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Practical issues of transdisciplinary research in sustainability science: lessons learned from the French network of Zones Ateliers

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THÈSE

Pour obtenir le grade de

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Défis pratiques de la recherche transdisciplinaire en sciences de la durabilité: le cas des Zones Ateliers

Practical issues of transdisciplinary research in sustainability science. Lessons from the French network of Zones Ateliers

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“The scarcest resource is not oil, metals, clean air, capital, labour, or technology. It is our willingness to listen to each other and learn from each other and to seek the truth rather than seek to be right.”

Donella Meadows

Abstract

Transdisciplinary research is seen as a promising way to address the complex sustainability issues facing contemporary societies and is therefore at the heart of sustainability science, a recent problem-driven and solution-oriented scientific field that focuses on these issues. However, transdisciplinary research in sustainability science (TRSS) remains relatively marginal. This thesis contributes to understanding its limited diffusion by adopting a pragmatic lens and examining the practical challenges faced by research communities and actors engaged in TRSS. Based on a set of qualitative methods (interviews, documentary analysis, observations) and a semi-quantitative analysis of the data collected, it empirically examines the French network of Zones Ateliers, a national research infrastructure aimed at promoting place-based and long-term research on social-ecological systems.

The thesis first focuses on the practical challenges of TRSS at the level of research communities by examining the extent to which they reorganise themselves when engaging in TRSS. It shows that research communities are research-based meta-organisations, which limits the range of organisational arrangements they can experiment with and the degree of transdisciplinarity they can achieve, particularly in their various governance bodies. The thesis then considers the practical challenges of TRSS at the level of research projects. First, it examines the actors involved in TRSS projects, the roles they perform, and the distribution of these roles between different categories of actors. It shows that, despite significant differences between categories of actors, and with the notable exception of citizens, societal actors have become major players in TRSS, and that the pluralism of societal actors tends to increase the number of roles played by different actors. Finally, it examines the relationship between the approaches and methods used in TRSS projects and the wickedness of the problems these projects seek to address. It finds that projects addressing more wicked problems tend to involve more actors, use more methods, and are more constrained in their degree of methodological and collaborative pluralism.

Overall, this research provides tools for analysing communities and projects involved in TRSS and for increasing the reflexivity of their members. It helps to clarify some previously neglected factors of the practical challenges of TRSS, such as the organisational arrangements available to TRSS communities or the degree of wickedness of the problems they address.

Résumé

La recherche transdisciplinaire est considérée comme une voie prometteuse pour aborder les problèmes complexes de durabilité auxquelles sont confrontées les sociétés contemporaines. Elle est de ce fait au cœur des sciences de la durabilité, un domaine scientifique récent axé sur les problèmes et les solutions qui se concentre sur ces problèmes. Cependant, la recherche transdisciplinaire en sciences de la durabilité (TRSS) reste relativement marginale. Cette thèse contribue à comprendre sa diffusion limitée en adoptant un point de vue pragmatique et en examinant les défis pratiques auxquels sont confrontés les communautés de recherche et les acteurs engagés dans la TRSS. Fondée sur un ensemble de méthodes qualitatives (entretiens, analyse documentaire, observations) et une analyse semi-quantitative des données collectées, elle étudie empiriquement le réseau français des Zones Ateliers, une infrastructure de recherche nationale visant à promouvoir la recherche à long terme sur les systèmes socio-écologiques.

La thèse se concentre tout d'abord sur les défis pratiques de la TRSS au niveau des communautés de recherche en examinant dans quelle mesure celles-ci se réorganisent lorsqu'elles s'engagent dans la TRSS. Elle montre que les communautés de recherche sont des méta-organisations ancrées dans la recherche, ce qui limite l'éventail des arrangements organisationnels qu'elles peuvent expérimenter et le degré de transdisciplinarité qu'elles peuvent atteindre, en particulier dans leurs différentes instances de gouvernance. La thèse se penche ensuite sur les défis pratiques de la TRSS au niveau des projets de recherche. Elle examine tout d'abord les acteurs impliqués dans les projets TRSS, les rôles qu'ils performent et la répartition de ces rôles entre les différentes catégories d'acteurs. Elle montre que, malgré des différences significatives entre les catégories d'acteurs, et à l'exception notable des citoyens, les acteurs sociétaux sont devenus des acteurs majeurs de la TRSS, et que le pluralisme des acteurs sociétaux tend à augmenter le nombre de rôles performés par les différents acteurs. La thèse examine ensuite la relation entre les approches et les méthodes utilisées dans les projets relevant de la TRSS et la gravité des problèmes que ces projets tentent de résoudre. Elle constate que les projets qui s'attaquent à des problèmes plus complexes ont tendance à impliquer davantage d'acteurs, à utiliser davantage de méthodes et à être plus contraints dans leur degré de pluralisme méthodologique et collaboratif.

Au final, cette recherche fournit des outils pour analyser les communautés et les projets impliqués dans la TRSS et pour accroître la réflexivité de leurs membres. Elle aide à clarifier certains facteurs précédemment négligés des défis pratiques de la TRSS, tels que les arrangements organisationnels dont peuvent disposer les communautés de recherche ou le degré de complexité des problèmes auxquels elles s'attaquent.

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From my point of view, a PhD is a journey, in which what counts the most is the process, not the final destination. Like any journey, it can sometimes be tricky. It is full of uncertainties and dangers, but the spirit of adventures and the joy of discovery are precious and definitely worth the price. Today I am coming to the end of this journey and I would like to express my gratitude to the people who have accompanied me along the way.

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My standpoint

One of the postulates of this thesis is that our choices as researchers are largely determined by our values and beliefs. This is particularly the case for researchers practising transdisciplinary research in sustainability science (TRSS), which is accompanied by a self-reflexive attitude towards the role and power of the researcher in shaping the process and its outcomes (Wittmayer and Schöpke 2014, p. 486). Moreover, transparency (in the choice of research methods and approaches and the selection of participants), communication skills and the ability to listen to others are assets when working with societal actors. In short, TRSS requires adopting approaches that are ‘unusual’¹ for conventional scientists, which might be ‘very uncomfortable’ for some, and ‘the only possible way of doing science in the Anthropocene’ for others. In this section, I would like to express how my background and experiences have shaped my interest in TRSS.

Since my early years of higher education, I have never specialised in a particular discipline. I graduated from Lomonosov Moscow State University with a degree in regional studies and international relations of the Russian Federation. In fact, I studied the political and social organisation of a given region, its historical and cultural background, its economy, legal system, etc. My passion for foreign cultures and languages, as well as a strong desire to study abroad, determined my decision to continue my education by enrolling in a research-oriented Master degree in political science, sociology and history “Roads to Democracy(ies)” at the University of Siegen in Germany. I have since become interested in natural resource management and dedicated my master's thesis to the study of participatory management of marine protected areas. I am therefore a fairly typical example of the growing number of junior sustainability scientists with an ‘undisciplinary journey’ (Haider et al. 2018).

At that time, professional opportunities opened up (an internship at the French Office for Biodiversity) and personal circumstances led me to the city of Brest in north-western Brittany, France. I was then recruited by the European Institute of Marine Sciences, more specifically by the LEMAR laboratory², where I worked on the adaptive management of the maërl beds in the bay of Brest. This experience allowed me to discover the challenges of working with scientists from different disciplines and with societal actors. It made me aware of the crucial role of the political and organisational context in establishing such collaborations. At the same time, I was introduced to the case study of this thesis, the French network of Zones Ateliers, by working with a leader of one of these platforms. These experiences revealed a desire to understand behind the scenes of researchers’ work, to explore how they actually go about collaborating with other disciplines and societal actors. Overall, my academic background or rather lack of background in a specific discipline, my professional experiences and sensitivity to the issue of scientific collaboration, as well as my

¹ Taken from the interviews with the practitioners of TRSS from the French network of Zones Ateliers

² The laboratory of the Marine Environmental Sciences

personal values and beliefs, have played an important role in my relationship with the object of this study, namely TRSS.

Moreover, this thesis is a part of a research project funded by the French National Research Agency (ANR)³, COLLAB² (2019 - 2023), which aims to study inter- and transdisciplinary collaborations in sustainability science. The members of COLLAB² come from different disciplines (sociology, ecology, biology and sustainability science) and have different perspectives on TRSS. Some of them are TRSS practitioners directly involved in TRSS projects, while others are outsiders to TRSS applying a pragmatic lens to document and analyse the concrete practices and outcomes of TRSS. This diversity of visions and perspectives enriched the regular meetings organised during the COLLAB² project and my own understanding of TRSS.

The insider and outsider perspectives were also combined in the supervision of my thesis. My supervisors have different disciplinary backgrounds (one in sociology and the other in ecology). A strong interest in TRSS and a long history of collaboration with societal actors (see Arpin and Cosson 2021; Bretagnolle and Tardieu 2021) translated in this thesis into shared objectives, openness and transparency in the choice of approaches and methods, willingness to listen to and learn from others. I believe that this collaboration has been fruitful for my thesis, as it has allowed me to integrate different approaches (both qualitative and quantitative methods) and to benefit from the rich experience of my supervisors regarding TRSS and the case study. In fact, both of them are directly involved in the management of two LTSER sites far away from each other: *Zone Atelier Plaine & Val de Sèvre* (<https://za-plaineetvaldesevre.com/>) and *Zone Atelier Alpes* (<http://www.za-alpes.org/>).

³ ANR-19-CE03-19-0002

Part I: Introduction

We are living in the Anthropocene era, characterised by a major and increasingly preoccupying human impact on the trajectory of life on Earth. According to the latest IPCC report, published in 2023, global temperatures will reach 1.5°C above pre-industrial levels in the next two decades. In 2022, Europe experienced the hottest summer on record. The COVID-19 crisis, climate change, droughts, loss of biodiversity are only the most currently obvious examples of the problems facing humanity today. These problems are increasingly interconnected, intractable and complex. They require urgent solutions. Faced with this complex reality, scientists are under particular pressure to find urgent solutions to these problems. Transdisciplinary research in sustainability science has emerged as a promising avenue to address these problems. How are research communities engaged in transdisciplinary research reorganising themselves? How are they adapting their usual approaches and methods? Who are the actors with whom they collaborate and how do these actors concretely contribute to the research process? These and other questions will be the focus of this work.

