The Fields of Interdisciplinarity: How do Practices of Place Transform Forest Science and European Forests?

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Abstract

This paper provides an empirical account of the problem of interdisciplinarity in the field sciences, considering it as a driver of ontological change. Our case study is an ongoing interdisciplinary research project in environmental science. Its objective is to trace the long-term histories of European old-growth forests. To account for the mechanisms involved when researchers seek to do interdisciplinary science in the field, we describe 1/ four research practices that take advantage of the spatial order of the study site in order to make forests temporal processes knowable, thereby producing a field site crisscrossed by multiple spatiotemporal orders; 2/ those practices geared towards articulating these spatiotemporal orders and the limits faced by the consortium towards their complete integration; 3/ how such articulation transforms the conception of old-growth forests as spaces shaped by historical processes integrating human activities and valued ecological processes. We argue that interdisciplinary research practice in environmental field sciences does not lead to a synthesis of pre-existing domains of knowledge production. Rather, it does tend to transform both the object of study and the disciplines involved. The field, as both an object of study and a research place, becomes a broker toward ontological changes.

Introduction

Anthropocene research studies typically focus on ‘real-life experiments’ (Krohn and Weyer, 1994) and often encompass two major dimensions. They are based on fieldwork, which contrast with lab science by the importance granted to place specific features (Kohler, 2002b), and they seek interdisciplinarity by combining concepts, theories and methods from different disciplines (Campbell, 2005; Mascia et al., 2003).

By doing so, these studies aim to track the complex entanglements between human activities and natural processes and accordingly to provide recommendations regarding which nature to preserve and how. In this manuscript, we relate the story of one research project which focused on European old-growth forests. Our point is to ask how interdisciplinary research practice in the field affects scientific understanding and definitions of a shared object of study.

Covering less than three percent of the European forest and often perceived as primary or pristine, old-growth forests convey the iconic imaginary of the so called 'wilderness' (Barredo et al., 2021). To date however, the way past and present human activities impact such forests and the degree of naturalness needed to designate them as 'old-growth' remain unclear (Larrieu et al., 2023). Combining disciplines as diverse as history, archaeology, genetics, sociology, ecology, or paleoecology, and with a strong emphasis on ecological history, the project we followed aimed to relate the long-term histories of European old-growth forests to their current biodiversity state. What happened in their past that produced their current, exceptional state?

Representatives of each discipline recognized the limits of their own methods and often spoke about the 'complementarity' of their approaches. Many also acknowledged they had no clear vision on how to achieve this complementarity in practice. A major problem they faced was the integration of their disparate research operations into a coherent research protocol, with a view to identifying the principles and causes underpinning temporal processes in forests. Indeed, central to the study of 'old-growth forests' in Europe is the issue of their temporality. The plural pasts that environmental sciences uncover through their heterogeneous methods are precisely what produce old forests, making them what they are and answering the normative question of what forests should be (Fisher et al., 2024).

As suggested by MacLeod et al. (2019), over the last decades, a substantial body of literature has produced diverse perspectives on what interdisciplinarity should encompass and how to classify its various forms. This work has primarily focused on theoretical approaches to conceptualizing and understanding interdisciplinarity and it is only recently that empirical approaches, particularly in the field of Science and Technology Studies, have received more attention (e.g., Borie et al., 2021; Fitzgerald and Callard, 2015; Lundershausen, 2018). Given that interdisciplinarity is meant to address 'real-world' challenges, there has been a significant emphasis on assessing its outcomes, discussing what constitutes interdisciplinary success and gaining insight into the mechanisms at play (Holmes et al., 2018). In this perspective, scholars increasingly stressed the need to engage with the epistemological and ontological 'tensions' constitutive of interdisciplinary collaborations (Krueger and Alba, 2022). Rather than viewing interdisciplinarity solely as a means to solve problems, they suggest it as a broker for reshaping the very conception of the problem itself. A pioneering contribution in this regard is the work of Barry et al., (2008) and what they termed a 'logic of ontology' in interdisciplinary research.

A logic is a set of rationales about the purposes of interdisciplinarity and about how interdisciplinarity should be guided and justified. A logic of ontology is "an orientation towards effecting ontological change" (Barry et al., 2008: 25). This orientation manifests itself in particular in its intention to re-conceptualize the object(s) of research and the problem these objects pose to research. Barry et al. (2008) demonstrate that interdisciplinary research practice often does not merely result in integrating previously existing knowledge production practices. It thoroughly transforms how a shared object is conceptualized and renews the kinds of problems this object poses.

Other studies have analyzed the processes involved in creating interdisciplinarity, outlining the circumstances in which diverse disciplines, with distinct methods, concepts, objects, theories, come to interact and generate new epistemological and ontological perspectives. Overall, they acknowledged that "interdisciplinarity is both a social and epistemic process that is contingent on the context, spaces and actors involved" (Honeybun-Arnolda, 2023: 415). So far however, little has been said regarding how interdisciplinarity relates to field sciences. Yet, the field as a site for the production of scientific knowledge touches on specific epistemic issues that have received increasing attention (Ezequiel and Martín Valdez, 2021).

