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From Archaeological Evidence for Agricultural Manuring to an Understanding of Settlement and Landscape Dynamics –

An Experiment in Non-invasive Archaeological Methods Undertaken in South-West France

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Abstract

Manuring is a farming practice which produces archaeological traces. Indeed, the introduction of waste into manure heaps has resulted in the spreading of broken pottery across manured plots. The interpretation of off-site find scatters as remains of manuring is based both on ancient texts and archaeological evidence. The chronological and spatial analysis of these scatters allows us to estimate the stability and durability of agrarian occupation.

Today, small GPS devices incorporated in low-cost smart phones enable us to map intra-plot densities for an estimate of the overall trend of occupation which does not necessarily discriminate between site and off-site, but is useful to discuss such a discrimination when necessary.

However, a sound appreciation of buried structures and the impact of past human activities on the landscape can only be reached by a combination of different non-invasive methods.

The REPERAGE project developed in the Garonne Valley near Toulouse (in south-western France) aims at developing a global non-invasive archaeological strategy combining high resolution mapping of fieldwalking artefacts, low altitude aerial surveys using drones' on-board multispectral and Lidar sensors, and geophysical surveys (GPR, magnetometer). The objective is to obtain a high level of information about diachronic settlement systems and dynamics, and their relationships with the natural environment.

Introduction

Off-site material collected by fieldwalking surveys has long been considered a sort of 'background noise', an impediment to the detection of sites. In the last forty years, the extension of archaeologists' interest from sites to wider territories has led to a reconsideration of such off-site material, and its use as a marker for formerly cultivated areas¹.

1. Archaeological evidence for manuring in agriculture

While the presence of off-site material is clearly discernible, its interpretation as the product of manuring practices is based on an initial assumption that the spreading of livestock manure collected in barns was actually employed in past periods. To confirm this hypothesis, we will first focus on the identification of written and iconographic sources attesting an ancient practice of manuring. Most of the Roman authorities on agriculture recommended the use of manure to improve the quality of the soil². These texts and recommendations on the use of manure were compiled and passed on by the agronomic literature of the Middle Ages from the 13th century onwards. As early as the Carolingian period, the 'Capitulare de Villis' had advised farmers to spread not only manure, but also the remaining waste produced by their farms³. Medieval iconography also attests to the practice of manuring⁴. The *Rustican* contains an agricultural calendar illustrating this practice for the month of February: two men are spreading manure in an enclosed field where many other piles have been already dispersed⁵.

The second assumption is that domestic waste, including sherds of pottery, could actually be incorporated into the manure, whether deliberately or not. These sherds and fragments of building materials were mixed with other waste on manure piles (which were usually located near the settlement), and then spread across the fields alongside the organic material. Only the former would have survived once the organic matter had decomposed. This assumption is supported by a number of sources confirming the incorporation of household waste, including the sherds of broken pottery, in the manure spread:

- the proximity between houses and stables or manure pits,
- the recommendation of this incorporation by agronomists,
- and the confirmation of this practice by archaeological sources, geochemical observations and archival texts.

Considering all of these arguments, we can conclude that the off-site material collected during fieldwalking surveys may indeed reflect the location of intensively cultivated areas. Research in this direction has permitted us to move on from viewing surveys only as a tool for the discovery of settlement sites, to using it as a means of understanding landscape as a continuous space, where 'off-site' material can mark the influence of settlements on the surrounding area. However, the location of areas improved by manuring will only provide a minimum estimate of the effectively exploited area.

Of course, the absence of off-site material does not allow the reverse conclusion that the areas in question were not cultivated, but may open up a range of further possible explanations which may not allow a choice at this point.

2. Arkeotracker, a high-resolution geolocation tool for fieldwalking

2.1. The demand for a tool

The traditional method of examining a rural area is to survey it through a dense mesh of prospectors collecting visible artefacts from its surface. The identification of a site will occur when an abnormal concentration of artefacts is observed. At this point, it is possible to expand the method in order to try to delineate the contours of the site and estimate the intensity of the occupation. In most cases, it is only at this stage that the question of 'fine spatialization' of the remains comes into play⁶. This spatialization can be done by recording the objects according to pre-defined grid tiles, sampling the remains on transects⁷, or by systematically pin-pointing the remains through the use of a total station or GPS. The arrival of GPS has significantly improved our capabilities for recording and the speed of their implementation⁸. This employment, however, is limited to site registration and analysis. Systematic georeferencing of the data collected outside the sites has been attempted, but remains experimental, due not only to the technical complexity it induces, but also to its low profitability when we consider the time spent on the documented surface⁹.

In order to overcome this barrier, it was necessary to develop a method which could address several constraints.

- Economy of time expenditure: The conventional use of a GPS employs *a posteriori* positioning of objects marked on the surface of the ground. While this method provides the advantage of accuracy, it is excessively expensive in time. It is hard to envisage its use outside confined sites on extensive plots where the sampling of material may result in the discovery of several hundred to several thousand artefacts per collection unit. The only solution to this problem would appear to be the immediate recording of information at the time of discovery.

- Accuracy and error probability in measurement: As E. Bannings pointed out¹⁰, there are many factors which can interfere with the measurement of an occupation area by a survey. These include human factors (inexperience or unequal experience within a team of prospectors), climatic influences (on the visibility of the vestiges) or specifics related to the nature of the sites (representativity of a set of artefacts). Taking the above factors into account in order to improve the detection and evaluating capacity for the discovered remains was another objective of our work.

- Cost-efficiency: As surveys are usually carried out within the framework of universities and non-profit archaeology, it was necessary to develop a technique which could be supported by a conventional research team both in Europe and, as far as possible, in countries on a lower economic level.

- Ease of use: The last major constraint which was addressed by the project was complexity. With an emphasis on simplicity, a non-specialized student had to be able to take charge and implement our method with a training reduced to a few minutes.

This was the framework within which we developed a smart phone application dedicated to assisting fieldwalking surveys. The idea was to take advantage of both the general availability of smart phones and the integration of GPS devices in the former which provide sufficient precision for the given objective.

2.2. The concept of the application

Our dedicated application, called Archeotracker¹¹, contains the essential code of an open source application developed by O. Guillaumin as part of the Open Street Map project¹². The initial application, OSMTracker has been adapted for archaeological use by Emile Hautefeuille.

Its operating principle is very simple. Each prospector must be equipped with a telephone using Android OS, on which the application was previously installed. The phone is worn on the arm in a waterproof case.

The application works without network contact, and it is recommended to set the phone to airplane mode in order to save energy.

Managing the collected data is simple. The application allows a prospector to record both his tracks and the artefacts he has observed and collected at the same time. Once a zone to be surveyed has been defined, the prospector starts a track which can be named with a dedicated registration code.

As soon as the track is opened, the application strictly records all the movements of the prospector at the rate of one point every second. This makes it possible to measure the speed of movement, and thereby the thoroughness of his collecting. When the track is opened, the application presents a simple interface which enables the prospector to record the artefacts according to major categories. Thus, when a pottery sherd is found, pressing the appropriate button of the screen makes it possible to record its location with a margin of error ranging from 2 to 5 m, depending on the GPS chip model fitted to the smart phone.