We begin this section by introducing the concepts of wicked problems and super-wicked problems and outlining their main characteristics. We analyse how the belief in addressing increasingly complex problems challenges the way science is done. We then provide the reader with a historical perspective on the development of science aimed at addressing wicked problems over the last decades, with the emergence of the concept of the social-ecological system in the 1990s and the rise of a scientific field called sustainability science in the 2000s. Special attention is given to an approach called transdisciplinarity, which was at the origin of what we call Transdisciplinary Research in Sustainability Science (TRSS), a central concept for this work. We then focus on TRSS, presenting its characteristics and reflecting on different perspectives related to this concept. Finally, we focus on the practical challenges faced by research actors at the stages of research design, process and outcomes. We conclude this section with an overview of the general and specific questions that lie at the heart of this thesis.

1. Wicked problems

Many current problems share several characteristics: they are complex, urgent, uncertain, and unique. Moreover, the solutions to these problems “are not true or false or good or bad, but the best that can be done at the time” (Brown et al. 2010, p. 4). They will inevitably lead to changes in the society that causes these problems. In the 1960s and 1970s, urban planners Churchman, Rittel and Webber described these problems as ‘wicked’ (Churchman 1967; Rittel and Webber 1973). They defined them as “ill-formulated”, with conflicting values, a high degree of uncertainty and “thoroughly confusing” ramifications in the whole system (Churchman 1967). Since then, the term has been taken up in various scientific fields, such as environmental sciences, regional and urban planning, education, and health (Termeer et al. 2019), and largely applied in relation to policy problems (Peters and Tarpey 2019). Due to its overuse, the concept has however become ambiguous and has lost some of its meaning. Turnbull and Hoppe (2019) even argue that the wicked problem distinction “is simply the old false distinction between social and natural sciences, rewritten in the language of policy and planning” (p. 318). We therefore find it necessary to remind the reader of the main characteristics that have been attributed to wicked problems.

1.1. Characteristics of wicked problems

A number of authors identify key characteristics of wicked problems (Xiang 2013; Head and Alford 2015; Head and Xiang 2016; Peters 2017). For example, Peters (2017) proposes to identify ten characteristics of wicked problems:

- (1) Wicked problems are difficult to define. There is no definite formulation.
- (2) Wicked problems have no stopping rule.
- (3) Solutions to wicked problems are not true or false, but good or bad.
- (4) There is no immediate or ultimate test for solutions.
- (5) All attempts to solutions have effects that may not be reversible or forgettable.
- (6) These problems have no clear solution, and perhaps not even a set of possible solutions.
- (7) Every wicked problem is essentially unique.
- (8) Every wicked problem may be a symptom of another problem.
- (9) There are multiple explanations for the wicked problem.
- (10) The planner (policy-maker) has no right to be wrong.

Nevertheless, there are different perspectives on these characteristics. For example, Xiang (2013) reduces these characteristics to five: indeterminacy in problem formulation, non-definitiveness in problem solution, non-solubility, irreversible consequentiality and individual uniqueness. Roberts (2000) highlights 'the lack of consensus on the definition of the problem, combined with a lack of consensus on the solutions'. Alford and Head (2017) argue that there are 'less' and 'more' wicked problems, and propose a typology of 'wicked problems', based on

1) the complexity of the problem itself and 2) the actors involved, each of whom having a specific perspective on the problem and its potential solutions. Let us briefly develop these two characteristics of wicked problems.

1) Complexity of wicked problems

Wicked problems are defined as particularly difficult to understand and even more difficult to solve (Brown et al. 2010; Alford and Head 2017; Termeer et al. 2019). This is due to a lack of knowledge or fragmented knowledge about the problem at hand (Alford and Head 2017). In fact, the problem is only understood once a (necessarily provisional) solution has been found. Because there are many possible solutions to a wicked problem, there are many possible definitions of the problem. Since there is no clear definition of both the problem itself and the solution, there are also no criteria for evaluating whether the solution was good or bad (Woezik et al. 2016).

2) Diversity of actors involved, often with conflicting values

Wicked problems tend to involve multiple actors who are affected by the problem at hand and who often have conflicting values and interests. Solutions to wicked problems will therefore inevitably lead to dissatisfaction among those parts of the population that feel marginalised. Bannink and Trommel (2019) argue that there are no perfect solutions, only clumsy or intelligently imperfect ones ('imperfect because they cannot be considered to completely cover the problem, intelligent because they truly acknowledge its wickedness'). Moreover, solutions to wicked problems require changes in the society that generates them. Turnbull and Hoppe (2019) go a step further and include the political distance between policy actors engaging with the problem as a defining feature of the wickedness of policy problems. Thus, the degree of wickedness has a dimension of political complexity.

1.2. From 'wicked' to 'super – wicked' problems

The term 'super-wicked' has recently been proposed particularly in the context of sustainability problems (Levin et al. 2012). Levin et al. (2012) attribute several characteristics to super-wicked problems: (1) time is running out, (2) those who created the problem are also trying to solve it, (3) there is no or only a weak central authority to address the problem, and (4) actors discount the future irrationally.

Climate change is commonly considered a super-wicked problem (Peters and Tarpey 2019) and can serve to illustrate the key features of such problems. First, we need to find a rapid and early response to climate change, because 'if not tackled in a timely manner, climate change is likely to disrupt the social systems that are the basis for both mitigation and adaptation' (Engler et al. 2021). Second, the solution will be challenging to implement as it will involve changing the practices of the entire global population. To mitigate the effects of climate change, we will need to make drastic changes to our daily lives – for example, transforming the way we travel and eat. Efforts must be made at many levels, from the

individual to the global. Finally, there is no unique solution to climate change, but rather a series of actions that will hopefully lead to systemic change. Levin et al. (2012) argue that the main challenge is not a lack of interest in tackling super-wicked problems, but rather 'to counteract the tendency of our political institutions, as reinforced by our individual tendencies as consumers and voters, to make decisions that give greater weight to immediate interests and to delay required behavioural changes, even when doing so is clearly contrary to our long-term interests' (p. 125). To overcome this tragedy, the authors suggest considering the creation of path-dependent policy interventions that can 'constrain our future collective selves.'

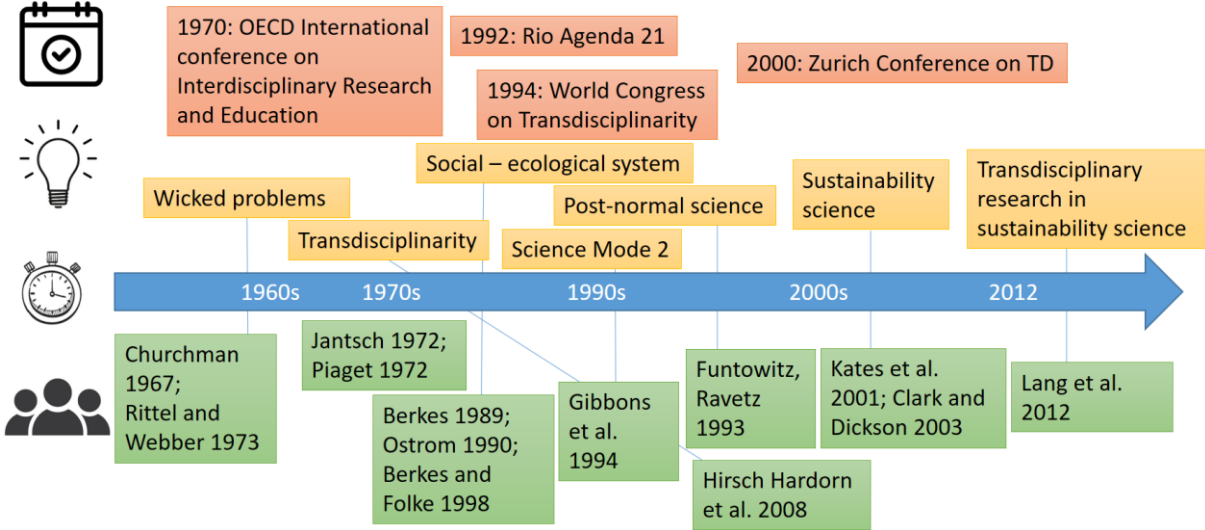
2. A new knowledge regime to address wicked problems: some historical elements

After the economic crisis of the 1970s and the fading of protest movements, a new knowledge regime emerged in the early 1990s (Pestre 2003). Efficiency, accountability, networking, autonomy, creativity, mobility, adaptability and participation became the keywords of a new 'contract' between science and society (Lubchenco 1998). A number of papers subsequently called for profound changes in scientific activity. Two of them proved to be particularly influential and remain key references today. The first (Gibbons et al. 1994) contrasted two modes of knowledge production. In Mode 1, knowledge production is portrayed as the result of theoretical and disciplinary science conducted within largely autonomous institutions. In Mode 2, it is described as a productive activity like any other, much more socially distributed, application oriented, socially distributed and assessable by a range of criteria, including social utility. Gibbons et al. (1994) therefore emphasised the role of context in the process of knowledge production aimed at tackling real-world problems. By focusing on socially relevant problems, they promoted close interaction between science and society and encouraged research actors to step out of the laboratory and engage with other actors to solve societal problems. The second (Funtowicz and Ravetz 1993) also argued for a new type of science, which they called 'post-normal science'. They contrasted post-normal science with disciplinary research conducted in universities and research organisations relatively remote from the rest of society. They saw such conventional research as incapable of dealing with the problems of postmodernity, where 'facts are uncertain, values in dispute, stakes high and decisions urgent' (Funtowicz and Ravetz 1993, p. 744), i.e. with what we have previously defined as wicked problems. They proposed a way of democratising science through 'extensive participation' and 'toleration of diversity'. They believed that post-normal science would make it possible to accept uncertainty and welcome diversity in science.

The 1990s were not only a turning point in the development of alternative approaches to science, but also a time of major events, such as the Earth Summit in Rio de Janeiro (1992), for the global environmental agenda. The following subsections introduce two key concepts, social-ecological systems and transdisciplinarity, which have prepared and accompanied the

emergence of a new knowledge regime from the 1960s to the present (see Figure 1) and have paved the way for a new scientific discipline, sustainability science.

Figure 1: Timeline of concepts



2.1. Social-ecological systems as complex adaptive systems

The origin of the concept of social-ecological systems (SES) lies in the work of the Canadian ecologist C.S. Holling (1973, 2001). In his work on the resilience and stability of ecological systems (1973), Holling highlighted the limitations of our ability to understand ecosystems. Suggesting that the first step would be ‘the recognition of our ignorance’, he proposes the resilience framework to better deal with the unexpected future of ecosystems (Holling 1973). Ecological resilience is defined as the amount of disturbance that an ecosystem can withstand without changing self-organised processes and structures (Gunderson 2000). Holling (1973) argues that ‘there is an inherent unknowability as well as unpredictability concerning these evolving managed ecosystems and the societies with which they are linked’ (Holling 1993, p. 554).