First among these specificities is the particular role played by place. Where the lab is often understood to suppress the specificities of place, aiming at "placeless knowledge", field sciences function by taking advantage of the spatial characteristics of their field sites, as they are found, to produce robust knowledge. Field scientists "proceed not by eliminating placiness, but by embracing it" (Kohler, 2002b: 191). Through what Kohler calls 'practices of place' in his study of 20th century field biology, field scientists seek out "patches of simplified nature", enabling them to "measure exactly, perform quasi-experiments, and read the record of natural processes as if they were experiments, inferring their principles and causes" (Kohler, 2002b: 204-205). Furthermore, as Gieryn (2006) has shown, the field is both *found,* taken as a 'natural' site, providing direct access to reality, and *made,* put into grids, objectified, quantified, using surveys and statistics, making control possible. This dual nature of the field means that not only do field scientists take advantage of the field as found, but also actively re-order and re-constitute the field through their research practices. While feeling, seeing, and understanding their study sites, field scientists shape the world they study.

This manuscript aims to analyze how fieldwork and interdisciplinarity combine when dealing with environmental issues. How are different disciplinary boundaries shaped and transformed by field characteristics, and how does this elicit new epistemological and ontological perspectives? In this respect, two theoretical contexts, mobilized in both field science and interdisciplinarity studies, have particularly captured our attention. On the one hand, the concept of 'boundary work' – which considers the constructed and flexible nature of disciplinary boundaries (Gieryn, 1983) – was used to describe the circulation of ideas, instruments, concepts, objects among different disciplines (MacMynowski, 2007) as well as between the field and the lab (Kohler, 2002a). On the other hand, the metaphor of the 'trading zone' in which different stakeholders collaborate (Galison, 1999), helped understand how researchers with distinct disciplinary approaches (Honeybun-Arnolda, 2023) – but as well scientific space and inhabited place (Kelly, 2012) – actually coexist and are dynamically transformed.

Building on these approaches, this paper provides an empirical account of how interdisciplinary field science re-arranges, redefines and reconceptualizes what is meant by old-growth forests. We particularly focus our attention on how scientists involved in the project relate spatial characteristics of forests to stories of their past and thus produce what we call spatiotemporal orders. Our argument is based on the description of two sets of interrelated practices of places (Kohler, 2002b). First, those practices related to the project's various research operations that help uncover the forest's multiple spatial and temporal orders. Second, those articulatory practices developed and contributed to getting the multiple spaces and times involved to hang together. Part of the dynamic of interdisciplinarity lies in the tension between maintaining research operations' integrity, each with its own spatial requirements, while developing practices that enable them to hang together. The interdisciplinary field embodies a multiplicity, crisscrossed by several distinct but related spatiotemporal orders, which are never fully integrated. We show that these practices interaction in the field reshapes the scientific perspectives on the forests studied and the disciplines involved. We argue that the rationale for interdisciplinarity in European forest science lies not so much in the synthesis of disciplinary knowledge as in reworking the scientific conceptions of the object of analysis.

An interdisciplinary team to study European old-growth forests

The case study retained to develop these points are two interrelated research projects, which, for the most part, include the same team members, field sites, and methods. When we, the authors of this manuscript, arrived in the lab hosting these projects, the first one had just ended. It was a two-year exploratory project (2017-2018) supported by a research public institution in France, with funds earmarked for interdisciplinary projects. It federated a disparate group of geographers, ecologists, archaeologists, and historians, around a shared object, namely old mountain forests composed of beech and fir, and a common goal, namely retracing the long-term trajectories of old-growth forests in Romania. The goal was to reach a better understanding of the part played by human activity in their history and their state of conservation. Researchers conducted an exploratory mission in areas known to the Romanian forest agency and the WWF, examining a series of forest sites that presented a high degree of 'maturity'. They selected four sites in adjacent valleys of the Maramures region with seemingly different management histories as their field sites.

This first project was presented to us as a 'test bed' for a larger project that followed. The latter initially received a four-year funding from the French Research National Agency (2019-2023), which we have been invited to take part in. We will refer to this project as the OFPP project, standing for Old Forests' Past and Present. This project focused on 8 field sites, each covering an area ranging from 45 hectares to several hundreds. Three were located in the central French Pyrenees and five in the northern Romanian Carpathians. The justification for selecting these particular sites was the forests' 'maturity', i.e., the "stage of natural development of a forest [...] evidenced by specific attributes: many large or old living trees, high volume of coarse woody debris in different decomposition states and many types of tree microhabitats on living trees" (Cateau et al., 2015: 59). Moreover, while these sites presented characteristics that were often valued and seen as requiring conservation, what made them interesting for this project is that they also presented traces of past anthropization. As Johanna, an archaeologist and the main investigator (PI) on the project (every name has been anonymized) explained:

> We currently tend to consider that it is the absence of human activity that produced mature, natural forests. However, every time we take a long-term look at their history, we find mining activity, pastoralism, and forest exploitation. Our objective is to see how human activities have participated in producing mature forests.

This objective was thus clearly identified at the beginning of the project and this is precisely what justified the diversity of disciplines invited to participate. Jerome – an ecologist who played a pivotal role in the study design – put it this way: "the interdisciplinarity specific to the OFPP project aimed to 'requalify' the concept of old forest by reworking the boundary between "natural" and "managed" forests."

The project federated 25 researchers, 2 PhD students and 8 technicians across 10 different research laboratories including five in France, one in Check Republic, one in Spain and three in Romania. The consortium was structured around two main tasks. The first focused on the long-term histories of forests while the second analyzed their recent and current bio-cultural diversity. Each task implemented several research operations, according to the various skills of the researchers involved (Table 1). An extra task (both the authors of this manuscript were in charge of) aimed at studying the consortium's interdisciplinary efforts and to build on its experience to question the relation between science and policy making.