As it is theoretically possible to identify each artefact with its own registration number, the emphasis here is to register the objects according to major categories. And as the survey is carried out in parallel strips in the conventional manner, each prospector can be equipped with the tool. Recording is limited to simply pressing the screen of the phone; the operation has no impact in terms of time. It is also possible to add a written note to comment on a given object.

When the survey line is completed, the recording mode is put on hold, to resume at the start of the next line. When a site is discovered, it is of course possible to record it on a specific track file which has its own registration code. Whatever the method used, it is then possible to geolocate the set of objects attached to the site. Each prospector can observe the spatial distribution of his discoveries in real time. This allows him to review places he has already passed through in a

random search of artefacts within a site. The tool can also be used to correct a trajectory when the gaps between prospectors are relevant.

Once a site has been prospected, it is possible to return to the prospecting zone file and resume the original line at the point where it was left.

When a day of surveying is completed, it is only a minor effort to retrieve the data for aggregation on a GIS. The GPS tracks recorded in each phone can be transmitted via Bluetooth connection to the team leader's phone. It can then merge the traces of the day into a single file, exportable in GPX format for use under GIS. Below, we will demonstrate how this data can be used to refine the interpretation of the results.

2.3. The main factors of input

2.3.1 Validity of the corpus of measured data

As the registration of artefacts relies on students with variable field experience, our first observation concerning the results generated by the application is that our operating choices are, by and large, relevant.

When we consider the 124 collection units which benefited from the use of this application in 2015 and 2016, we can observe a good match between the total number of artefacts registered via the application and the count of the collected objects at the end of the field (Fig. 1). Indeed, over 75 % of the collection units display a difference of less than 25 % of this total number of artefacts, and nearly 90 % of collection units have a difference of less than 50 %. These observations are generally reassuring with regard to the users' handling of the application. The few deviations observed probably correspond to involuntary "clicks" related to the tactile character of the interface.

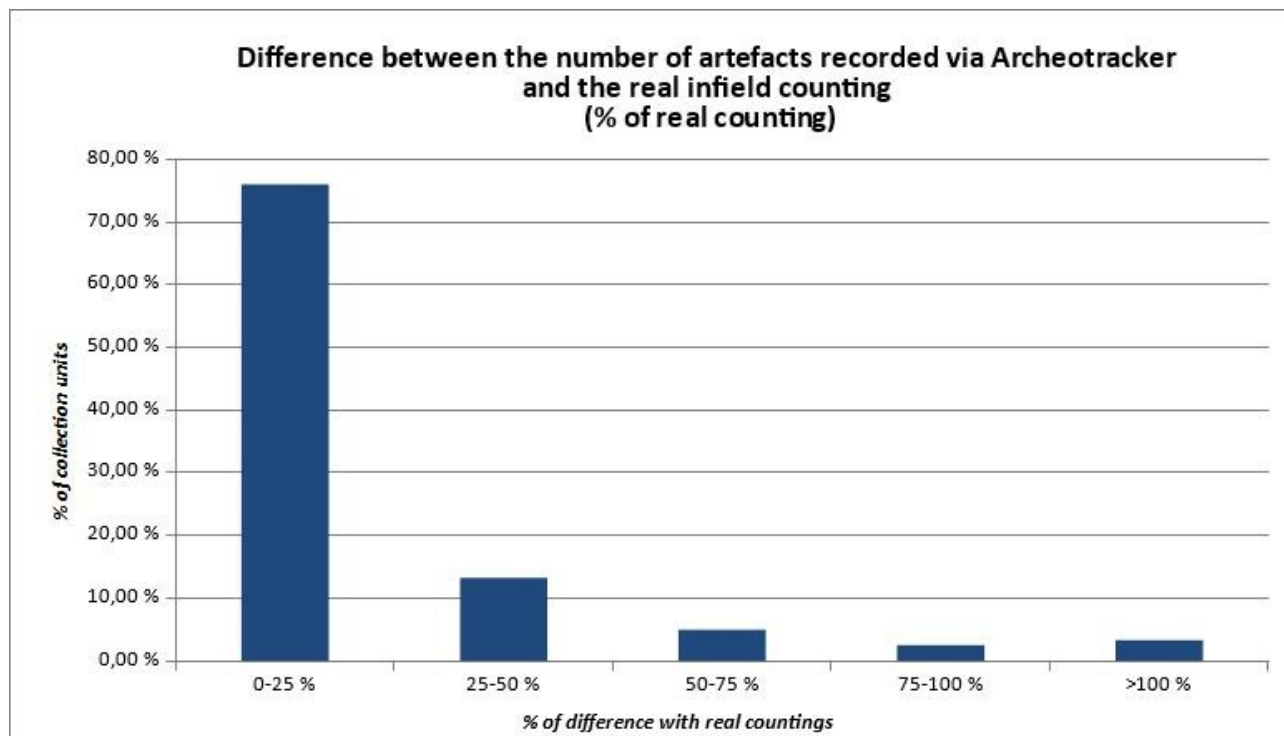


Fig. 1 Difference between the number of artefacts recorded via Archeotracker and actual in-field counting.

2.3.2. Accuracy in the identification of sites

The procedure which we followed in our field operations testing the feasibility of using the Archeotracker application consisted of a combination of the traditional method of delimiting sites by visual recognition of the material concentration and a systematic geolocation of the characteristic vestiges of the concentrations. The objective was to compare the approximate delimitation which is generally achieved with the measurable area of concentration suggested by the individual location of the vestiges. A good match between the visually estimated areas and those that can be restored through the cloud of points can be discerned (Fig. 2).

