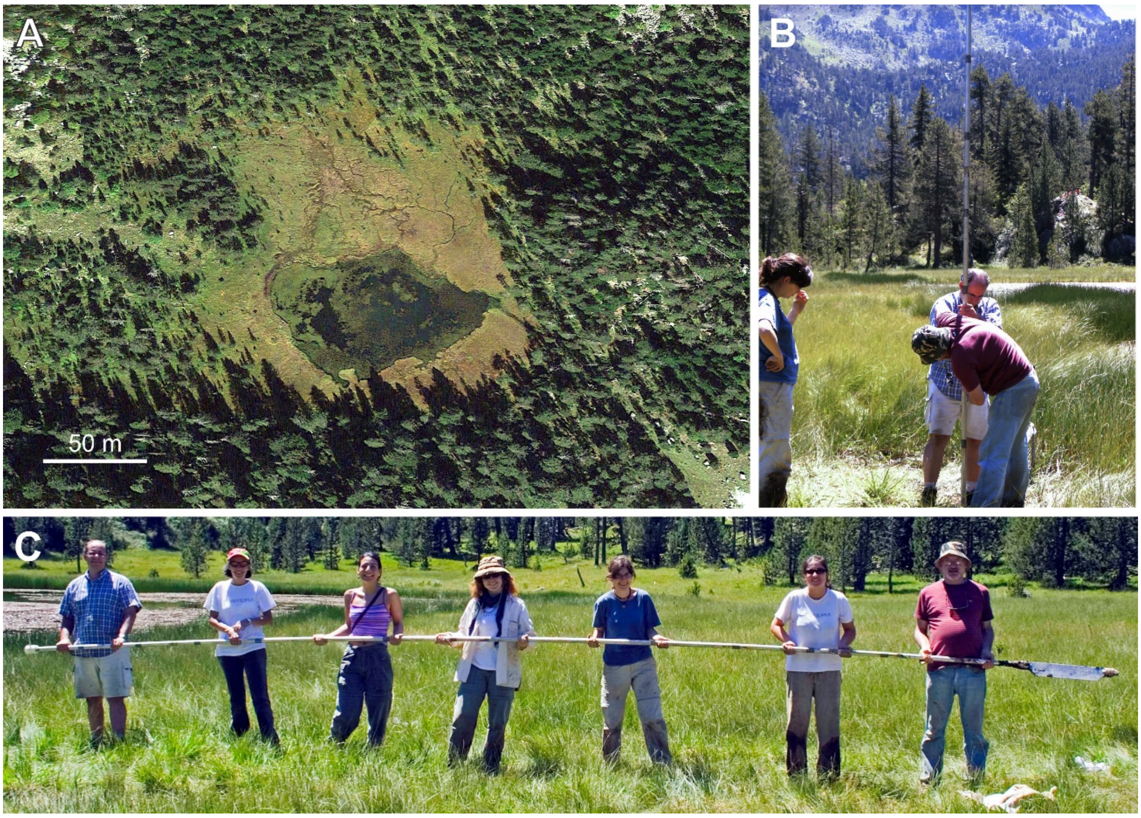

Figure 4. Coring the Bassa Nera with the Russian corer Natasha, in 2007. A) Google-Earth image of the Pletiu dera Muntanheta with the Bassa Nera inside. B) Coring at the margin of the pond. C) Members of the PATAM group showing the maximum coring length (7 m); from left to right: Riker Yll (a collaborator), Teresa Vegas-Vilarrúbia, Arantza Lara, Sandra Nogué, Núria Cañellas, Encarni Montoya and Valentí Rull. Photos by O. Huber.

5. Serendipity

Serendipity also emerged from the Lake Montcortès record. As quoted above, the finding of annually-laminated sediments had already been anticipated, but another significant outcome came out of the blue. The first pollen analyses, developed on the initial radiocarbon-dated cores retrieved (Figure 2), were of low resolution (centennial) and revealed the continuous presence of *Cannabis* pollen along the last millennium, with a conspicuous peak in the 19th century [27,28]. Further coring campaigns led by TVV and funded by the Ministry of Science, together with the development of an updated precise annual chronology based on varve counting performed by Pablo Corella (IPE-CSIC), allowed the generation of a high-resolution *Cannabis* pollen record, which is also unique to the Iberian Peninsula [29]. The comparison of this record with historical documents has provided insights into the history of hemp cultivation and retting at subdecadal resolution, unraveling previously unknown events. Among them, a relevant finding was the long and uninterrupted history of hemp retting activities in the lake between the 16th and 19th centuries, coeval with the development of the Royal Navy – the main consumer of hemp fiber for the fabrication of sails and cordage – during the worldwide expansion of the Spanish Empire. Once this observation came to light by serendipity, a planned research ruled and sponsored by the same researchers and funders mentioned above, with the collaboration of bacterial geneticists from the University of Girona, was able to identify the RNA from retting bacteria in the sediments, which confirmed that large-scale hemp retting was actually carried out in Montcortès during the entire Modern Age [30].

6. Discussion and final remarks

The examples provided here illustrate three types of paleoecological performance that are typical in many research ventures of this type and provide us with some insights into this particular scientific activity. Quaternary paleoecology is not merely a blind activity aimed at coring everything to find sediments as old as possible, but a scientific approach where hypothesis testing is possible. The difference with the so called experimental sciences is that, in paleoecology, controlled experiments where one or few variables can be isolated and tested separately are not possible, and explanations for the observed phenomena should be approached by finding the suitable evidence contained in the corresponding paleoecological archives. Blind paleoecology is the only option in previously unstudied regions, and in these conditions, any new finding is a discovery. However, as knowledge progresses, it is possible to devise a set of possible explanations for the observed phenomena and concentrate efforts on finding of appropriate evidence to test the available hypotheses. Methodological advances, such as the current rise of molecular biomarker research, contribute to expanding not only the possibility of new findings but also of conceiving novel explanations.

Another message is that, even in relatively well known areas, the finding of new unexpected observations may open previously unsuspected possibilities, in what is called here serendipity. In the case of Lake Montcortès, the finding of cannabis pollen was complementary to what was already known, but in other cases, serendipitous findings might change the course of the investigation and lead to paradigm shifting. For this to be possible, it is necessary to maintain an open mind and take advantage of any departure of the new evidence found from the established paradigms. Ignoring the challenging evidence or trying to force it to fit with the accepted schemes is against the scientific spirit and may lead to the perpetuation of flawed theories rather than to the progress of knowledge. Conversely, the obsession for breakthrough ideas may foster overinterpretation of the evidence – also known as overselling and not unusual in highly-rated generalist scientific publications – which is equally dangerous, as it slows science advance or, what is worst, it may corrupt knowledge itself by creating false “truths” and unwarranted research directions that, sooner or later, will have to be readdressed.

Finally, the examples presented here demonstrate that the “all-done” paradigm is false, even in areas that have been studied for decades from a paleoecological point of view, as is the case of the Pyrenees. This paradigm is clearly dogmatic, and hence, unscientific. Dogmatic knowledge propagation was practiced in antiquity but was abandoned long ago with the emergence of modern science based on empirical evidence, rather than on the opinion of purported scientific authorities who feel entitled to guide the destinies of local science. Fortunately, not only discovery and serendipity but also creativity and the generation of novel ideas on old problems are still possible everywhere, even in "old Europe", using evidence-based scientific procedures.

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