The use of the concept of SES, which emerged in the 1990s, has grown steadily over the past three decades (Schoon and van der Leeuw 2015). It expresses the need for a systemic approach to the study of social systems and ecological systems, focusing on their interactions (Berkes 1989; Ostrom 1990; Berkes and Folke 1998). Recent publications on SES have largely focused on wicked sustainability problems such as climate change (Charles 2012; Fedele et al. 2019), biodiversity loss (Mehring et al. 2017), deforestation (Kyere-Boateng and Marek 2021; Müller-Hansen et al. 2019) and poverty (Adams et al. 2020; Osinski 2021). Akamani et al. (2016, p. 744) draw a parallel between the concept of social-ecological systems and wicked problems, arguing that they share common characteristics, such as scale, uncertainty, and path-dependence.

Preiser et al. (2018) define SES as complex adaptive systems and attribute several characteristics to them: they are adaptive, dynamic, they have no clear boundaries and there are non-linear interactions within the system. According to these characteristics, a reductionist stance is no longer appropriate for the study of SES, as it leads to breaking down 'the complexity of the situation (...) into basic parts which are studied separately' (Hazard et al. 2019). The Newtonian worldview supports the reductionist stance by dividing a given phenomenon into elementary parts that can be observed and quantified. By observing, experimenting with, and measuring a given phenomenon, conventional scientists produce scientific knowledge based on the principles of verifiability and reproducibility. These two pillars of the reductionist stance contradict the nature of social-ecological systems and wicked problems. The reductionist stance is therefore criticised for leading to a fragmented view of reality. In contrast, systems thinking is considered to be able to account for the complexity of social-ecological systems.

2.2. Transdisciplinarity

The term transdisciplinarity has its origins in the OECD conference on interdisciplinary research and education held in France in 1970 (OECD 1972; Klein 2013). Transdisciplinarity was then defined as a common system of axioms that transcends the narrow scope of individual disciplines through an overarching synthesis (Klein 2013). In this sense, transdisciplinarity was very close to what we now understand as (inter-)disciplinarity, or transcending disciplinary boundaries. For example, Piaget (1972) referred to transdisciplinarity as 'a higher stage in the epistemology of interdisciplinary relationships based on reciprocal assimilations' (Klein 2013, p. 192). Jantsch (1972) defined transdisciplinarity as 'the ultimate degree of coordination in the education/innovation system' (p. 17). In other words, these authors referred to transdisciplinarity as the highest degree of interdisciplinarity. While interdisciplinarity is perceived as a higher level of interaction and integration between disciplines, transdisciplinarity is a step forward that aims to create something new that is greater than the sum of its parts (Holzer et al. 2018).

The German philosopher Mittelstrass (1992) emphasised the role of transdisciplinarity in solving real-world problems. According to him, 'if the problems do not do us the favour of defining themselves in disciplinary or even subject terms, then special efforts are required, which usually lead out of the subjects or disciplines' (Mittelstrass 2005, translated from German). Since then, the concept of transdisciplinarity has evolved considerably. It has gained momentum in the 2000s (see Hirsch Hadorn et al. 2008). The Swiss Transdisciplinary Network (TD-Net) was a major step in providing a theoretical and methodological foundation for transdisciplinarity (Pohl 2010). According to Pohl (2010, p. 68), transdisciplinarity in Switzerland was promoted by two initiatives: the scientific journal GAIA – Ecological Perspectives for Science and Society, launched in 1991, and the "Swiss Priority Program Environment", launched in 1992.

Over the last decade, the literature on transdisciplinarity has grown exponentially (Jahn et al. 2012; Lang et al. 2012; Wiek et al. 2012; Brandt et al. 2013; Klein 2013; Felt et al. 2016; Abson et al. 2017). The concept of transdisciplinarity has largely been used by scholars from a variety of scientific fields such as health, education, urban and land-use planning, and digitalisation (Renn 2021) and, in particular, the newly established field of sustainability science.

2. 3. Sustainability science: problem-driven and solution-oriented science

The 2000s marked an acceleration of the turn in the transformation of ‘conventional’ scientific approaches with the emergence of sustainability science (Kates et al. 2001; Clark and Dickson 2003). Sustainability science is a rapidly evolving academic field that is defined by the problems it addresses rather than by the discipline it employs (Brandt et al. 2013, p. 1). Among the many definitions that coexist in the literature (see Komiyama and Takeuchi 2006; Kates 2011; Spangenberg 2011; Shahadu 2016; Fang et al. 2018; Mino and Kudo 2020), we find Fang et al.'s (2018, p. 12) to be the most comprehensive: ‘Sustainability science is a use-inspired basic science of sustainable development, which focuses on understanding human-environment interactions and linking the understanding to actions by promoting a place-based, multi-scale, and transdisciplinary approach’ (p. 12).

Whether sustainability science is a research approach, a discipline or a tool is still debated. Some scholars consider it to be an independent discipline, while others argue that it is an ‘umbrella science’ (Shahadu 2016) that brings together different ontological and epistemological traditions. In any case, promoters of sustainability science argue that the organisation, structuring and conduct of scientific research should change significantly if current societies are to become sustainable (Jerneck et al. 2011; Wiek et al. 2012). These changes should take place at all levels, from the individual to the research laboratory, the research community, the university department, etc.

Spangenberg (2011) divides sustainability science into science *for* sustainability and science *of* sustainability. Science for sustainability provides more practice-oriented approaches to solving sustainability challenges, while science of sustainability provides the conceptual, theoretical and methodological foundations for sustainability science (Spangenberg 2011). Here we are more interested in the first understanding of sustainability science as we want to understand how research actors actually go about tackling sustainability problems. To address sustainability challenges, some scientists call for self-reflexivity (Wittmayer and Schöpke 2014; Haider et al. 2018; Horlings et al. 2020), methodological pluralism (Poteete et al. 2010; Persson et al. 2018; Olsson and Jerneck 2018), and new organisational arrangements that are expected to foster collaboration with other disciplines and societal actors (Lang et al. 2012; Yarmine et al. 2012; Reed and Rudman 2022).

Over the last two decades, considerable efforts have been made to develop the theoretical and methodological foundations of sustainability science. While the evidence-based implications and outcomes of sustainability science continue to be debated, it is now widely recognised that sustainability science needs to foster collaboration between research actors and societal actors to be effective. Transdisciplinary research in sustainability sciences has emerged as a promising approach to address wicked sustainability problems. We have therefore argued that a new ‘knowledge regime’ that emerged in the 1990s has exerted significant influence on scientific research over the last thirty years. In the environmental field, the will to overcome the reductionist stance in science has led, in particular, to the concept of social-ecological system; the observation that collaboration with societal actors is crucial to addressing wicked problems and producing societally relevant outcomes had led to the approach now commonly called transdisciplinarity. The concept of social-ecological system and the transdisciplinary approach have played a major role in the emergence of a problem-driven and solution-oriented scientific discipline: sustainability science. Different research poles and schools of thought provide theoretical and methodological foundations for transdisciplinary research in sustainability science (TRSS), and different worldviews are associated with it. The next section explores this recent discipline and its main features, and presents different perspectives on it.

3. Transdisciplinary research in sustainability science: an emerging and increasingly popular scientific field

In the previous section, we traced the emergence of a new knowledge regime over the last fifty years, in response to a growing dissatisfaction with conventional academic research. During this period, a number of research approaches have emerged and developed into theories, concepts and scientific fields. Transdisciplinary research in sustainability science (TRSS) has emerged as a promising approach to deal with wicked problems and transcend disciplinary and academic boundaries (Lang et al. 2012). Indeed, proponents of this approach argue that it stimulates mutual learning and trust building among actors, promotes the democratisation of science, and fosters the empowerment of the actors involved. Some considerable efforts have been made to provide conceptual, theoretical, and methodological foundations for TRSS (see: Td-Net; Faculty of sustainability at Leuphana University; TDAcademy). Nevertheless, some authors criticise TRSS, considering it to be a ‘fuzzy buzzword’ that is commonly used without understanding its actual meaning (Popa et al. 2015). The next subsection examines the main features of TRSS and different perspectives on this increasingly popular, but still relatively marginal, scientific field.

3.1. What is transdisciplinarity?

The term transdisciplinarity has been defined and interpreted in different ways, and it can lead to some misunderstandings. For example, it is not the same thing as multi- or interdisciplinarity. Multidisciplinarity draws on knowledge from different disciplines but stays within their boundaries (Choi and Pak 2007). Interdisciplinary research is defined as ‘a mode of research by teams of individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond of the scope of a single discipline or area of research practice’ (National Academies Committee on Facilitating Interdisciplinary Research 2005, p. 188). Before clarifying how we understand transdisciplinarity here, we present two perspectives on it: 1) a metaphysical perspective on transdisciplinarity introduced by Nicolescu (1996), which has been particularly influential in France, and 2) a pragmatic perspective on transdisciplinarity, which has been more influential in German- and English speaking countries and has become dominant in the international literature (Klein 2013).

1) Metaphysical definition of transdisciplinarity

In his definition of transdisciplinarity, Nicolescu (1996) mainly emphasises the search for the unity of knowledge beyond scientific disciplines. For him, transdisciplinarity begins with the ‘respect for the collective and individual Otherness’ (Nicolescu 2002). Following these ideas, Rigolot (2020) presents transdisciplinarity as a ‘way of being’. He argues that since the need for knowledge ‘integration’ and ‘implementation’ is a central goal of transdisciplinarity, transdisciplinarity ‘extends far beyond the scope of research projects and appears constantly and ubiquitously in real life’ (Rigolot 2020, p. 4). Sellberg et al. (2021) develop the theory of the Triple-S: they perceive transdisciplinarity as a process that emerges at the interface of Science, Society and Self: connecting researchers, the society in which they are embedded, and the academic system in which they operate.

2) Pragmatic perspective on transdisciplinarity

In this perspective, transdisciplinarity goes beyond collaboration between different disciplinary fields, but remains within the realm of scientific research. It is understood as a research approach, in which research actors work jointly with practitioners to solve a real-world problem (Klein et al. 2001; Hirsch Hadorn et al. 2008). Slightly different definitions of transdisciplinarity in line with this perspective, can be found in the literature. For example, Jahn et al. (2012) define transdisciplinarity as a ‘*critical and self-reflexive research approach that integrates different interdisciplinary scientific and extra-scientific insights to co-produce knowledge to address complex problems*’ (Jahn et al. 2012, pp. 8-9). Lang et al. (2012, pp. 26-27) define it as ‘*a reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific societal bodies of knowledge*’.