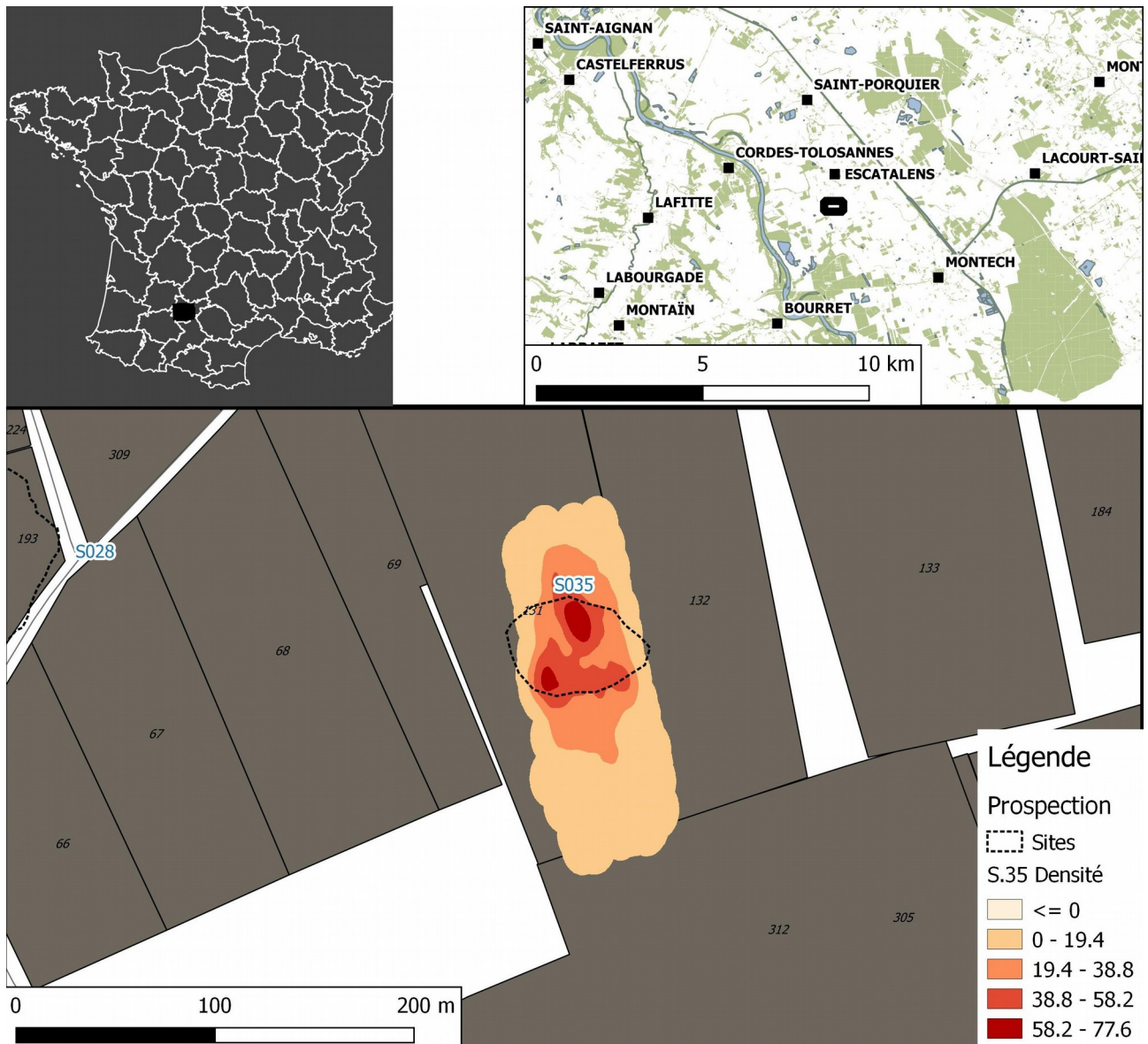


Fig. 2 Comparison between the field concentration control (black dotted lines) and the density map generated from Archeotracker data.

2.3.3. A posteriori identification of sites

The individual location of the vestiges present in the topsoil and their spatial representation in the form of density maps can lead to the identification of certain particular concentrations of material which have not been identified in the field (Fig. 3). The identification of these anomalies in the distribution of off-site scatters should normally prompt a return to the field for a verification of these anomalies. However, it should be recalled that the concentration criterion is not the only one to be taken into account in the identification of a site index. The composition (in particular with regard to chronology) of the material which makes up the concentration must also be appreciated, since "artificial" concentrations of material of various origins may well have been generated by post-depositional phenomena (erosion of slopes, accumulation of alluvial material) or be foreign to

the history of the actual land use (e.g. resulting from the transport of material from one place to another).

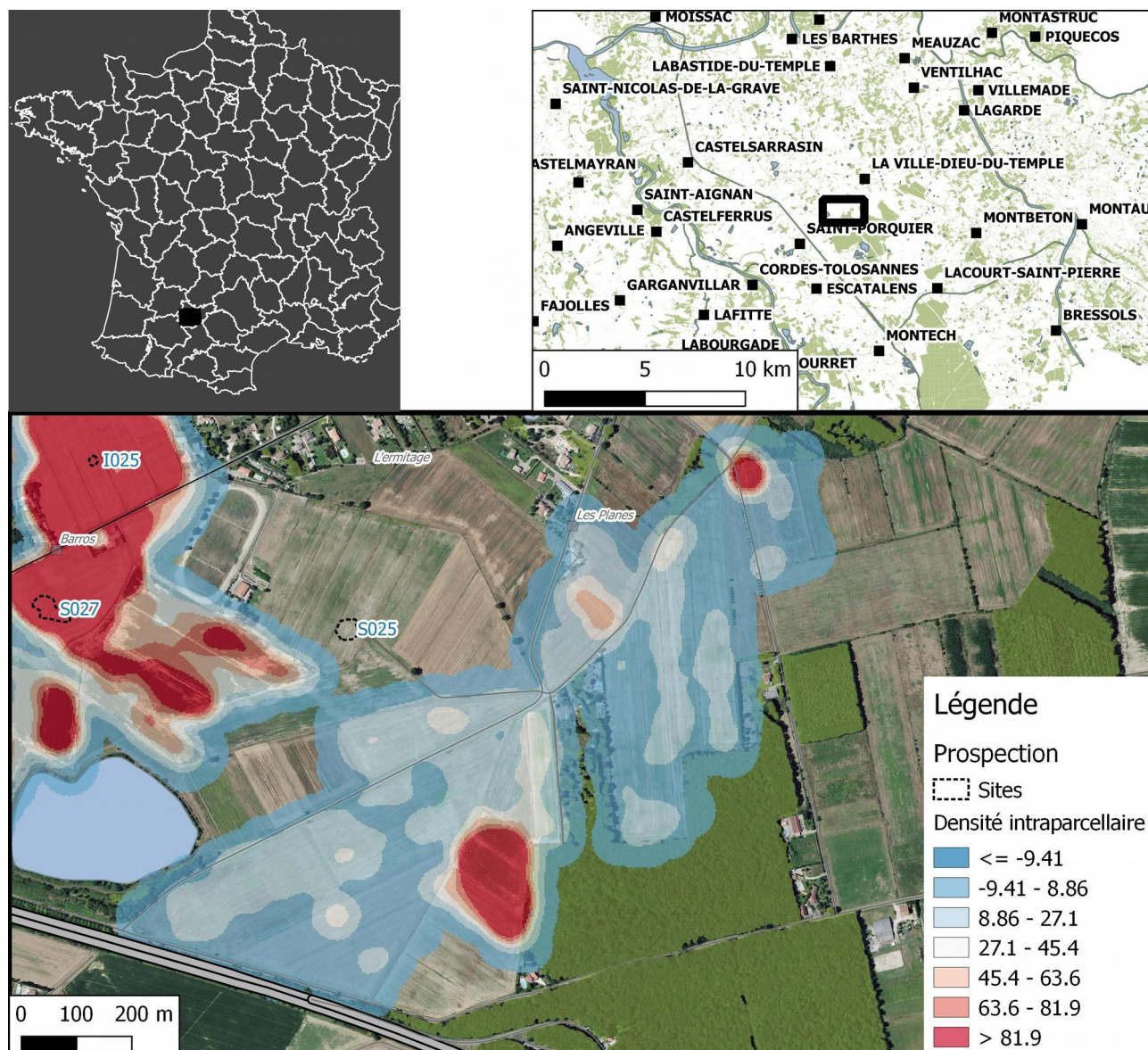


Fig. 3 A posteriori identification of potential sites.