People, materials and methods

As mentioned earlier, both this manuscript authors joined the teams after the first exploratory project had ended. R.V is a geographer interested in both the spatial relationship between humans and non-humans, and the way science and technique study it. When he was hired as a permanent researcher in late 2018, her new colleague, Johanna, directly proposed him to be part of the consortium and to coordinate the extra task of the upcoming project. Once the OFPP project was funded, E.F, this paper's initial author – and a young researcher with a background in Science and Technology Studies – was appointed on a two-year contract as a post-doctoral researcher in charge of supporting R.V.

This implied that the research for this article was both funded by the OFPP project and took the OFPP project as its case study. Our offices were set up in the lab that hosted the OFPP project. It is important to point out that, despite our participation in the research project during the research stages this manuscript relies on, we kept a position as observers. Accordingly, our implication within the team, including our participation to field missions, was dedicated to better grab the aspects of the project that structured this paper, but never to interfere with them.

The survey itself was based on participant observation, semi-structured interviews, and document analysis. Participant observation, which extended over the first 18 months of E.F's contract, focused on coordinating meetings, forest scientists fieldwork and lab work. An approximately one-month intensive observation was spent with

Table 1. Overview of the research operations involved on the OFPP project across its two main tasks. "1-ha plots" refers to the 40 one-hectare plots delimitated across the 8 study sites (3 sites in France, 5 in Romania) to conduct part of the research operations.

Research operation	Support for data collection	Sample materials	Task concerned
Pedo-anthracology	pits on 1 ha plots	Charcoal remains in soil for analysis of past forest cover and fire events	Task 1: Long term histories
Paleo-entomology	pits on 1 ha plots	Insect remains in soil as proxy for past environment	
Archaeo-anthracology	Charcoal kilns on 1 ha plots	Charcoal remains in soil for analysis of past charcoal production and forest management	
Palynology	lakes or bogs adjacent to study sites	Pollen in sediment cores for analysis of past vegetation cover	
Geochemical analysis	lakes or bogs adjacent to study sites	Sediment cores for stratigraphic analysis of heavy metal and other pollutants	
LiDAR	2-3 plots at a time on 1 site in the Pyrenees and 1 site in the Carpathians	Digital terrain model of the micro-relief of the forest floor; digital model of the structure of forest stand	
Environmental DNA - fungus	Sampling grid on 1 ha plots	DNA remains of fungus in composite soil samples for analysis of species diversity	Task 2: Recent and current bio-cultural diversity
Environmental DNA - insects	Trees on 1 ha plots	DNA remains of insects in sawdust samples for analysis of species diversity	
XRF analysis	1 ha plots	Soil samples for analysis of recent heavy metal pollutants	
Tea Bag Index	1 ha plots	Index of decomposition rates of organic material left in topsoil over several months	
Index of Biodiversity Potential	1 ha plots	Observation of Tree Related Micro-habitats (TreMs) and other ecological descriptors of forest stand	
Ecological description of forest stand	1 ha plots	Volume of dead wood as descriptor of stand structure	
Dendrochronology	3 fir and 3 beech individual trees on 1 ha plots	Wood cores for analysis of the forest trajectories over the last several hundred years	
Dendro-archaeology	Traditional wood structures in vicinity of study sites	Wood cores for analysis of wood provenance and forest economy	
History	Public and private archives	Documents relating to forests, their management, ownership, and regulation	
Sociology	Communities living adjacent to study sites	Interviews on practices and representations related to forests	

teams in the forests field, while three weeks were dedicated to observe teams at the bench in the lab. This paper's materials come from the copious notes taken during, and immediately after, these observation sessions. These observations were completed with a series of 11 semi-structured interviews with the scientists working on the project. The interviews focus was a history and schematic description of the research design, accounts of implementing research design in practice, and the work necessary to coordinate this diverse group of scientists' activities. These interviews also served as a retrospective study of the initial exploratory project (2017-2018) and as 'test bed' for OFPP. Both data collection and analysis tended to focus on a subset of disciplines that took on a central role in the project. This 'central role' manifested itself either in the managerial and scientific responsibilities taken on by discipline representatives or the importance of the discipline in the overall study design. The documents collected included research projects submitted to obtain funding for the project, sampling protocols, scientific articles written by consortium members, emails between consortium members, notes from coordination meetings, presentation supports by consortium members, scientific reports related to the study sites, and documents from outside organizations (WWF Romania, French National Forest Office, Natura 2000) that described the study sites.

During the analysis stage of our materials, we were particularly interested in how the specificities of the field sciences, *i.e* practices of place, found and made, related to the challenges and justifications for interdisciplinarity. The analysis was based, first, on organizing materials into a series of corpuses, or bodies of text that could be read as a relatively coherent unit. We thus organized our materials by research operations (cf. Table 1), with particular focus on charcoal sampling for the needs of pedo-anthracology, wood coring for dendrochronology, sediment sampling for palynology, data collection for an Index of Biodiversity Potential, and sampling for studying mushrooms environmental DNA. Although non exhaustive, these research operations provided a relevant and complementary material to build our argument. A separate corpus was established for practices related to the articulation of disciplines in the field. We then conducted thematic coding of these corpuses with a view to accounting for the role of place, both in the challenge of articulating the disciplines and in the hope of transforming scientific understandings of old-growth forests.