Transdisciplinarity therefore appears as (1) a problem-driven and solution-oriented research approach, (2) which promotes collaboration between different scientific disciplines and societal actors, (3) involves knowledge co-production processes, and (4) demands (self-) reflexivity. Two of these characteristics appear to be particularly important: 1) transdisciplinarity brings together research actors and societal actors; 2) it addresses complex real-world problems.

This pragmatic approach has been developed in Europe by the Swiss Academy of Science through TD-net⁴, TD Academy⁵. Germany has a number of renowned centres for TRSS: the Department of Sustainability at Leuphana University⁶, the Institute for Socio-Ecological Research in Frankfurt⁷, the University of Applied Sciences in Potsdam⁸, etc. On the other side of the world, Gabriele Bammer, a professor at the Australian National University, has created a platform called 'Integration & Implementation Insights'⁹ (i2S) to share experiences of TD practitioners and provide insights for newcomers to the field. It is this pragmatic approach to transdisciplinarity that we adopt in this work.

3.2. Transdisciplinary research in sustainability science and its main characteristics

Transdisciplinary research has been a cornerstone of sustainability science since its inception in the early 2000s (Komiya and Takeuchi 2006), and transdisciplinary research in sustainability science (TRSS) has become a field of inquiry in its own right (see Lang et al. 2012). We highlight the two main features of TRSS:

1) *Collaboration between research actors and societal actors in TRSS*

Numerous studies have been devoted to exploring and guiding collaborative processes in TRSS. For example, Lang et al. (2012) have highlighted the need for early engagement of societal actors in transdisciplinary research processes. Knowledge co-production is considered crucial for the production of socially relevant and robust knowledge in TRSS (Weichselgartner and Truffer 2015). Norström et al. (2020, p. 2) define it as “[i]terative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future”. They propose four general principles for knowledge co-production: knowledge co-production for sustainability should be context-based, pluralistic, goal-oriented and interactive.

2) *Addressing wicked real-world problems in TRSS*

Another feature of TRSS is its focus on addressing wicked real-world problems (Jahn et al. 2012; Jahn et al. 2021). It therefore aims to produce ‘transformation knowledge’ (Hirsh

⁴ <https://transdisciplinarity.ch/en/about-td-net/>

⁵ <https://td-academy.org/en/home/>

⁶ <https://www.leuphana.de/en/institutions/faculty/sustainability.html>

⁷ <https://www.isoe.de/en/>

⁸ <https://www.fh-potsdam.de/en>

⁹ <https://i2insights.org/2022/07/05/i2insights-as-a-repository/>

Hardorn et al. 2008) or ‘actionable knowledge’ (Mach et al. 2020) that supports decision-making and can be used by political, economic and societal actors.

This solution-oriented perspective has led to the recent development of studies on the methods that can be used in TRSS to deliver useful and relevant knowledge. Over the last decade, a number of toolboxes have been developed to guide research actors and societal actors interested in TRSS in the selection of appropriate methods (see Table 1). Books on research methods in TRSS (Biggs et al. 2021; Hemström et al. 2021) have also been published recently.

Table 1: *Toolboxes of methods in TRSS*

Toolbox name	Research centre, country	Website
TD-NET toolbox	TD-Net, Swiss Academy of Science, Switzerland	https://naturalsciences.ch/co-producing-knowledge-explained/methods/td-net_toolbox
Sustainability Methods Wiki	H. von Wehrden, Leuphana University, Germany	https://sustainabilitymethods.org/index.php/Main_Page
MSP (multi-stakeholder partnership) tool	Wageningen University and Research, Netherlands	https://mspguide.org/msp-tools/
TD Academy toolbox	Collaborative platform, Germany	https://www.td-academy.org/downloads/Toolbox.pdf
Action Catalogue	The Engage2020 project, the European Union’s Seventh Framework Programme for research, technological development and demonstration	http://actioncatalogue.eu/search
Research methods and tools for transdisciplinary research	UCLouvain, Belgium	https://www.lptransition.be/td/methods
Transdisciplinary field guide	Utrecht University, Netherlands	https://www.uu.nl/en/research/transdisciplinary-field-guide/methods-resources/practical-toolkit
TransImpact (TDAcademy)	ISOE – Institute for Social-Ecological Research and the Center for Technology and Society (ZTG) at Technische Universität Berlin, Germany	https://td-academy.org/downloads/Toolbox_EN.pdf

The concept of TRSS has been widely mobilised by the research community over the past two decades. Advocates of TRSS see it as the best approach to tackle the wicked problems of contemporary societies. Scholz and Steiner (2015, p. 669) describe TRSS as ‘extremely rewarding—personally and societally’. Several authors have highlighted its benefits, which include trust building (Harris and Lyon 2013), mutual learning (Scholz et al. 2000), empowering local actors (Osinski 2021), and contributing to the production of socially robust knowledge (Nowotny et al. 2001). However, they have also warned that TRSS is not an easy path and underlined some of its challenges, including processual issues - insufficient legitimacy of the actors involved, conflicting methodological standards, lack of knowledge integration (Lang et al. 2012; Brandt et al. 2013), the selection and implementation of appropriate research methods (von Wehrden et al. 2017), the establishment of organisational structures that serve the purpose of fostering inter- and transdisciplinary collaboration (Mauser et al. 2013). We have seen in this section that TRSS has two main characteristics: 1) collaboration between research actors and societal actors; 2) the will to address so-called real-world problems. The question that arises in this context is whether research is organised and conducted in such a way that the specific characteristics of TRSS are taken into account. We aim to contribute to answering this question by focusing on the practical issues faced by research actors engaged in TRSS. The following section is devoted to a literature review on the practical issues of TRSS.

4. Practical issues of TRSS

The previous section has shown that a growing community of scholars sees TRSS as a promising approach to tackle wicked sustainability problems. However, some are more sceptical and believe that there is a lack of empirical evidence on the positive outcomes and practical realisations of TRSS (Polk 2014; Hansson and Polk 2018). They believe that this gap is due to several organisational and procedural issues. To begin with, these issues relate to the very practice of research. First, engaging in TRSS requires research actors to be self-reflexive and able to adapt their conventional methods and approaches to a specific goal (researching a wicked sustainability problem). Second, it requires collaboration with colleagues from other disciplinary backgrounds, as well as with actors outside academia. Finally, it requires a rethinking of established epistemological orientations. Indeed, TRSS poses several practical issues to the research community that is willing to adopt it. This section presents the issues of TRSS based on a literature review. We divide these issues into three groups, each representing a phase of the research process: research design and framework (setting up objectives and research question, selecting participants, choosing appropriate methods and tools), research process (when the research activities take place), and research outcomes (when the results of the previous phase are evaluated in terms of their relevance). Based on the literature review, Table 2 provides a summary of these issues.

Table 2: Overview of practical issues in TRSS

Issues concerning research design	Issues concerning research process	Issues concerning research outcomes
Putting in place an organisational structure that would fit both sides of the boundary (Lang et al. 2012)	Organising and structuring participatory process (Lang et al. 2012)	Being accountable on both sides of the boundary (Lang et al. 2012; Brandt et al. 2013)
Integrating all relevant actors (Lang et al. 2012; Lawrence et al. 2022)	Distributing roles to the actors of TD process, dealing with power inequalities (Brandt et al. 2013; Jahn et al. 2021)	Lack of legitimacy of transdisciplinary outcomes (Lang et al. 2012)
Framing societally relevant problem (Lang et al. 2012; Brandt et al. 2013)	Applying multiple methods (Poteete et al. 2010; Brandt et al. 2013)	Project evaluation: tracking scientific and societal impacts (Lang et al. 2012; Williams and Robinson 2020; Bulten et al. 2021; Jahn et al. 2021; Lawrence et al. 2022)
Choosing appropriate methods and approaches (Poteete et al. 2010; Lang et al. 2012; Brandt et al. 2013)		

4.1. Research design issues

Organising and framing the research process in TRSS raise several issues at different levels (including the national level, which falls beyond the scope of this thesis). First, there is the question of how research is structured and evaluated at the level of the research community. Indeed, the current funding and institutional context contrasts with the collaborative research that it aims to promote (Yarime et al. 2012; Bammer 2013; Lyall 2019; Biggs et al. 2021). The integration of different actors from within and outside academia requires a rethinking of the organisational arrangements of research institutions, with a focus on how knowledge is produced and evaluated. Lang et al. (2012) argue that different institutional cultures and ways of working can be a barrier. For example, research actors tend to take more time to produce results, whereas policy and decision-making analyses consider much shorter timeframes (Lang et al. 2012).

Second, issues also arise at the level of research projects. At this stage of the process, research actors have to make crucial choices about what problem to address, who to involve in the research process and, finally, what methods and approaches to use. These decisions will affect the whole research process and its outcomes. Several authors have recognised these issues, including the integration of all relevant actors (Lang et al. 2012; Lawrence et al. 2022), the framing of societally relevant problems (Lang et al. 2012; Brandt et al. 2013) and the selection of appropriate methods and approaches (Poteete et al. 2010; Lang et al. 2012; Brandt et al. 2013; von Wehrden et al. 2017; Biggs et al. 2021). While the literature advocates methodological pluralism in TRSS, it also recognises the challenges it poses to the research

community. In particular, it highlights the need for contextual knowledge and for a certain level of expertise and skill in mastering methods, as well as the high investment in data collection (Poteete et al. 2010). Methodological pluralism within a single project therefore requires establishing and nurturing close interdisciplinary collaborations. Poteete et al. (2010) also argue that methodological choices are often driven by data availability or career incentives.

4.2. Research process issues

The second set of issues concerns the research process, i.e. how the chosen methods and the collaborative process are implemented in practice. A first issue concerns the organisation of the collaborative process. Different aspects have been considered: who should be involved, when should it start, and how intensive should it be? As mentioned above, early engagement of all relevant societal actors has been considered necessary (Spangenberg 2011; Jahn et al. 2012; Lang et al. 2012), and found to positively influence certain societal and practice-relevant outcomes (Newig et al. 2019). Regarding the intensity of collaboration, Schneider and Buser (2018) have explored the degree of interaction between research actors and societal actors in 16 TRSS projects. They have found that different degrees of interaction can be beneficial depending on six factors: (1) each project's intended contribution to sustainability, (2) the desired form of knowledge, (3) how contested the issues are, (4) the level of actor diversity, (5) actor interests, and (6) existing collaborations between actors.