2.3.4. Multiscalar approach: possibility of spatial analysis at the scale of a landscape

The analysis of the occupation dynamics of a rural area relies on the processes underlying the installation and abandonment of settlements as well as on the measurement of the ways of exploiting the surrounding territory. While the modelling of disruption or continuity as a tool of analysis has become a classic, the measurement of the links to unmanaged territory remains a much more complex affair. In France, the considerable advances made in preventive archaeology over the past thirty years have, moreover, provided little progress in this field. Field archaeology remains marginal. However, the possibility of localizing each and every artefact collected on the

surface opens the way to a mapping of the densities of off-site material at the intra-plot scale. This approach makes it possible to go beyond the mapping of the density of vestiges generally carried out by parcel (or fragment of a parcel, i.e. the Collecting Units) of a size generally between 2 and 5 ha. It is possible to analyse the distribution of this material with a high spatial resolution. Generally interpreted as the archaeological trace of manure spreading¹³, this off-site material makes it possible to establish a link between the sites and the landscape by recording the gradient in the intensity of agrarian investment in the landscape over time. A finer interpretation of the distribution and the modalities in variation of this gradient was hitherto limited by the heterogeneity in the size of the collection units. Spatial analyses based on the individual location of the remains in Archeotracker now enable us to generate density maps with a spatial resolution of a few square meters. This is particularly helpful when reviewing the archaeological sites identified - but also of the current habitats - in a wider context of land development. In cases where a high stability of settlement exists, the date of establishment for the current occupation can be inferred by dating the halo of off-site material surrounding it.

3. The combination of non-invasive methods in the REPERAGE project

The programme described above was developed as part of a project to study the settlement dynamics of the central valley of the Garonne in the south-west of France. This project, entitled REPERAGE, aims to study the processes of human settlement of the river valley and the lower terraces of the Garonne, through the use of, among other methods, systematic prospecting campaigns (Fig. 4).

Following the planned route of a railway track, it aims at developing a comprehensive, non-invasive archaeological strategy which combines high resolution mapping of fieldwalking artefacts, low altitude aerial surveys using unmanned aerial vehicles on-board multispectral and Lidar sensors, and geophysical surveys (GPR, magnetometer). The objective is to obtain a high level of non-invasive knowledge on diachronic settlement systems and dynamics, relationships between past human societies and the natural environment, preceding the implementation of the actual field operations of rescue archaeology.

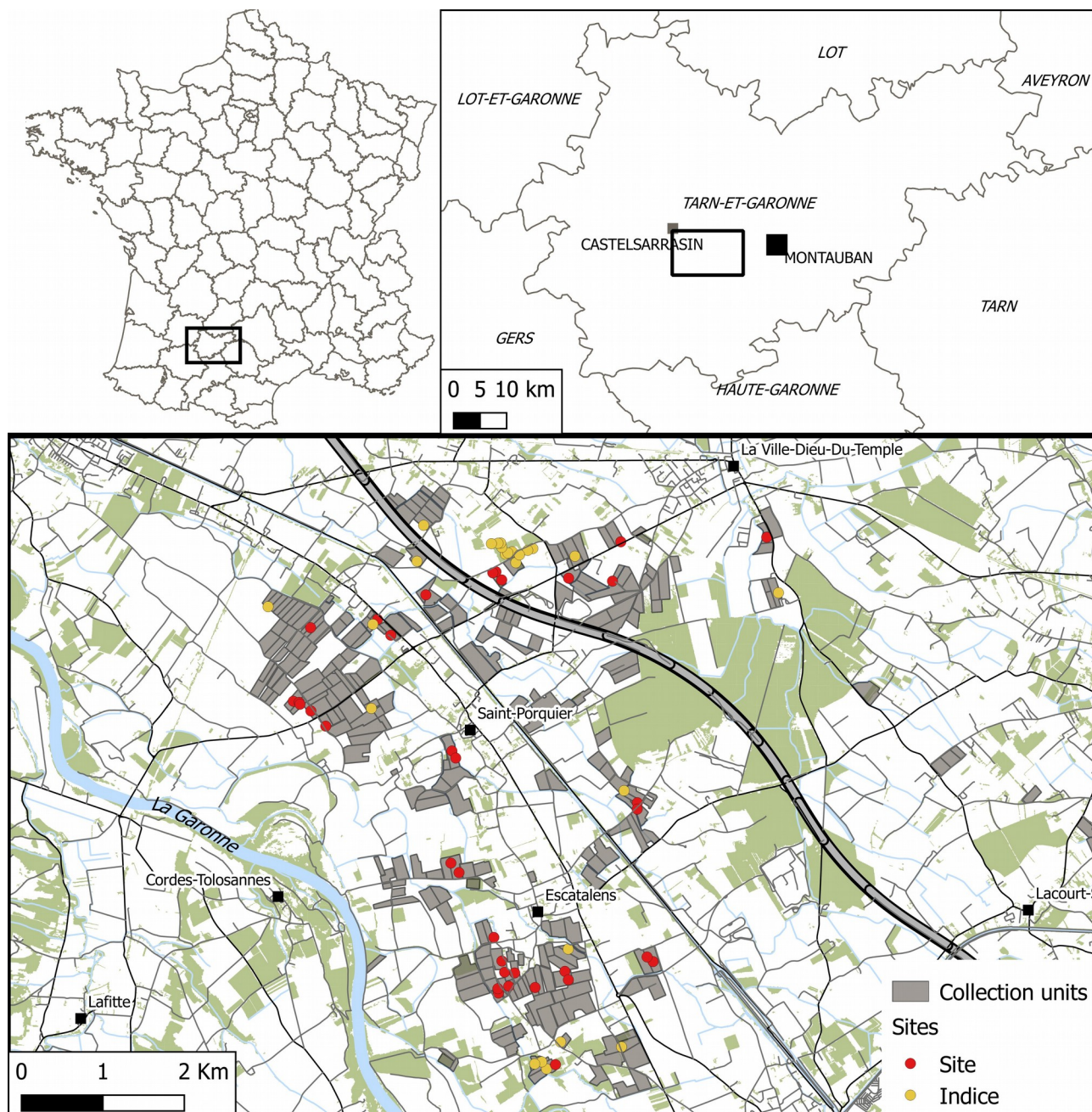


Fig. 4 Location of the study area.

The main historical and archaeological questions of this study are related to the main issues of the medieval period in the South-West of France, and (more specifically) concern the nature of ancient and late-antiquity occupation as well as the establishment of the settlement centres in the Early Middle Ages, the articulation between nucleated and dispersed settlement in the Middle Ages and the medieval organisation of the territory.