Practices of place in interdisciplinary field science

The following section is organized in three parts. First, we describe several practices that set up the field in such a way as to turn place into an actor in the production of disciplinary knowledge on mature forests temporality. Second, we examine those practices of place meant to articulate each research operation field. By examining the limits of these articulatory practices, we show that articulation is always partial, never definitive or complete. Third, we show that field research in practice was rationalized through the ontological transformation of the object of analysis. Namely, interdisciplinary fieldwork led project researchers to reconceptualize as well as redefine old-growth forests in Europe, and to rework the common distinction between 'natural forests' and 'managed forests'.

Producing multiple spatiotemporal orders

In the field, pedoanthracologists, *i.e.* scientists studying Holocene paleoenvironments, are interested in the charcoal remains found in the soil. They dig a pit down to bedrock, clean its vertical surface and place plastic yellow markers on the borders between soil horizons, that is, layers of soil that can be distinguished by their structure and composition. They take pictures of it and inspect each horizon carefully. They smell the dirt, take it in the palm of their hand, and rub it between their fingers. They scribble down descriptions of these horizons, paying particular attention to what led them to differentiate each of them. Finally, they take soil samples. Several kilos of soil from each horizon are placed in plastic bags, which they then label with plot number and soil horizon. These samples are taken back to the lab, where they are dried and sifted. This enables them to isolate the charcoal fragments remaining in the soil. These charcoal fragments are examined under a microscope to determine their genus or species and then sent to an outside lab to be dated. We have seen them do this several times, standing around a hole in the ground discussing the structure and composition of the soil, examining the structure of the charred wood under a microscope. When we asked them about the history of the field site, they told us stories about the site's vegetation within a several hundred-meter radius at different time periods over the last 10000 years.

Palynologists are also keen on telling stories about vegetation cover over thousands of years. However, in contrast with pedoanthracologists, they were unable to inscribe their research operations inside the 1-ha plots selected for the study. Palynology is the study of plant pollen and spores trapped and conserved in the environment, and it requires intact sediment from lakes or bogs. None of the plots presented such features. For both the French and Romanian sites, they found lakes or bogs relatively close to the selected study sites. In the Pyrenees, they started by attempting to sample sediment from the Burat Lake, situated several hundred meters above the nearest plot. To take samples, Olivier takes a clear plastic tube from his backpack, to which he attaches a series of aluminum poles. After using a bathymeter to map the bottom of what is hardly larger than a duck pond, he climbs onto an inflatable dinghy and wades out to the deepest point. This area looks flat and smooth on the bathymeter map, which suggests the sediment may be intact. He pushes the corer to the bottom of the lake, doing his best to keep it perpendicular to the sediment, and presses it into the mud. Now, all that remains in the tube as he pulls it out is just a measure of brown water. No good. He tries again and again, before concluding that the sediment has been disturbed, hence making sampling impossible. Another palynologist comments on the site topology, points to the steep slope running up from the edge of the lake, and explains that sliding debris has probably disturbed and covered the sediment. They then try sampling the bog adjacent to the lake, returning to the site a few months later with several hundred kilos of material flown to the site in a helicopter. This time, it takes the weight and effort of two full-grown adults to press a one-meter-long corer into the thick, wet bog. They then carefully remove the corer from the peat and place it in a plastic shell designed to protect it. When we asked palynologists about the past of their study sites, they would tell us stories about vegetation cover and the type of milieu dating back to several thousand years ago. These stories were not specific to a given local site, but concerned a region of up to 50 km^2.

For dendrochronologists working on these 1-ha plots, the past of the forest had nothing to do with the species composition of the site thousands of years ago. Dendrochronology is the science aiming to date events such as environmental changes, using patterns in trees annual growth rings. When Océane, a forest ecologist, carefully pulls out the tree corer from an old, twisted beech, she looks at it and says, "that's a really nice series of rings". Here, tree-rings make it possible to read the forest past. Cores are taken back to the lab and studied under a binocular microscope. Each ring's width is measured to the thousandth of a centimeter precision. These measures are fed into proprietary software, which allows them to cross reference several core samples rings and reconstruct a 'reference chronology' for each site. Tree rings "register" the "signal" or "signature" of forest events. This allows dendrochronologists to identify changes in tree growth rates for given years or periods. Events that affect the state of affairs of the entire forest are inscribed in individual trees life histories. By collating and cross-dating trees' individual life histories, and by comparing them with the known meteorological conditions in the areas at hand, dendrochronologists can tell the story, not only of individual trees or plots, but of several hundred-hectares study sites over hundreds of years.

While the dendrochronologists take coring samples from beech and fir on the plots, a forest ecologist on the team counts the number of Tree-Related Microhabitats (TreMs) on the plots with the help of an archeologist and a historian. Johanna stands in the center of the circular plot, and Jérôme, the forest ecologist and engineer who developed this research operation, walks out to the edge along a 56-meter radius, before coming back to the center on an adjacent radius, eventually covering the surface of the entire 1-ha plot. Along the way, he stops at the base of each 'habitat tree', and yells "one habitat tree"! Johanna yells back, "One habitat tree!" and scribbles it down on her clipboard. Then Jérôme yells the type of TreM on the habitat tree and Johanna repeats this back and scribbles it down on her clipboard. The forest is filled with the echoing "tree snag", "cavity", and "exudate". Jérôme explains that a TreM is "a morphological feature present on a tree" that is "used by sometimes highly-specialized species during at least part of their life-cycle". The point of counting TreMs is to calculate the Index of Biodiversity Potential (IBP), which Jérôme tells me is a "descriptive" tool that is both "crude" and "refined". The IBP provides a "refined" description of tree morphology and stand structure, translating a state of matter that exists in the present. Each morphological feature is a micro-habitat and indicates the forest's *potential* to host biodiversity, but the IBP does not account for species presence or richness. In this sense, the IBP can be said to be 'crude'. The IBP provides a description of an *actual* state of affairs in the forest taken as a proxy for a *potential* state of affairs, a potential biodiversity. Jérôme calls this the "hosting capacity" of the forest stand.