Another issue concerns the choice of appropriate methods. Several authors advocate for methodological pluralism in TRSS (Poteete et al. 2010; von Wehrden et al. 2017; Biggs et al. 2021). However, the use of multiple methods can be challenging for research actors. For example, Poteete et al. (2010) acknowledge that the use of a research method requires specific skills and competencies. They argue that methodological choices are often driven by data availability or career incentives rather than by the problem addressed (Poteete et al. 2010, p. 11). Brandt et al. (2013) argue that the choice of methods is 'unavoidably subjectively biased' as it is driven by researchers' epistemological traditions.

4.3. Research outcomes issues

The third set of issues relates to the outcomes of the research process. The evaluation of TRSS is seen as one of the main issues. For example, Brandt et al. (2013) consider that the production of transdisciplinary research with high scientific impact remains an issue. They note a lack of high-impact peer-reviewed journals that attempt to communicate with the many disciplines involved in transdisciplinary research. An empirical study by Newig et al. (2019) shows that integrating practitioner knowledge into research negatively impacts academic outputs and citations, while it positively influence some societal outcomes. Bulten et al. (2021) explore practical and more fundamental tensions between the roles of research actors in TRSS. In agreement with Jahn et al. (2021), they find that it is challenging to combine

transformation-oriented roles, where researchers are involved in dialogues for change, with knowledge-oriented roles, where researchers focus on the production of knowledge. On the other hand, societal actors may be sceptical about the practical relevance of TRSS outcomes ('salience') (Lang et al. 2012). Jahn et al. (2021) argue that limited resources require prioritisation of activities that are very often accountable to the scientific community.

Tracking its societal impacts is another issue for TRSS (Lang et al. 2012; Bulten et al. 2021; Jahn et al. 2021; Lawrence et al. 2022). TRSS is expected to produce outcomes that would benefit cotemporary societies as a whole and help them address the wicked problems they face (Jahn et al. 2012; Lang et al. 2012; Wiek et al. 2014). However, while methods such as bibliometric analysis allow for an assessment of the scientific impact of TRSS, albeit with limitations, it is more difficult to identify and assess the societal impacts of TRSS (e.g. trust building, mutual learning, empowerment of marginalised actors) and, in particular, its capacity to effectively address wicked problems. Williams and Robinson (2020) have proposed an evaluation framework for sustainability transition experiments. They have noted that most of the literature on the evaluation of TRSS projects has focused on the processes and on the short-term rather than the longer-term impacts. They have also confirmed the difficulty of evaluating the societal impacts of TRSS.

In this section, we have outlined a number of issues that the research community faces when embarking on TRSS. These issues relate to all three phases of TRSS: research design, research process and research outcomes. They include the selection and application of relevant methods, the involvement of participants of TRSS process, the establishment of an organisational structure appropriate to the specificities of TRSS, and the evaluation of its scientific and societal outcomes. The following section presents the research question and the three sub-questions to which this thesis seeks to contribute.

5. Thesis design

In the previous section, we have focused on the practical issues that research actors face when practising TRSS. Indeed, collaborating with societal actors and addressing wicked sustainability problems raises the fundamental questions on how knowledge is produced, with whom, and who is accountable for its outcomes. In this section, we present the research question and the three sub-questions that arise from these practical issues (see Figure 2): (1) designing, implementing and maintaining organisational arrangements that are conducive to TRSS; (2) selecting and interacting with societal actors in the TRSS process; (3) selecting and adapting research methods to the sustainability problem at hand. From these issues we derive the three research questions that we are willing to address in this work. We have focused on the issues related to the first two stages of transdisciplinary research processes (research design and research process), rather than on the issues related to the third stage (research outputs). In this section, we also present the multi-level approach we used to explore the

practical issues of TRSS. We have focused on the research infrastructure and research project levels rather than the individual level.

5.1. The practical issues addressed in this thesis

At the level of the research infrastructure

1) *Setting up an organisational context adapted to the characteristics of TRSS*

One of the main issues of TRSS relates to its organisational arrangements: despite the numerous calls for transdisciplinary research, the current institutional organisation, funding process and evaluation modalities of academic work are at odds with the collaborative research it aims to promote (Yarime et al. 2012; Bammer 2013; Lyall 2019; Biggs et al. 2021). The lack of institutional support is reflected in the following issues: while transdisciplinary research takes time, long-term funded projects remain rare; research proposals are very often evaluated within disciplinary silos; and educational systems are poorly adapted to train students and early career researchers in TRSS (Biggs et al. 2021, p. 462). Establishing organisations that are sufficiently inclusive and meet the expectations of both academic and societal actors is therefore a major issue for TRSS (Werlen 2015). Through this work, we aim to contribute to the understanding of the role of organisational arrangements in the production of research outcomes.

While the level of research communities deserves close attention (Grove and Pickett 2019), very few studies have explored the organisational arrangements in TRSS at this level. To fill this gap, we have focused on the level of research infrastructures that are expected to promote TRSS. The EU's Horizon 2020 programme defines research infrastructures as 'facilities that provide resources and services for the research communities to conduct research and foster innovation in their fields'. There are a few examples of research infrastructures at national and international level that aim to foster collaboration between research actors and societal actors and address sustainability challenges (see e.g. Unesco Man and Biosphere Programme - <https://en.unesco.org/mab>; eLTER and LTSER platforms - <https://elter-projects.org/ltser-platforms>). In this work, we investigate the organisational arrangements in the French network of Zones Ateliers (see next chapter) to address the following research question: to what extent and in what ways are research communities reorganising themselves in the face of increasing demands for inter- and transdisciplinary research? More specifically, we are interested in exploring the relationships between the organisational arrangements of a given research community and the levels of inter- and transdisciplinarity in advisory and governing bodies, projects and peer-reviewed articles.

At the level of research projects

2) *Selecting and interacting with the societal actors involved in TRSS processes*

Another issue related to the research design phase is the selection of all relevant actors in the research process (Lang et al. 2012). De Vente et al. (2016) empirically show how the context and design of participatory decision-making processes influence environmental and social outcomes. They suggest that the most important factors determining process outcomes are who participates, how the process and communication between participants is organised, and how process outcomes are linked to policy and implementation of solutions. According to Lang et al. (2012), limited resources and methodological reasons are an obstacle to involving a variety of actors in TRSS research projects. Furthermore, a common trend in TRSS is to involve the 'usual suspects', i.e. actors who have been involved in previous research projects or who are generally interested in participatory and civic engagement processes (Lang et al. 2012). As a result, some societal actors are left behind in transdisciplinary research processes. There are also actors, such as citizens, who are not represented by any institution. Involving these types of actors is another difficulty.

We argue that the issue lies not only in the selection of the participants, but also in the distribution of activities that they undertake throughout the research process. Hilger et al. (2021) identify 15 roles that actors can perform in TRSS projects, allowing for the possibility that all actors can perform any of these roles. This thesis aims to contribute to this body of literature by investigating the roles of all actors involved in TRSS projects and the distribution of roles among them.

3) Choosing and applying research methods and approaches

Addressing wicked problems implies rethinking and adapting methods and approaches that have often been designed for conventional academic research (i.e. disciplinary and detached from 'real-world' problems). Many studies have adopted a normative lens and offered recommendations on how to go about approaches and methods in TRSS. For example, von Wehrden et al. (2017) call for mixed methods, longitudinal research and clear procedural guidelines in TRSS. Along the same lines, Biggs et al. (2021) call for transparency in methodological choices.

We aim to contribute to the debate on research approaches and methods in TRSS by examining how research actors select their research approaches and methods in practice. As TRSS explicitly aims to address wicked problems, we expect that research actors engaged in TRSS projects will tend to select their research approach and methods according to the degree of wickedness of these problems. In particular, we want to test empirically whether the number of societal actors involved and the number of methods used in research projects aimed at addressing wicked problems increases with the degree of wickedness of these problems.

5.2. Research question and sub-questions

While TRSS is increasingly seen as promising for addressing wicked sustainability problems, it is still far from having become mainstream (Jahn et al. 2012; Polk 2014). We argue that this is partly due to the practical issues that TRSS poses to research actors, which remain underexplored, but deserve close attention. Our aim is to contribute to the development of TRSS by better understanding these issues on an empirical basis. The literature reviewed above has shown that there is a lack of studies that examine the issues of TRSS from a pragmatic perspective. This thesis aims to contribute to filling this gap by addressing some of the practical issues faced by the research community in the practice of TRSS.

We have seen that TRSS requires research actors to 1) address sustainability problems of interest to local communities, and 2) collaborate with colleague from other disciplines and societal actors. This implies the establishment of organisational arrangements at the level of research communities that can facilitate this type of research. It also requires research actors to adapt their usual ways of working to contextual factors (such as the problem at hand, the number of actors affected by the problem, the level of conflict between these actors, etc.). It puts research actors and societal actors in an unusual position, where they are expected to produce both scientifically and societally relevant results, and to perform a variety of roles (Hilger et al. 2021). In this thesis, we want to explore and provide empirical evidence on how research communities and actors actually evolve when they engage in TRSS. Therefore, we would like to contribute to answering the following research question: **To what extent, how and in what ways do research communities and actors modify their usual ways of working when they engage in transdisciplinary research in sustainability science?**

To answer this research question, we focus on two levels: that of the research infrastructure and that of the research project. We address the practical issues of TRSS associated with organisational arrangements (at the level of research infrastructure), the actors' role distribution and the choices of research approaches and methods (at the project level). Figure 2 presents the three research questions that arise from these issues. First, we focus on the issue related to putting in place an organisational structure that would fit the features of TRSS. Second, we explore the challenge of selecting the participants in TRSS processes and interacting with them. Therefore, we aim to combine an issue associated with the research design phase (*selecting the relevant actors*) and an issue associated with the research process phase (*interacting with these actors*). Third, we explore the issues related to the research design phase, linking the problems addressed in TRSS projects and the methods and approaches selected to address these problems.