3.1. Systematic fieldwalking

Since 2014, systematic fieldwalking surveys have covered nearly 650 hectares, most of which lie in the immediate vicinity of the future railway track. These surveys permitted the discovery of about 40 concentrations of surface material which indicate potential archaeological sites dating from Prehistory to the present day (Fig. 5). They have also allowed the collection of nearly 60 000 off-site artefacts, including 15 000 shards of pottery, the only material remnants of manure spreading from Protohistory. The study of the ceramic material is still under way, but the major trends in land use dynamics are in line with the models generally established for France. Sedentary occupation is identifiable from the end of the Bronze Age and during the Iron Age; it expanded and intensified markedly during the Roman period before decreasing slightly during the Middle Ages and the modern period. It must be borne in mind, however, that we have access only to these occupation periods, and that the medieval and modern sites which are still occupied today cannot be taken into account in these calculations. The challenge in our work lies precisely in specifying the establishment dates of these current occupations by observing the halo of off-site scatters which can be detected around them.

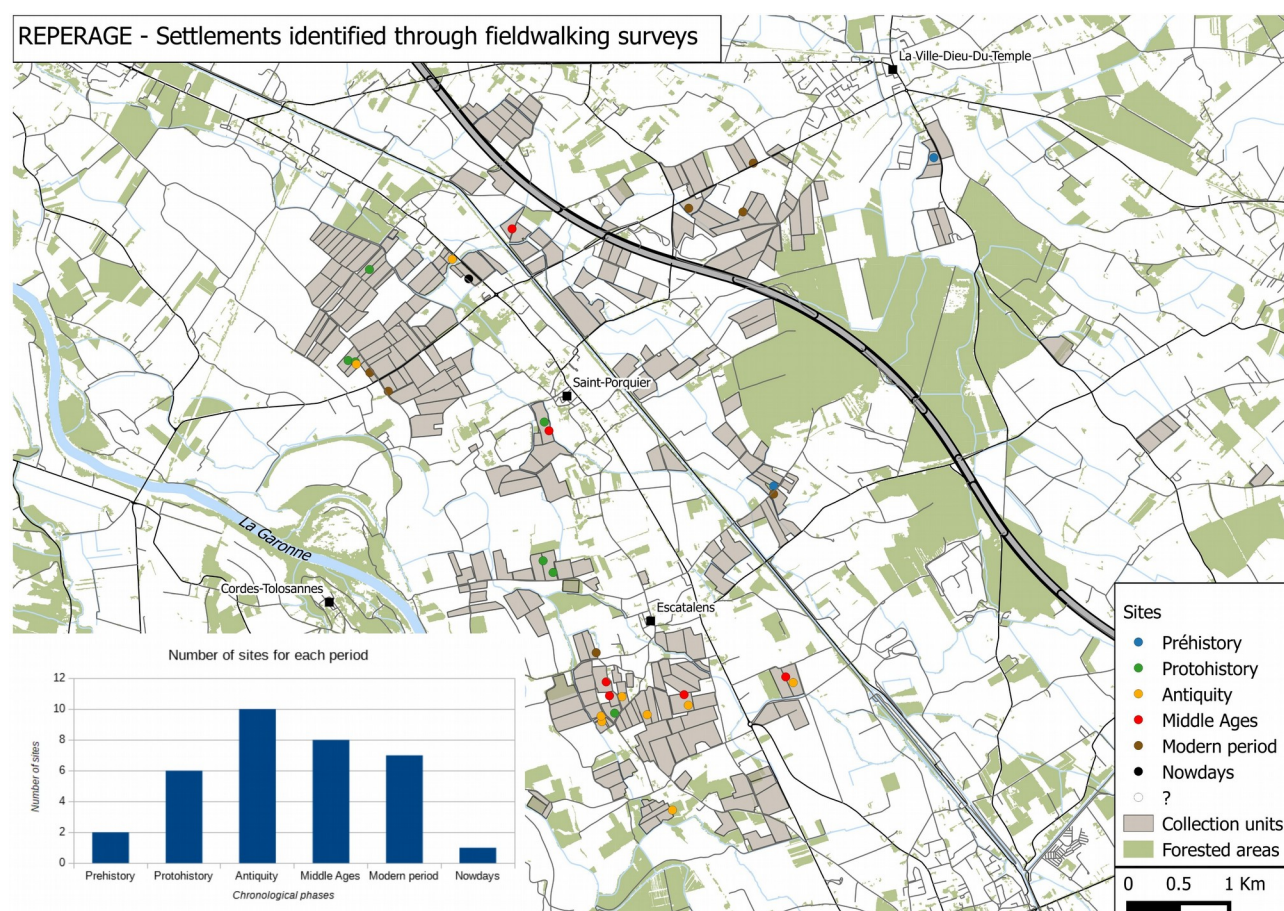


Fig. 5 Map and graph of settlements identified through fieldwalking surveys.

3.2. Ground Penetrating Radar (GPR)

At the site of Notre-Dame-de-Baude, located in the town of Labastide-du-Temple in our study area, indications that the parish church had existed prior to the founding of the Templars had been identified by F. Hautefeuille in modern written documentation during the 1990s.

It is likely that the building was located on the site of a Gallo-Roman *villa*, a mosaic of which had been excavated in the 1950s.

A systematic fieldwalking survey of the plot using the Archeotracker application confirmed the presence of a concentration of vestiges from the ancient and medieval periods.

The GPR prospecting of the concentration zone revealed both the ground plan of the ancient buildings and the subsequent establishment of a church on the masonry foundations of the former¹⁴.

3.3. Magnetic surveys

The use of a GSM-19 magnetometer, generally reserved for the coverage of sites of exceptional interest, was tested on concentrations of surface features, with the aim of specifying the location and nature of any buried vestiges. The two site indices tested, which dated from the Roman period, each revealed the presence of a strong magnetic anomaly in the subsoil testifying to the probable presence of buried structures or buried masses of metal (Fig. 6). On the other hand, we are somewhat disappointed that we have not been able to map more accurately any structures (masonry, ditches). Nevertheless, the use of this methodology at least validates the existence of buried vestiges at the location of the concentrations detected on the surface, and this in a completely non-invasive way.