Our empirical description illustrates how the different research operations involved in the project rely on a set of practices that take advantage of the spatial organization of the field site to access forest temporalities. These practices shape different spatiotemporal orders.

Pedoanthracology relies on the specific characteristics of charcoal remains in the soil. Charcoal is immutable and immobile; it does not move and it does not change. Carbon dating of charcoal remaining in the soil provides low resolution temporal data, with a margin of error that can be up to several hundred years. However, since charcoal is relatively immobile, the charcoal location is said to be the place where the tree grew. This means that with the location of the charcoal, a radiocarbon date, and species determination, pedoanthracologists can reconstruct the milieu within a few hundred meters of where the charcoal was found, at a given date in the past, based on the species ecological requirements and phytosociology (the group of plants commonly associated with the tree).

Palynology, as Clothilde told me during an interview, requires a "history in place". Every year, pollen is released into the air by plants and ends up floating on the surface of the water. In the lake, the pollen is mixed up and homogenized before settling on the bottom. If the sediment is undisturbed by water currents, sliding terrain, or human activities, then it accumulates, slowly, over thousands of years, in chronological order. That is, sediment is organized *stratigraphically*, unlike the soil horizons that pedoanthracologists so carefully describe, which relies instead on carbon dating charcoal fragments. This stratigraphy means palynologists can construct a 'depth-age model', "that is, depending on the depth, you get the sediment age". This is what Clothilde means by a "history in place". While pedoanthracologists can successfully study the past of the forest even if the soil has been displaced, palynologists require sediment to remain undisturbed. Hence, palynologists seek out those places where sediment stratigraphy is intact.

Dendrochronology relies on what Océane calls the 'sensitivity' of trees to site conditions, climate variations, and changes in the structure of the forest stand. By 'sensitivity', Océane means that tree ring sizes vary with these changes. Some trees do not register any changes; light, humidity, and soil conditions are so favorable that their growth does not vary from one year to the next. Other trees are so constrained by their site conditions that they do not grow at all during one given year. This is especially true of beech trees. Therefore, Océane selects trees for coring that are 'dominant' – their crown reaches the canopy, warranting they receive sufficient sunlight from year to year to sustain growth – but also 'constrained', i.e., growing on a large rock, covered in lichen, stunted or twisted, etc., so that even small forest events register directly in the wood. Importantly, the form of the tree itself is organized chronologically; rings are arranged according to the order in which they grew, in a timeline that is linear and unidirectional. An event – be it drought, disturbance, release, change in climate conditions – occurs in the forest and is inscribed, in an orderly manner, directly in the spatial form of the tree.

The IBP relies on the spatial organization of the field site – the 'refined' description of stand and tree structure; plot boundaries make it possible to calculate an index. This spatiality is related both to the forest's temporality and mode of existence. Calculating the IBP relies on a set of past 'abiotic and biotic events': "a falling rock could injure the bark, lightning could strike a tree and crack the wood open, or a woodpecker could dig a breeding cavity in the trunk", which 'created' the TreMs. These past events are logically necessary for the TreMs to exist, and their accumulation indicates that the forest is 'mature'. Meanwhile, ecologists are primarily interestd in them through their current subsistence in the structure of the stand and trees. They make two inferences: from both TreMs' present to the past events that cause them; and from the TreMs' subsistence in the present to the field site's 'hosting capacity', its 'biodiversity potential'. However, this biodiversity actuality is undetermined. There may or may not be high levels of species, genetic, and ecosystem diversity. In addition to temporality, we are dealing with modality, or the way biodiversity exists. The IBP turns into an actor in its study design in order to account for the site's *potential*.

Articulating multiplicity

Now that we have described how these practices of place produce multiple spatiotemporal orders, let us examine the practices meant to articulate them. As shall be seen, each of these practices ensures only a partial articulation of the disciplines involved in the project.

The first articulatory practice of place is site selection. During interviews and fieldwork, we asked consortium members how they selected study sites, and they insisted the selection of study sites was central to study design. As one of the palynologists explained, regarding her discipline in particular:

> Your initial question about the selection of sites is crucial, and it really depends on the research question (...) So you see, depending on the question, we won't have the same way of selecting sites. This rule of thumb applies to everything, even to you, when doing your interviews: If you always interview the same person, it just won't do.

This suggests that research design is deductive: a research question and a hypothesis are formulated; sites are selected according to whether it is possible to test the hypothesis and answer the research question. And yet, site selection also depends on *exploration*, central to the 2018 first field mission in Romania, which does not square with the deductive study design. This is how an ecologist working on the project presents this first 'exploratory mission':

> We went out prospecting. We ended up in (this village) almost by chance, because there was a boarding house there that seemed nice. Johanna had a map that showed there were mines in the valley, but we didn't know what we would find, nor whether we would find forests matching what we wanted to study. (...) We didn't know anything about the site. We ended up finding a map of the old forests (in the area), produced by WWF. But we got the map only after we arrived. The boarding house owner gave it to us. One day, he came in with a little pamphlet, saying, "look, the green outline is where the UNESCO forests are". So, we looked at it and said, "yeah, look, old-growth forests". So, we went there and visited all the forests on the map. (Jérôme)

Exploration entails ranging over unknown terrain and surveying what exists there. It is impossible to know ahead of time what will be found and whether what will be found corresponds to the type of study that can be conducted. From the start, the overall project sets out to study *mature* forests long-term history. As such, a major requirement was that the sites they selected contained mature forests. It was understood that all the different specialty consortium members could contribute to answering the assemblage of research problems related to recounting forests' long-term history. The team working in the fields of ecology, mycology, and entomology would fill out their understanding of the present state of the forest through localized studies based in these forest sites. The archaeologists, historians, historical ecologists and paleoecologists would account for the forests' pasts and for the role humans had played in their development.