Figure 2: Research design




				
	Challenge of...	Research Design	Research Process	Research Outcomes
Level of research infrastructure	RQ 1: To what extent and in what ways are research communities reorganising in the face of rising calls for inter- and transdisciplinarity?	Putting in place an organisational structure that would fit both sides of the boundary (Lang et al. 2012)		Being accountable on both sides of the boundary (Lang et al. 2012; Brandt et al. 2013)
Level of research project	RQ 2: What roles do all the actors involved in TRSS projects perform and how are these roles distributed among them?	Integrating all relevant actors (Lang et al. 2012; Lawrence et al. 2022)	Distributing roles to the actors of TD process, dealing with power inequalities (Brandt et al. 2013; Jahn et al. 2021)	Lack of legitimacy of transdisciplinary outcomes (Lang et al. 2012)
	RQ 3: What is the relationship between the wickedness of the problems and the research stances and methods adopted to address these problems?	Framing societally relevant problem (Lang et al. 2012; Brandt et al. 2013)	Applying multiple methods (Poteete et al. 2010; Brandt et al. 2013)	Project evaluation: tracking scientific and societal impacts (Lang et al. 2012; Williams and Robinson, 2020; Bulten et al., 2021; Jahn et al. 2021; Lawrence et al. 2022)
		Choosing appropriate methods and approaches (Poteete et al. 2010; Lang et al. 2012; Brandt et al. 2013)	Organising and structuring participatory process (Lang et al. 2012)	

Fig. 2. An overview of the practical issues in TRSS based on the literature review. Framed are the challenges that are addressed in this work and from which the three research questions are derived e.g. RQ1 in orange; RQ2 in red; RQ3 in purple.

5.3. Thesis structure

The remainder of this thesis consists of three parts, including a methodological part, a results part comprising three chapters written in the form of scientific papers, and a discussion and conclusion part. Table 3 summarises the three chapters presenting the issues that will be addressed and the levels and research phases at which they arise. In the first article, we document and analyse to what extent and in what ways research communities are reorganising themselves in the face of increasing demands for TRSS by exploring the organisational arrangements of the French network of Zones Ateliers (Chapter I). In the second article, we examine the roles performed by both research actors and societal actors and the distribution of roles between them, focusing on a sample of 14 research projects (Chapter II). In the third and final article, we explore the influence of problem wickedness on the research stances and methods that research actors choose by focusing on a sample of 17 TRSS projects

(Chapter III). We then discuss our findings, highlight the limitations of our study and finally suggest the way forward for future research.

Table 3: Structure of the thesis

	Chapter I	Chapter II	Chapter III
	Organisational issue: setting up an organisational context adapted to the characteristics of TRSS	Participation issue: involving actors and distributing roles in TRSS processes	Methodological issue: adapting research methods and stances to the level of wickedness of the problems
Issue addressed	Creating an organisational context adapted to the characteristics of TRSS	Selecting and interacting with the actors in TRSS processes	Adapting research methods and approaches to the wicked problem at hand
Level	Research community	Research project	
Research Phase	Research design	Research design + research process	Research design
Research sub-question	To what extent and in what ways are research communities reorganising in the face of rising calls for inter- and transdisciplinarity?	What roles do all the actors involved in TRSS projects perform and how are these roles distributed among them?	What is the relationship between the wickedness of the problems and the research stances and methods adopted to address these problems?

Part II: Methodology

This thesis dissertation examines to what extent, how and in what ways research communities and actors change their ways of working when they engage in TRSS. To explore this question, we adopt a pragmatic lens to empirically analyse how research actors actually do in practice when they engage in transdisciplinary research and address wicked sustainability problems. We believe that TRSS still suffers from a lack of empirical evidence of its value, partly because the research community underestimates the practical issues of TRSS. This thesis aims to contribute to the understanding of the work of research actors engaged in TRSS by investigating the case of the French network of Zones Ateliers, a national research infrastructure aimed at promoting inter- and transdisciplinary collaborations in sustainability science. In the following section, we present the French network of Zones Ateliers as well as the methods we used to collect and analyse our data.

1. The case study

Zones Ateliers present themselves as follows: ‘The Zones Ateliers (ZA) focus on a functional unit (a river and its watershed, landscapes - agricultural or urban - and biodiversity, from Antarctica to sub-Saharan Africa, or the coastline, or the environments characterized by chronic radiation of natural or enhanced natural origin) and develop a specific scientific approach based on observations and experiments on workshops sites, to conduct multidisciplinary research in the long term. A ZA is therefore, most often, a network of ‘atelier’ sites.’¹⁰ We present this network, its functioning and why we found it an interesting case to study whether and how research communities and actors transform their practices when they engage in TRSS.

1.1. The French Zones Ateliers: from 2000s to nowadays

ZAs are a major tool of the French national centre for scientific research (CNRS) to promote place-based and long-term inter- and transdisciplinary research (Lévêque et al. 2000; Lagadeuc and Chenorkian 2009; Bretagnolle et al. 2019). The theoretical basis of this concept was first presented in an article by Lévêque et al. (2000). The authors defined ZAs as ‘geographical areas, often at a regional scale, with a certain functional unity (e.g. a forest, a river basin, a mountain range). They are defined according to scientific questions involving long-term research on anthroposystems’. The authors insisted on the long-term and interdisciplinary dimensions of ZAs. In fact, the term ‘Zones Ateliers’ was used as early as 1994 during a national seminar convened by an organisation dedicated to ‘hydrosystems’, the Groupement d’Intérêt Public pour la Recherche sur les Hydrosystèmes (GIP Hydrosystèmes). The seminar was followed by the creation of experimental sites, ‘Zones Ateliers’, with the aim to conduct long-term research bringing together various skills and disciplines, including social

¹⁰ <http://www.za-inee.org/>, consulted on 5/03/2023.

sciences, to address the complexity of the systems involved (Arpin et al. 2022). However, this first generation of ZAs was very short-lived. ZAs reappeared in 2000, in a call from the then CNRS interdisciplinary environmental programme, the Programme Environnement Vie et Société (PEVS) (Lévêque et al. 2000).

The first Zones Ateliers were set up to analyse the transformation of large river basins (Rhône, Seine, Loire and Moselle) and were the successors of several interdisciplinary CNRS programmes on the environment¹¹. Since then, a number of Zones Ateliers have been created. To date, there are 15 ZAs¹², located in different social-ecological contexts, from intensively managed agricultural areas to mountain ranges, from the African savannah to the Antarctic Ocean, and from cities to protected areas (see Map 1). They vary in size, address multiple sustainability issues and are located in diverse social-ecological contexts (see Table 4). The ZAs are brought together in a national network ('Réseau des Zones Ateliers' (RZA) in French: <https://www.za-inee.org/>). The RZA was formally created in 2000 to create synergies between the ZAs. It fosters joint activities across ZAs (concerning e.g. data management), and organises annual meetings of all the ZAs. For example, a national colloquium of the French network of Zones Ateliers was organised in November 2020 to mark the network's 20th anniversary. It was an opportunity to share what had been done so far and to discuss the future scientific orientations.

Table 4: Presentation of the French network of Zones Ateliers

Zone Atelier	Date of creation	Main focus	Size (km ²)	Type of SES
ZA Alpes	2008	Trajectories and functioning of mountain SES	100,000	Mountain SES
ZA Antarctique et sub-Antarctique	2000	Long-term dynamics of biodiversity and polar ecosystems	7700	Antarctic and sub-Antarctic SES
ZA Arc Jurassien	2013	Impacts of the past and present evolution of climate and landscape on populations and communities, and on relationships between the environment, ecology and human health in mountain SES	13,500	Multiple SES (grasslands, forests, karstic hydrosystems, wetlands)

¹¹ The most famous of these programmes was the *Programme Interdisciplinaire de Recherche sur l'Environnement* (PIREN, Interdisciplinary Research Programme on the Environment), initiated by the CNRS in 1978 (Jollivet 2001; Muxart 2004; Brun et al. 2017).

¹² The most recent Zone Atelier (Zone Atelier Environnementale Rurale) was created after we collected the data for this thesis, so it is not represented in our sample of projects. However, we conducted an interview with one of its leaders in September 2020.

ZA Armorique	2002	Climate, agricultural and environmental policies, changes in land uses	6750	Urban and rural SES
ZA Bassin du Rhône	2001	Functioning, dynamics and restoration of the heavily transformed Rhône hydro-sociosystem	96,500	Multiple SES (rivers, streams, lakes, and catchments)
ZA Brest-Iroise	2012	Functioning and evolution of the coastal social-ecological system in a context of global change	6690	Marine and coastal SES
ZA Environnement Urbain	2010	Functioning of the urban Social-Ecological Systems and its relations with neighbouring social-ecological systems	3000	Urban and periurban SES
ZA Hwange	2010	The dynamics of biodiversity and the sustainable use of the savannas	15,000	Savanna SES
ZA Loire	2001	Loire hydrosystem and human societies in the Loire watershed and their co-evolution	117,000	Multiple SES (river, forest, grasslands, intensive agriculture, urban, and periurban)
ZA Moselle	2000	Impact of human activities on the quality of water resources in the Moselle watershed	16,500	Urban and rural SES
ZA Plaine & Val de Sèvre	2009	Design and implement socio-ecological experiments to conserve biodiversity and investigate impacts of human activities on the functioning of agro-ecosystems	450	Rural SES (agro-ecosystems and villages)
ZA Pyrénées Garonne	2017	Dynamics of interactions between human societies and the functioning of ecosystems	16,073	Multiple SES (mountains and valley)
ZA Seine	2001	Functioning of the watershed as a social-ecological system (PIREN-Seine), flows of urban micropolluants (OPUR), restoration of the ecological functioning of an anthropised estuary (Seine-Aval)	~77,000	Multiple SES (river, forest, urban, agriculture)
ZA Terres Uranifères	2015	Short and mid-term risks of low-dose radionuclides for people and ecosystem services	The Rophin uranium mine	-
ZA Environnement Rural	2022	Functioning and trajectories of sparsely populated socio-ecological system	~3,000	Multiple SES (forest, farmland, flood meadows, peatlands)

1.2. Diversity of problems addressed by the French Zones Ateliers

The French Zones Ateliers are located in areas with various anthropogenic pressures and face a wide range of wicked sustainability problems: climate change (e.g., *Zone Atelier Alpes* and *Zone Atelier Antarctique et Terres Australes*), water pollution (*Zone Atelier Seine* and *Zone Atelier Brest-Iroise*), biodiversity loss (*Zone Atelier Bassin du Rhône*, *Zone Atelier Plaine & Val de Sèvre*, *Zone Atelier Alpes*), adaptive governance of protected areas (*Zone Atelier Hwange*). The social-ecological systems (SES) conceptual framework has recently been placed at the heart of ZAs (see Bretagnolle et al. 2019), which has contributed to an SES turn in ZAs. For example, the research objectives of the *Zone Atelier Hwange*, which aims to study the dynamics of the savannah socio-ecosystem of Hwange National Park on the north-western border of Zimbabwe, have evolved significantly. From 'analysing the functioning of food webs' and 'exploring the socio-ecological linkages involved in the functioning of the interface' in the period 2015-2018, they have become 'analysing the functioning of food webs and anthropogenic impacts' and 'exploring the role that conservation, protected areas and the management of their interfaces can play in the resilience of socio-ecosystems' respectively.