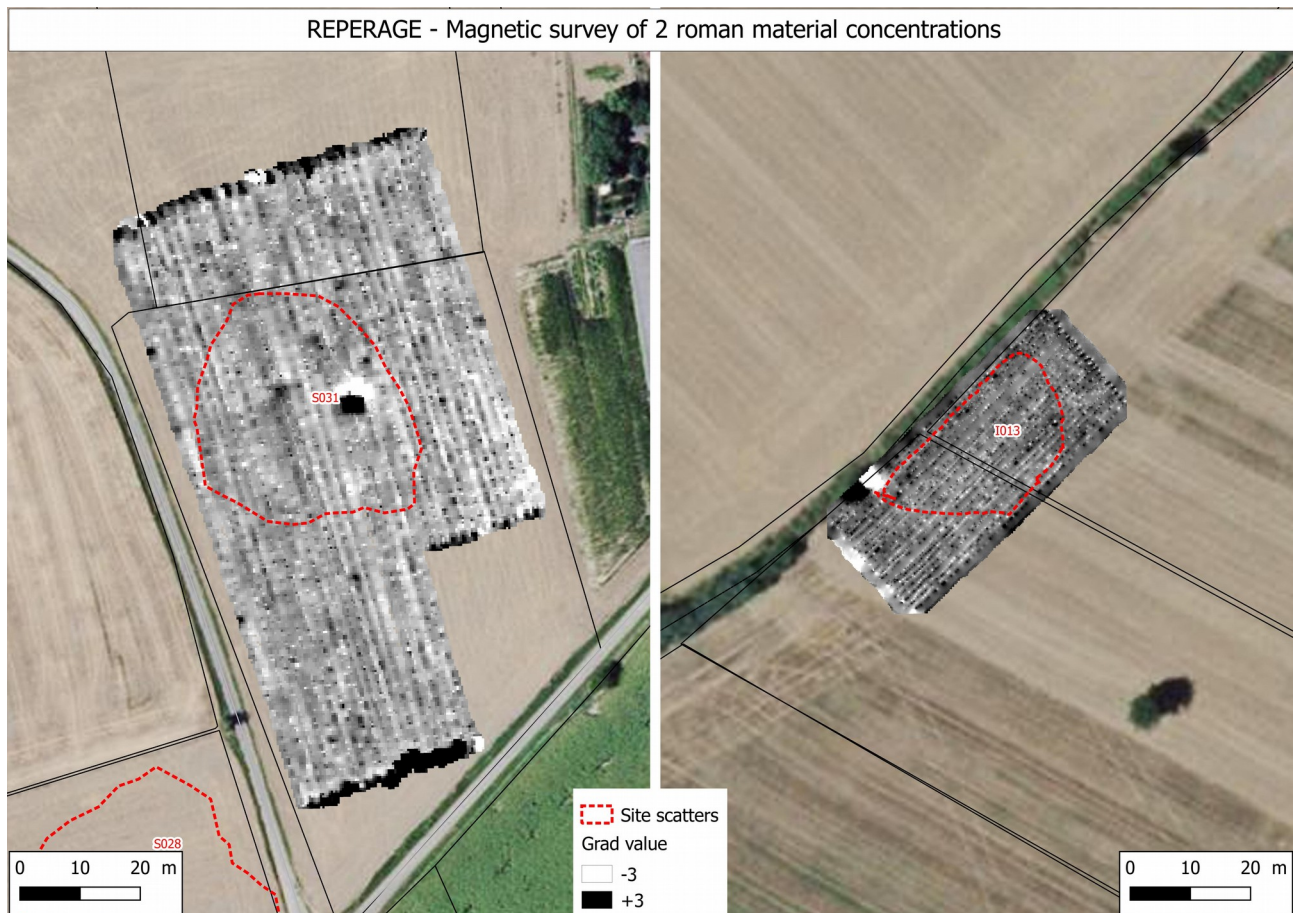


Fig. 6 Magnetic survey of two Roman material concentrations.

3.4. Drone overflights

In a similar way, we have used the resources of drones carrying different sensors relevant for archaeology during the last four years.

3.4.1. Infrared/Multispectral sensors

First of all, we developed the use of a thermal imager embedded in an octorotor drone (octocopter). On bare soil, the objective is to detect anomalies of the surface temperature of the plots produced by the thermal inertia of the buried remains. Obviously, buried masonry or ditches do not react to changes in temperature at the same rate as the sediment that contains them. On cultivated soil, the infrared reflectance of plants growing above buried vestiges will be different from that of plants growing under normal conditions. The validity of this procedure was first tested on concentrations of Modern Era features identified by pedestrian prospecting whose existence was confirmed by the Napoleonic cadastre¹⁵. Then, an overview of concentrations of antique and medieval features made it possible to identify infrared reflectance anomalies. The site of Notre-Dame-de-Baude, which we have already mentioned, also allowed the identification of thermal anomalies at the location of the concentration of surface features and the structures identified by

the GPR (Fig. 7). Our objective is to increase the number of flights over the same sites, varying the conditions of intervention (soil cover, temperature, humidity), so as to define a reference frame which is as precise as possible regarding the conditions favourable to the identification of Reflectance anomalies. To develop this approach, we equipped ourselves with a fixed wing drone equipped with a multispectral sensor (5 bands) capable of a greater autonomy. The truly multispectral character of the sensor allows us to develop an authentic remote sensing approach similar to that used with satellite images, including the calculation of vegetation indices and the possibility of automating the detection of reflectance anomalies.