Selecting sites according to a research question several disciplines can contribute to is, at least in theory, a powerful practice of place for articulating the different spatiotemporal orders produced through heterogeneous research operations. It presents however, a major limit, related to precedence given to ecological considerations (*i.e.,* forests maturity) in site selection. The historian working on the project explained that, since study sites were selected according to ecological criteria and not according to archival documents availability, he was faced with a dearth of materials. If he wanted to conduct a historical study of old-growth forests, he would begin by *exploring* relevant archives, find a location he had 'a nice corpus' for, and then sought out mature forest sites that overlapped with his historical documents. Similar difficulties could be identified for dendro-archaeology, which takes wood cores from the structure of buildings (pastoral huts, churches, cabins…) and uses the tools of dendrochronology to analyze forest management practice, the forest economy, and the provenance of wood. Since exploration was conducted primarily in forests and sites selected according to ecological criteria, it was exceedingly difficult to find structures whose dendro-archaeological study could contribute to the overall project.

A second practice of place, developed early on during the project, was to inscribe as many of the research operations as possible inside shared 1-ha plots. In each study site, five 1-hectare plots were delimitated. This was understood to be a robust method of articulating the different research operations implied in the project. Whenever possible, each research operation would work inside a set of shared 1-ha plots selected from within the larger study sites. Five plots were placed semi-randomly (*i.e.,* placed randomly along a trail inside the site, in order to ensure accessibility) in each of the eight study sites. This is how Jérôme presented the reasons for inscribing as many research operations as possible inside these 1-ha plots:

> The point of the project, which I defended from the beginning, and which was later accepted by everyone, is to circumscribe all the protocols of each discipline, well, most of them actually, within a 1-hectare circle. And within this hectare, we have a description of the stand. So, fungus, dendrochronology, charcoal survey, dead wood survey, density, etc., everything is inside a 1-hectare plot, because, with the IBP, we have an environmental description of the plot. Afterwards, obviously, palynology, sociology, etc., were disconnected, outside the plot. And I can't do the IBP in a peat bog. But everything that's based on sampling, (...) it is more judicious to put them all on the same plot, where we have an environmental description. And then, if we find variations in fungi, etc., we can see whether it is correlated with variations in the quantity of dead wood, for example. With IBP, dead wood, dendrometry, everything I do, we have a description of the sample environment, whatever the type of sample. (Jérôme)

Jérôme claims the articulation of these different research operations is based on the ability to relate their findings to an external environment. This is possible because this environment has been constituted and described with the tools of ecology, notably through the IBP survey. The spatial articulation of these practices of place relies, in part, on turning one of the heterogeneous fields – i.e., the field of forest ecology, which provides a description of stand structure, dendrometry, and quantifies deadwood, which serves to verify that the sites under study are indeed mature forests – into an *environment*, that is, a state of matter which surrounds and contains the other field sites. It is this environment of *mature forests* that the other research operations must explain.

A limit to this practice of place is that several research operations on the project required such specific sites that they could not be made to fit on the selected plots. The team labeled them 'off plot approaches'. The environmental historians working on the project require archives to talk about local forest history. To be able to talk about the provenance of wood, the person doing archaeological dendrochronology requires pastoral huts and old churches from which to sample wood cores. The project sociologist requires local community members to conduct interviews about traditional forest management practice. Palynologists require lake or peat bogs for sediment sampling.

The third practice of place oriented towards articulation is scaling. An important working hypothesis of the project was that the history of a changing 'milieu' and of past management practice could be related to the current 'environment' (species composition, biodiversity hosting capacity, stand structure, dead wood volume…). For such meaningful differences to show up in their results, researchers need to find the right *scale* at which they can make the different disciplines relate to each other. That is, while many of the research operations took their samples from the 1-ha plots, it was not necessarily at plot scale that such differences would appear in the analysis. Nor could they assume that meaningful differences would appear at field site scale.

For instance, two of the Romanian field sites were selected precisely because one presented visible and invisible effects of human exploitation (signs of recent logging, heavy metal pollutants from an adjacent mining site) while the other did not. Yet, the preliminary results from this study, published in 2020 in *Quaderni Historici* (Py et al., 2020), suggest that the anthropized 'managed forest' does not present "any significant difference in structure, composition and litter decomposition" when compared to 'unmanaged' old-growth forest (Py et al., 2020: 389). According to an entomologist working on the project, the problem was finding the proper scale at which to observe trends:

> Are anthropized forests [in the study] less rich than old-growth forests? Not so at plot scale. However, when you cumulate the data, they are. That's where scale is interesting. (...) Locally, we don't see any change. But if you stop there, you're not looking at the right scale! For us, what emerges in the results is that there actually is a valley effect.