1.3. The French network of Zones Ateliers is part of an international network of LTSER sites

The French network of Zones Ateliers is in line with an international agenda to promote inter- and transdisciplinary research in sustainability science (see section 2 of Introduction). It is the French representative of the Long-Term Social-Ecological Research network (LTSER) at the international level (iLTER) (Dick et al. 2018). The LTER platforms were first introduced in the United States in the 1980s (Callahan 1984). They were set up in natural landscapes with limited human activities with an aim to facilitate long-term observations of physical, chemical, and biological processes (Dick et al. 2018; Bretagnolle et al. 2019). However, the Anthropocene era has provided new orientations for how scientific research is conducted. This global trend also affected the LTER platforms, and an “s” standing for “social” was added to their acronym (Haberl et al. 2006). According to Mauz et al. (2012), the added value of LTSER network is its stronger political goal (sustainability), and inclusion of societal actors in the research process. Currently there are about 80 – 115 LTSER sites globally (Dick et al. 2018). In Europe, the LTER-Europe network (<https://elter-projects.org/>) emerged simultaneously with the LTER platforms (Mauz et al. 2012; Bretagnolle et al. 2019). However, it was officially established much later in 2007 (Mirtl et al. 2013). According to Mirtl et al. (2013), the LTER-Europe’s science strategy has four major characteristics: it is based on a systems approach; it is process-oriented, long-term and site-based.

1.4. Members and partners of the Zones Ateliers

The Zones Ateliers involve a large number of research actors with ‘more than 1,500 people from more than 118 partner institutions and more than 230 of doctoral candidates’¹³. Research actors from various scientific disciplines (ecology, biology, climatology, geology, physical geography, mathematics, oceanography in the earth and life sciences; sociology, history, human geography, political science, economics, anthropology, archaeology in the human and social sciences; sustainability science) are involved in the governing bodies of the ZAs. Zones Ateliers also involve a wide range of societal actors: public and private actors, NGOs, resource users, local communities, citizens. Collaboration between research actors and societal actors has sometimes been established long before the official creation of ZAs, and societal actors have even played an important role in the creation of some ZAs. For example, protected area managers were instrumental in the creation of the Zone Atelier Alpes. The partnerships that have been established with societal actors have also led to an increase in the financial resources of some Zones Ateliers, such as the Zone Atelier Bassin du Rhône.

Box 1: The role of sites in establishing long-lasting collaborations between researchers and societal actors: the case of the Lautaret station

The Lautaret Station is located at an altitude of 2100 metres on the Lautaret Pass in the Écrins National Park. It is a ‘service unit’ of CNRS that provides researchers with a range of services, including technical and logistical support for their scientific work and the organisation of their stay at the station. Although located in a high mountain environment, it is well connected to transport and scientific networks and has all the characteristics of a hybrid laboratory-field site (Vetter, 2011). It has long played an important role in mountain plant research, and a number of monitoring activities have been carried out in and around the Lautaret station over varying and sometimes very long periods. It has been gradually involved in several national and European research infrastructures and hosts numerous scientific projects. It is also an important training centre for students of alpine ecology and life sciences, and a major site for science tourism, with a famous alpine garden and exhibition centre (Vialeto et al. 2021). It has therefore become a hub where researchers, students, natural resource managers, visitors and artists can meet and work together. This example highlights the important role of sites in creating inter- and transdisciplinary collaborations.



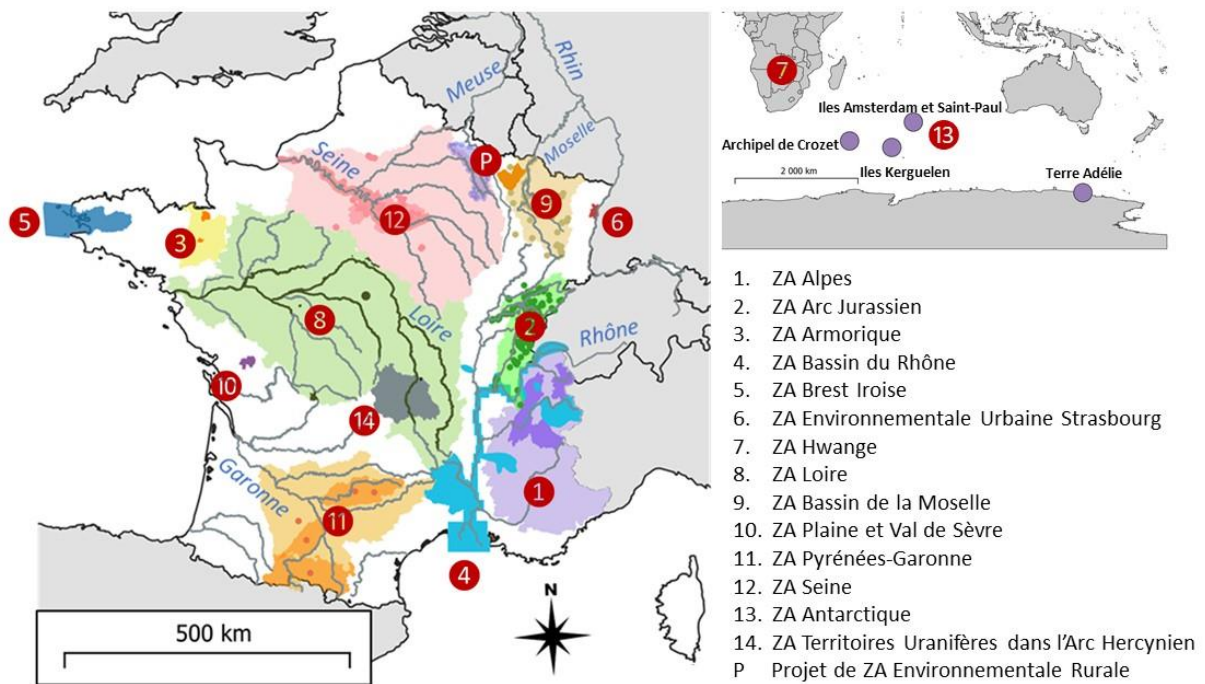
1.5. Functioning of the Zones Ateliers

The CNRS Institute of Ecology and Environment (INEE) is in charge of the ZAs. Candidate ZAs must submit an accreditation document that includes a presentation of their project for the next five years. Existing ZAs must be renewed every five years on the basis of a document

¹³ <https://www.inee.cnrs.fr/fr/zones-ateliers>, consulted on 14/03/2023.

presenting their results and their project for the next period. CNRS commissions evaluate these documents and on this basis the INEE decides whether or not to renew the Zone Atelier. CNRS provides each ZA with an annual budget of 30,000 euros and does not impose any organisational structure on them (Arpin et al. 2022). Therefore, the ZAs are free to organise themselves as they wish and have indeed adopted a variety of organisational arrangements (see Table 6: The ZAs and their organizational arrangements, and Chapter I of the results part). Most ZAs organise annual meetings to present the results of research projects and to discuss their future scientific agenda. There are a number of governing bodies common to all ZAs, including the leading team (usually represented by two research actors), the board of directors (usually represented by the leading team and representatives of member labs), and finally the governing committee (which in some cases includes, among others, representatives of societal actors). Some, but not all ZAs have a governing document, the Charter, which sets out the rules and obligations of the actors involved in a given ZA.

Map 1: The French network of Zones Ateliers



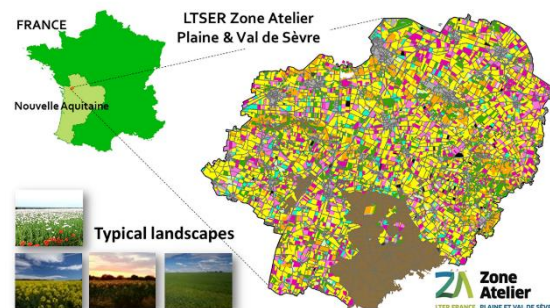
1.6. Recent evolutions of the national network of Zones Ateliers

Since the start of my Ph.D. in October 2019, the functioning and dynamics of the network have evolved significantly. A new Zone Atelier (ZA Environnementale Rurale) has been created; one ZA project has been abandoned at an early stage, while other projects have emerged. Following the appointment of a new director of the RZA in January 2021, a dozen working groups have been created within a so-called Laboratoire d'Idées des ZAs (LIZA) to facilitate synergies between the Zones Ateliers. Two of these working groups were of particular interest for this thesis, as they focused on inter- and transdisciplinarity in the ZAs.

The network of Zones Ateliers has been encouraged to strengthen its relationship with another research infrastructure, OZCAR, which focuses on the critical zone, i.e. the layer of the Earth that is critical for life. RZA and OZCAR are jointly involved in the construction of a European research infrastructure called eLTER, which aims to build a European science of social-ecological systems, based in particular on the standardisation of protocols for monitoring a set of variables considered essential for understanding the functioning and dynamics of SES across Europe. In addition, INEE has recently invited the RZA to strengthen its links, and perhaps even to merge, with the Observatoires Hommes-Milieux, another instrument for promoting long-term and place-based research on social-ecological systems. CNRS and another national research institute have developed an ambitious national sustainability science project, Transform, which aims to promote the development of sustainability science in France and considers ZAs, among other instruments, as important research and demonstration sites. Although it is beyond the scope of my dissertation to explore these developments, they at least deserve to be mentioned here, as they illustrate the speed, scale and complexity of the ongoing transformation of the Zones Ateliers and of TRSS more generally in France.

¹⁴Box 2: The transformative research of the Zones Ateliers, as highlighted by the case of the Zone Atelier Plaine & Val de Sèvre

The Zone Atelier Plaine & Val de Sèvre (ZA PVS) covers a large rural area (ca. 435 km²) with about 400 farms. It includes 24 municipalities with a total human population of ca. 34,000 inhabitants (Berthet et al. 2022). It represents an agro-ecosystem that produces a diversity of resources (cereals, water, habitats, biodiversity, etc.) The ZA was officially created in 2009. However, its history dates back to the 1990s, when long-term observations were established on its territory. This long-term dimension has allowed the research actors from the Centre d'Etudes Biologiques de Chizé (CEBC) to study the dynamics of the agro-ecosystem. In their article, Berthet et al. (2022) adopted a reflexive stance to observe how the scientists' roles, objectives and approaches have evolved drastically over the last 25 years. The authors revealed that the research objectives have changed from environmental monitoring in the 1990s to transforming territory in the 2020s, and from a purely disciplinary ecological approach to co-producing transdisciplinary knowledge with local inhabitants. The researchers' approach to learning about the social-ecological system has also changed, from a 'positivist' to a more 'constructivist' and holistic approach, and from a 'knowledge-transfer' perspective to a 'post-normal science' perspective aiming at transformative change of the whole SES (Berthet et al. 2022). Many ZAs show some signs of similar change, but no other ZA has gone as far as ZA PVS in endorsing and implementing TRSS.