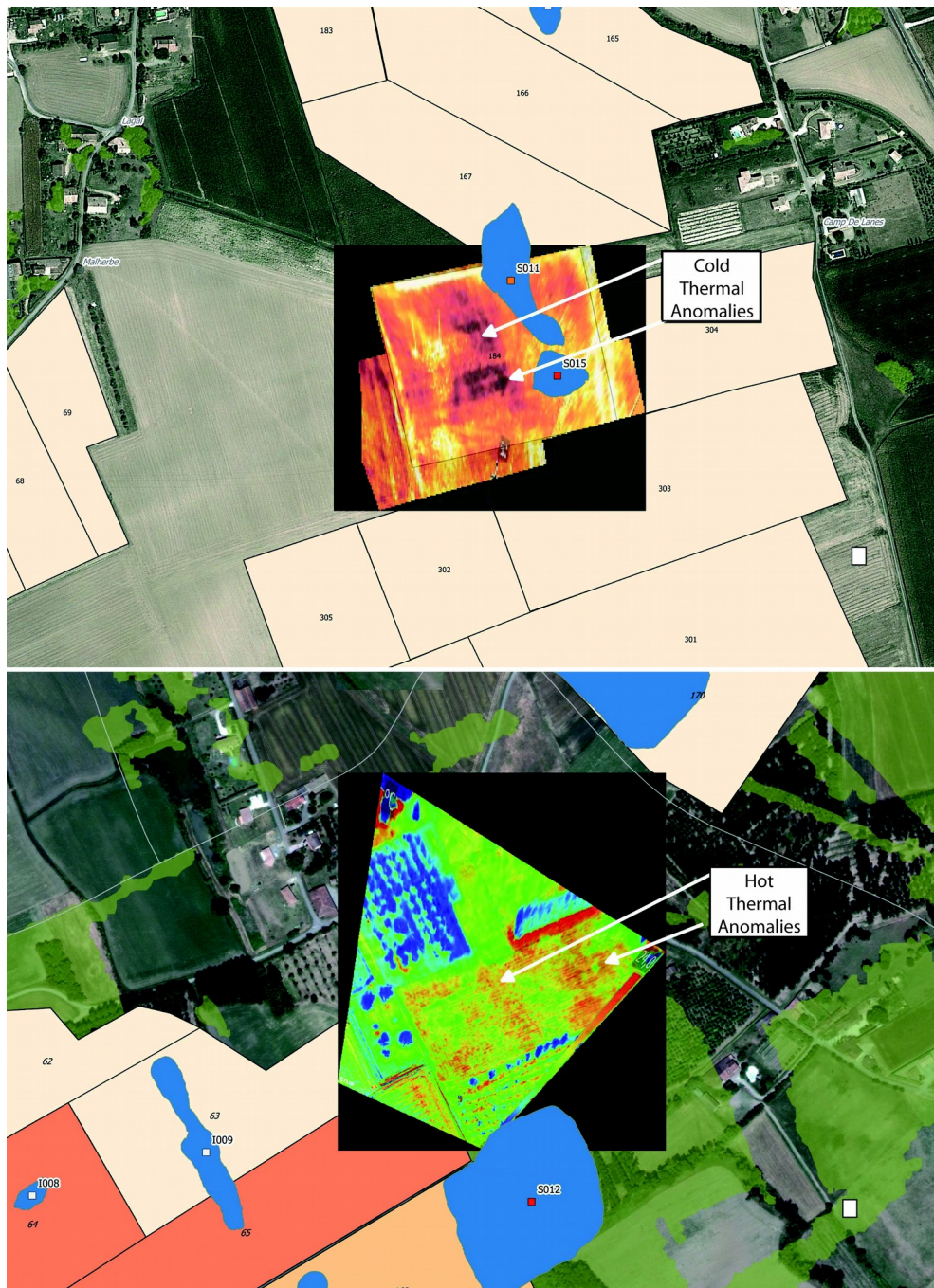


Fig. 7 Infrared anomalies.

3.4.2. Lidar sensor

We also used an opportunity to acquire a multi-rotor drone equipped with a miniaturized Lidar sensor. This equipment makes it possible to document the small forested areas generally not covered by traditional Lidar examinations for reasons of cost (Fig. 8). Indeed, the fixed costs associated with getting the Lidar airborne in an airplane or a helicopter explain why only forested heights of a certain size are affected by Lidar examination. In our case, even if the Lidar sensor is less powerful than a conventional Lidar, lowering the flight altitude to 50 meters can result in a point density equivalent to or better than a conventional Lidar (up to 20 or 30 points per square meter under good conditions). Above all, the flexibility in using the drone makes it possible not only to choose the optimal moment for the overflight but also to repeat overflights over the same sites in order to intensify the coverage of the area.

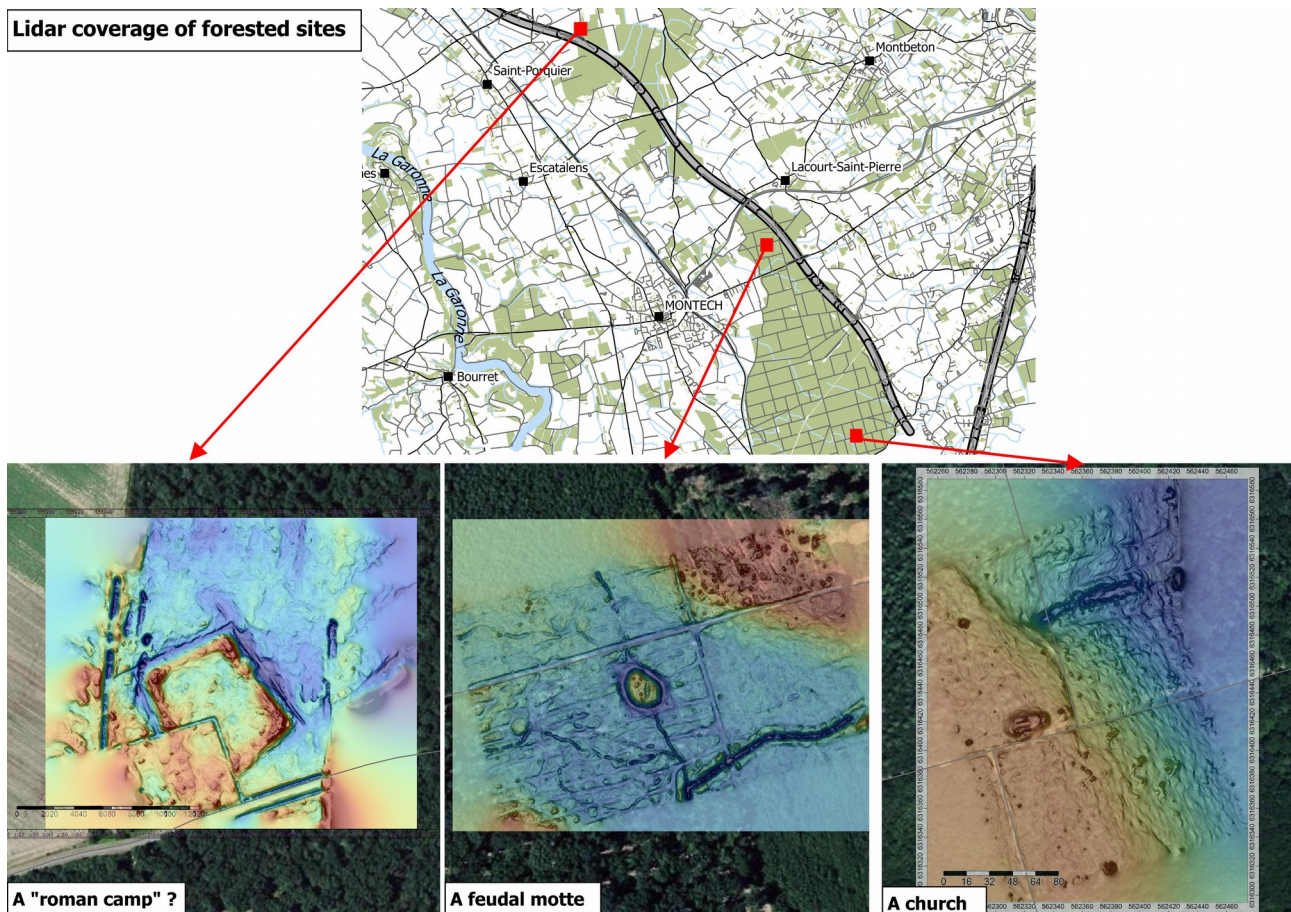


Fig. 8 Lidar coverage of forested sites.

As a result, we were able to document three archaeological sites located in forested parts of our study area. Dating to Antiquity and the Middle Ages, they were known from ancient texts, but the difficulty of accessing them in the dense undergrowth had not previously allowed the drafting of precise plans.

The first case is a site identified at the beginning of the 20th century as a probable "Roman camp". The Lidar survey now makes it possible to draft a precise plan. It is composed of a

trapezoidal enclosure of about 70m to a side, intersected in the south-west by a recent clearing. The accuracy of the measurements makes it possible to determine the width and depth of the ditches. It only remains to collect finds on the surface to specify the dating of this structure, which is again made difficult by the density of the forest cover.