Passage between scales is achieved differently for each of the research operations and usually depends on the sampling strategy. Mycologists and entomologists interested in the genetic diversity of insects and mushrooms test the robustness of their sampling protocol by calculating an 'accumulated species richness curve', a kind of marginal analysis of the benefits of taking more samples. The curve visually represents the number of new species per additional sample. If the curve starts to plateau at the top, it means that even if they continued accumulating new samples, the number of new species would not increase significantly. This sampling protocol allows passage between scales by 'duplicating local measures' and through 'accumulation'. According to the entomologist working on eDNA:

> You could wonder whether the sampling is robust enough and, to be honest, it probably isn't. But sampling is how you go from one scale to another. There is what we call the local scale, the 1-hectare plot. Then the landscape scale, when you add up all your 1-hectare plots. And finally, the intermediate scale, which is the site, or stand. That is a management unit, i.e. the unit a forestry treatment is applied to, and at which management choices are made. And some things happen at this scale, that don't at other scales, and that you are not going to see by just averaging for data. It's cumulative.

The limit to scaling up is that not all the research operations involved in the project were designed to scale. The measure for biodiversity hosting capacity, the IBP, is a case in point.

> For simplicity's sake, our index is limited to the forest stand, disconnected from the landscape scale. Which we know is a mistake! Indeed, if you want to reason in terms of biodiversity, obviously you have to reason in terms of the landscape. You have to change scales, to look at how fragmented and isolated your forests are. But I don't look at the scale when I quantify the stand hosting capacity. My biodiversity hosting capacity is what it is in a given place. (Jérôme)

Jérôme explained that the reason scale is so important to biodiversity is because small patches can host high levels of species diversity, but, because of how isolated these fragments are, the species in question have low genetic diversity and have insufficient access to diverse habitats. This poses a serious threat to the species' continued capacity to maintain a healthy and stable population in future. While those who developed the IBP are aware of the necessity to situate biodiversity at 'landscape' scale, they developed their protocol to help foresters and forest engineers maintain managed forests with a sufficient number of TreMs. The goal was not to produce landscape level analyses, and, within the framework of the project, it is difficult to scale.

Transforming European Forests

Taken together, the articulatory practices of site selection, shared plots, and scaling represent the overall spatial organization of the study design. This study design, based on a series of eight field sites, each covering only a few hundred hectares, and forty 1-ha plots, and integrating both 'on plot' and 'off plot' sampling strategies, is meant to produce historical knowledge at high spatial and temporal resolution at a very local level. However, the multiple spatiotemporal orders produced by these heterogeneous practices of place are never completely integrated. Instead, as we shall now see, the novel entanglement of these spatio-temporal orders produced a transformed object of analysis. That is, old-growth forests became something else through these interdisciplinary associations.

According to our notes, this is how Johanna, the PI, related the study design to the research objective during the June 2021 fieldwork in France:

> We selected sites deemed to have characteristics that should be conserved and protected: a high degree of naturalness, maturity and age, often associated with old-growth forests. The objective of the overall project is to look in detail at what in their past, what in their history could produce this present state that we value? Indeed, we currently tend to consider that it is the absence of humans which produced these forests. However, everywhere we looked, we found clues of mines, charcoal-kiln terraces and pastoralism. The objective is then to see how human activities have participated in producing these spaces. (Johanna)

This ensemble of partially-articulated spatiotemporal orders transformed how forest scientists conceptualized the place of human activity in old-growth forests. This transformation was precisely what justified their interdisciplinary efforts. The originality of the project, and the rationale for interdisciplinarity, was to integrate human activity into the historical processes that produced mature forests' present, valued ecological state, where most approaches tend to see human activity as necessarily harmful. This was at the heart of the project objectives, as one forest ecologist explained during an interview:

> What is interesting about this multidisciplinary, interdisciplinary approach, whatever you call it, is the objective of requalifying these forests. [...] What we want to emphasize is that natural forests, mature forests are the result of past anthropization. Granted, they have not been exploited for three or four hundred years, but they co-evolved with humans and humans had an important place in these forests. Humans didn't wipe out everything. They had management methods that were reasonable and well-suited to the forest. In fact, what we really want to question is the dichotomy, common in forest science, between "natural forests" and "managed forests". And that's what multi-disciplinarity makes possible. (Océane)

However, it is important to say that the ontological changes as described here were not only framed *a priori*, declared as truth within the project objectives. They concretely occurred thanks to the study design. Shared outings into the field were essential to effecting this transformation. During an interview, the PI for the project, who had previously worked primarily in managed forests, explained she was 'shocked' when she first visited a mature forest. As an archeologist and the daughter of a saw-mill owner, Johanna explained:

> I used to think that a nice forest is a high forest. And a clean one, too. Yes, a clean forest, so no dead wood on the ground. A forest with dead wood everywhere is a forest that is not well-managed. It's a forest that's dying. And so, I changed my… I don't know what you'd call it, there was a "paradigm shift", if you will. And I discovered this is what a forest, a natural forest, in quotation marks, looks like. But paradoxically, what was also fascinating was that there were traces of management in these forests too, especially in Baiut, there were traces of recent management. (Johanna)

On the other hand, the ecologists on the team, accustomed to working in Old-Growth Forests, did not necessarily notice these traces. Johanna gave the example of a team of ecologists that visited one field site on their own. Their initial field report claimed that the site presented no visible signs of past human activity and concluded that the forest was pristine and natural. However, when an interdisciplinary team visited the same site, they found dozens of tree stumps on the 1-ha plot, which was clear evidence the forest had been exploited less than 50 years prior. The PI explains:

> So, we realized that the fact of going into the field all together was very enriching. Indeed, everyone observed different things. And that can open you up to seeing new things. I liked that a lot. It frees

> your eyes to notice things that you don't observe, wouldn't observe otherwise, because you become monomaniac when you always work from your own discipline. (Johanna)

So, shared outings into the field effected a 'paradigm shift' for an archaeologist who tended to see heavily managed, "clean" forests as healthy, and she taught the ecologists used to working in mature forests how to pay greater attention to traces of past management.