The second case is the site of feudal motte-type castle, also identified at the turn of the 19th century. While the well-preserved mound (up to 2m in height) had been relatively well described by older authors, the Lidar survey revealed a complex water drainage network to connect this enclosure to the surrounding water system. Sherds of pottery collected on the surface make it possible to date part of this site to the medieval period, and more probably to the Early Middle Ages.

The last example is that of the church of Gavancelle. This place name is mentioned in a list of churches belonging to the diocese of Toulouse at the beginning of the 11th century. The present place name, "the cross of Gancelle" probably preserves the memory. On the ground, a mound is visible, surmounted by a recent wooden cross. The Lidar coverage of the sector has made it possible to place this mound in its original micro-topographic context. It is possible to measure all the relevant aspects: length, width, and preserved height. Unfortunately, no other clearly interpretable micro-topographic anomaly could be detected around it (neither agricultural vestiges nor remains of masonry). On the other hand, it is clear that the church was located on a plateau which definitely overlooked the area immediately to the east.

Conclusion

Summing up, our approach is that of a non-invasive kind of archaeology aimed at detecting anomalies (spectral or topographical) with the help of drones, validated on the ground by surface collections of artefacts, and supplemented by the mapping of buried remains through geophysics.

This archaeology of landscapes and territories will clearly allow us to locate, date, characterize and rank settlements and portions of the landscape used by ancient societies without recourse to the destructive method of excavation.

As regards the reconstruction of the interactions between ancient societies and the Garonne River, there seems to be a variable attitude over time (Fig. 9). In particular, there is a gradual separation of settlement sites from the river from Protohistory to the present day. While the average distance to the Garonne was around 2 km during the protohistoric periods, this increased gradually to reach more than 3 km today. This evolution can also be observed in the average altitude of settlement sites, which tend to rise over time from an average of 82m in Protohistory to an average of 97m during the Middle Ages.

This evolution can only be interpreted in the light of the dynamics which shaped the Garonne river over time¹⁶. The resident populations probably sought to protect themselves from the floods

and wanderings of the river bed which are clearly attested by the Napoleonic cadastre for more recent times.

Indeed, between the end of the 18th and the end of the 19th century, the municipalities bordering the river had to redraw the cadastral maps almost every decade due to the shifting of the river banks.

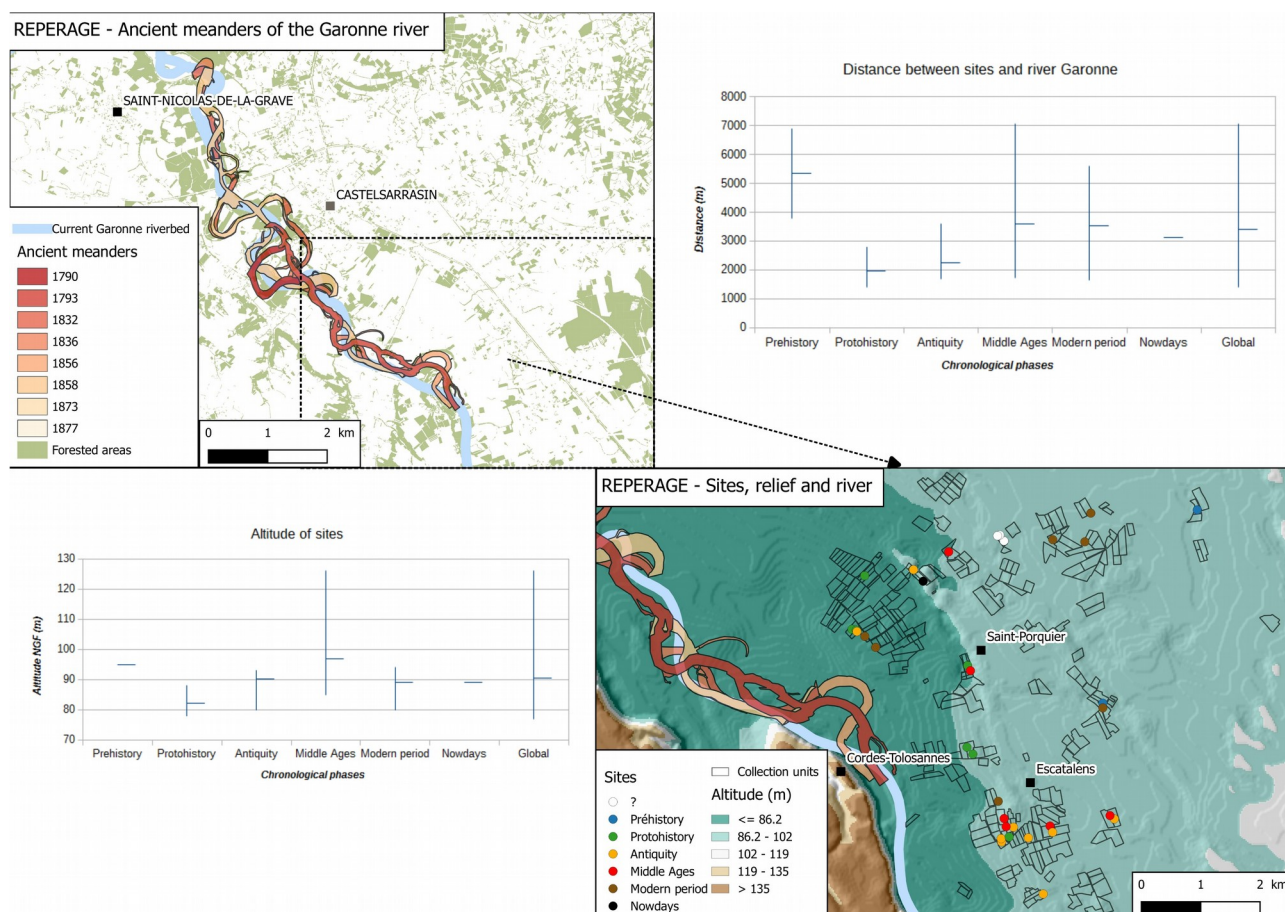


Fig. 9 Distance between sites and the Garonne river / Average altitude of sites.

We still have a lot of work to do in precisely analysing the long-term evolutions of the settlement pattern. Although the Middle Ages as a whole are fairly well represented, the very beginning of this period and the phase of transition from Antiquity is relatively poorly documented. It is a peculiarity of this southern half of France that it provides only very few sites of the early Middle Ages lying in the open landscape. This peculiarity could be explained either by a longer occupation of Roman settlement sites or by an early and sustained establishment of sites occupied from (Late) Antiquity to this day. The occupation phase of the early Middle Ages would be difficult to discern either way, being obscured by the more obvious vestiges of classical Antiquity or trapped under present-day structures which are difficult to access by excavation or survey. A precise dating of off-site scatters recorded by the Archeotracker application around current structures, and a spatial analysis of the location of ancient and medieval sites should provide some answers to this question.

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