These changes had an important impact on how the ecologists and historians working on the project problematized and defined their object of study. During an interview, one ecologist explained to me that, after working with the historian on the project, he now sees the historically changing property regimes in place as an essential component in explaining how old-growth forests attained their current maturity levels. Who owned the forest and what ownership allowed them to do can account for the forest's ecological characteristics. Conversely, the historian working on the project told me that he "can no longer see [him]self working on forests without the ecologists' outlook." This was because working with ecologists "changed [his] vision and understanding of forests. [He] previously didn't use to see forests as autonomous ecosystems." And this historian added:

> Knowledge and interdisciplinarity are created in the field. By observing others' disciplines, by participating to sampling, I was able to understand the purposes, the methods, and how to bring things together.

In short, where the articulation of the plural spatiotemporal orders produced in the field was always partial and incomplete, the project did manage to effect a significant change in how the scientists involved understood and problematized their object.

Conclusion

By taking up the challenges faced by project members as they attempt to describe old-growth forests collectively, this paper provides an empirical account of the specificities of the field as a place where environmental sciences can become interdisciplinary.

We locate the purpose of interdisciplinarity in 'a logic of ontology', that is, a rationale that justifies interdisciplinarity through its orientation towards effecting ontological change in the research objects and relations (Barry et al., 2008). As such, we identified how interdisciplinarity in the field, by combining multiple practices of place, transformed both how scientists interact and what old-growth forests are.

As a starting point, we showed how the practices of place of each discipline involved in the project contribute to shaping their own boundaries by enacting not only place but also time differently. Each discipline took advantage of the spatial characteristics of the field – the structure of a forest stand, the relative immobility of charcoal trapped in the soil, the form taken by a growing tree, the history in place of lake sediment, the microrelief of the fossilized forest floor…, – to access a series of heterogeneous temporal processes. Thus, they effectively produced multiple spatiotemporal orders.

We further showed that the main interest of this interdisciplinarity project lied in its ability to transform the field as a trading zone between the different disciplines involved, a zone where different practices of place have been incited to communicate, where people, tools and ideas could circulate, where new conceptions of the study object could emerge. Through the project interdisciplinary design, several practices were developed with a view to articulating the plural spatiotemporal orders. Each presented significant limits, and the complete alignment of all disciplines never occurred. Our account insisted on, and drew out, the tensions between making room for each discipline and finding a way to relate across the distance that separated them. In the field, each discipline distributed agency unequally. Each practice of place constituted the field site as a different kind of actor, with different kinds of behavior, even when project members were understood to be working in the 'same' field. This means that, even in a shared study site, each discipline conserved its 'truth spots' (Gieryn, 2006), understood here as specific spatial properties of the field from where, or about which, certain knowledge claims can be made. In the field, forest places and times remain plural, hanging together in partial connection and partial contradiction.

However, whatever the hybridization of the various research operations implemented in the project, the members of the consortium came to see the field as being crisscrossed with several spatiotemporal orders and this transformed their understanding of mature forests. Such transformation was achieved by recounting the long-term history of mature forests in Europe, in order to question the idea that their current and valued ecological state was the result of an absence of human activity. It was possible precisely because they shared a common project in which each ecological and historical approach conceded compromises in favor of the overall project goal of requalifying old-growth forests.

Importantly, the transformation of their object of study occurred not only conceptually, but registered too in how the project's scientists perceived forests. Indeed, shared periods of fieldwork, with representatives of different disciplines participating in all research operations, led members of several disciplines to transform their experience of the forest while being in each other's workspaces (Hadfield-Hill et al., 2020). As these researchers questioned the distinction between 'natural' and 'mature' forests and learned to perceive the forest differently, an important shift occurred in what counted as a research problem. Instead of looking at simply whether or not there had been human activity in forests in order to adjudicate on its 'pristine' state, they sought to account for those human activities that could be compatible with the continued existence of mature forests.

By describing the transformations operated in field sites as both study objects and research places, we questioned the common understanding of interdisciplinarity as an effort to synthesize or integrate previously existing entities or domains of knowledge production (Fitzgerald and Callard, 2015). Rather than relying on a stable state or a result, we showed that interdisciplinarity in the field hinges upon a risky dynamic of becoming, between making a place for the disciplines to maintain the repertoire of practices that can ensure the production of robust knowledge, and finding a way to align and articulate the spatiotemporal orders they find and make in the field. Although their articulation will remain forever incomplete, the encounter in the field between research operations transforms the object of study, the problems it poses, the disciplines involved and scientists' perceptions.

While doing science can be considered as a specific way of interacting with the environment (Ingold, 2021; Latour, 2004), our account shows how interdisciplinarity, as a framework to embrace the full complexity of the Human/Nature relationship in the Anthropocene, involves transformations deeply imbricated with the field specific characteristics. The field becomes an opportunity, a broker between different disciplines and an active agent toward ontological changes.

Acknowledgements

This work was funded by the French National Research Agency (ANR-19-CE03-0010). We are keen to acknowledge all consortium members for giving us the opportunity to follow the project and for accepting to participate in interviews.

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