1.7. Why is the French network of Zones Ateliers an appropriate case study?

The RZA is a long-term, place-based research infrastructure that aims to promote TRSS in a variety of social-ecological contexts. It offers a wide range of organisational arrangements and of inter- and transdisciplinary research projects. Indeed, its inter- and transdisciplinary

¹⁴ The map of the Zone Atelier Plaine et val de Sèvre is taken from the article by Bretagnolle et al. (2018). Different colours on the map represent land use in the ZAPVS, e.g. winter cereals in yellow, woods in brown and urban areas in grey.

focus, its long-term dimension, the diversity of social-ecological contexts and of the problems it addresses make it a perfect case for investigating the practical challenges of TRSS. Moreover, working within a single national research network had two important advantages: first, the commonality of language facilitated the collection of information; second, the homogeneity of institutional, political and administrative contexts simplified the analysis. Last but not least, the involvement of my supervisors in the management of the Zones Ateliers was an important advantage. Vincent Bretagnolle has led the Zone Atelier Plaine & Val de Sèvre since its creation in 2009 and the RZA from 2014 to 2019. Isabelle Arpin has been co-director of the Zone Atelier Alpes since 2020. Their involvement in the Zones Ateliers has facilitated access to the field and their knowledge of the case study has contributed to the formulation of the research questions.

2. Data collection and fieldwork

We combined different qualitative and semi-quantitative methods to collect the data for this thesis. The qualitative methods used include semi-structured interviews, observations, and documentary analysis. The use of qualitative methods has contributed to an in-depth understanding of several indicators (e.g. problem wickedness, actor pluralism or role distribution) in a sample of research projects. In addition, semi-quantitative methods have been mobilised to give more robustness to the results. For example, working on the organisation of the 15 Zones Ateliers (Chapter I of the results part) and on a sample of transdisciplinary projects (Chapters II and III of the results part) allowed for semi-quantitative analyses. We have therefore tried to combine the advantages of a broad analysis (robustness of findings) by studying a variety of cases and of an in-depth analysis ('thick' descriptions of processes) by studying a limited number of cases through an ethnological approach. The process of data collection was organised in several phases presented in the following section (see Table 5 at the end of this section for an overview).

Phase 1. Semi-structured interviews with the leaders of the Zones Ateliers

Together with one of my supervisors, I conducted 18 semi-structured interviews with the leaders of each Zone Atelier. These interviews had three main purposes: (1) to obtain general information about the study sites (research problematic, functioning, members involved); (2) to explore the organisational arrangements of each ZA (governing bodies and their members); (3) to identify transdisciplinary projects. The interviews have also highlighted some of the practical challenges that research communities and actors face when embarking on TRSS. This survey enabled me to familiarise myself with the case study, to collect a wealth of material, to identify some of the practical issues faced by researchers and, as a result, to refine the research questions.

Some of the ZA directors were interviewed twice, so the number of interviews exceeds the number of ZAs. In total, we interviewed 23 scientists with different disciplinary backgrounds

(18 from the natural sciences: ecology, geology, biogeochemistry, evolutionary biology, physics; 3 from the humanities and social sciences: political science, human geography, history; 2 with a mixed profile – they had switched from ecology to sustainability science or economics) and 2 managers who provided scientific and technical coordination (See Annex 4 for the list of interviews with the leaders of Zones Ateliers). Their profiles also varied, ranging from junior researchers to senior researchers. The interviews were conducted in French and lasted between 79 minutes and 235 minutes (this interview was split into two parts). The questions covered the background and involvement in the management of the Zones Ateliers, the types of collaboration established within the site and the practical issues associated with this task, the organisation and functioning of the ZA and, finally, the TRSS projects appropriate for further analysis (See Annex 1 for the interview guide).

The interviews were conducted via Zoom or Skype from March to May 2020 during the first lockdown in France due to the COVID-19 pandemic. Although the COVID-19 pandemic posed challenges throughout this work, it also played a positive role in this survey. Most of the interviewees were confined to their homes and had much more time to answer our questions than in a normal period. All the interviews were transcribed and uploaded to the Sygade platform, an INRAE data storage tool. The interviews were analysed using qualitative analysis software (MaxQDA). The software allowed us to code the interview excerpts according to the main themes identified beforehand. We therefore coded each interview according to our research questions: we first focused on the organisation of the Zone Atelier and the level of inter- and transdisciplinarity in the ZA bodies, projects and publications. This coding process was inspired by grounded theory (Corbin and Strauss 1990). The principle of grounded theory is to study a particular phenomenon through the collection and analysis of data. In other words, it is an inductive approach that allows new hypotheses and theories to be constructed through the process of data collection.

- **Selecting a sample of research projects**

A specific aim of the interviews was to identify one or more transdisciplinary research projects in each Zone Atelier. Research projects can be defined as ‘temporally, financially and staff-wise limited units of activities in relation to one or more related research goals’ (Newig et al. 2019, p. 149). They are relatively easy to identify and represent meaningful units for research actors and their partners. We selected projects with the following characteristics: (1) ongoing or recently completed (2) transdisciplinary research projects (3) addressing a wicked sustainability problem. We asked the informants to specify the objectives, partners and stage of development of the projects that met these criteria. Based on the informants’ suggestions, we obtained an initial sample of 30 projects and, after excluding the projects for which we lacked information, a final sample of 17 research projects, representing all Zones Ateliers. The projects covered a variety of more or less wicked sustainability problems, involved a variety of research actors and societal actors, and were set up in different SES contexts. We gathered information about the projects through documentary analysis (see Phase 2) and by consulting the projects’ websites. Where necessary, we asked the project leaders for additional

information about their projects or for clarification. Another advantage of the interviews with the ZA leaders is that they helped us to gain access to the project leaders, by providing us with their personal contact details.

Phase 2. Documentary analysis

The second phase was to obtain further information on the organisation of the ZAs and on the research projects included in our sample through a documentary analysis. We examined various types of documents, including the accreditation and renewal documents as well as the websites of the ZAs, scientific articles, internal reports, project calls, master's theses. Accreditation and renewal documents provided a particularly rich source of material for our study, as they include 1) the members, bodies, academic and societal partners and the spatial extent of the ZAs; 2) the results of the past project and the project for the coming period and 3) appendices with lists of publications and research projects related to the ZA over the last five years. These documents provided us with important data for our three research questions. Scientific articles on the research projects included in our sample were also an important source of data. They often provided us with details of the objectives, partners and outcomes of the projects. Finally, we also relied on visual documents, such as videos and PowerPoint presentations provided by the project leaders.

Phase 3. Ethnographic study

We conducted an ethnographic study of three research projects included in our sample. The first ethnographic study was carried out by Mathilde Ratouis, a Master's student who did an internship in the COLLAB² project from June to December 2020. She studied the relationships between the nature of the problem addressed, the method used and the results obtained in two projects in our sample, RhônEco and SPARE. She conducted 15 semi-structured interviews with the project partners (9 with natural and social scientists, 4 with local and regional authorities and 2 with citizens). All interviews were fully transcribed and analysed using MaxQDA software.

I carried out the second ethnographic study in March 2021 at the Centre for Biological Studies of Chizé (CEBC), in the Zone Atelier Plaine & Val de Sèvre. The aim of this study was to collect empirical data on the Aliment'Actions project (Berthet et al. 2023). More specifically, it concerned the roles and concrete activities of the members of this project: stage of their involvement in the research projects, their role and concrete activities in the project (See Annexes 2, 3 for the interview guide). I conducted a total of 19 interviews with scientists, master students, farmers, local authorities, a journalist specialising in environmental issues, and a consultant in the transformation of rural areas towards sustainability (See Annex 5 for the list of interviews with the project members). I also carried out participatory observation by visiting four local farms and participating in farmers' daily activities, and by interviewing

visitors to the local farmers' market. Moreover, I discussed the Aliment'Actions project with the municipal council of La Foye-Monjault.



Photo 1: The photo was taken at the "Ferme de Péré" meat farm in the commune of Marigny, Deux-Sèvres.



Photo 2: The photo was taken at the farmers' market in the commune La Foye-Monjault (from left to right: Kristina Likhacheva, Hermine De Craecker, Marjorie Talineau and Richard Gobin).

Source: <https://www.lanouvellerepublique.fr/deux-sevres/commune/la-foye-monjault/un-premier-marche-mensuel-dans-le-froid>

Box 3: Are Zones Ateliers the French real-world laboratories? The example of the Aliment'Actions project

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Aliment'Actions (AA) was launched in 2018 for a period of ten years. It aims to transform food consumption and production practices in the ZA Plaine & Val de Sèvre, and to increase the resilience of the agri-food system. It is part of a larger action research project, Transform'Actions (Berthet et al. 2022). Berthet et al. (2023) attribute several characteristics to the project, which (a) is a place-based research project anchored in a long-term and large-scale research infrastructure, (b) adopts an SES perspective, (c) is carried out by a transdisciplinary project consortium, (d) is carried out following an adaptive, iterative, and reflexive process, and (e) has a research design based on experimentation and monitoring. AA is characterised by its diversity in terms of the methods and approaches used: theatre plays, animation techniques (e.g. six thinking hats (De Bono 2017), open forum, Samoan Circle), collective design workshops, etc. It also involves a large number of societal actors: farmers, citizens, local authorities, NGOs, etc. Another feature of AA is that its research design is based on experimentation, with different villages presenting the experimental units. In fact, AA is atypical in terms of its methodological approach, its objectives and the actors involved, and is very similar to the so-called real-world laboratories.



The concept of real-world laboratories has gained recognition in recent years (Schäpke et al. 2018; Schneidewind et al. 2018). Schäpke et al. (2018) attribute five core characteristics to real-world laboratories: contribution to transformation, experimental methods, transdisciplinary research mode, scalability and transferability of results, and scientific and societal learning and reflexivity. Berthet et al. (2023) argue that AA reflects such characteristics, as it aims at societal transformation, involves a variety of societal actors, has a long-term setting, and involves experimentation (Gaba and Bretagnolle 2020). They also argue that it has some unique features, such as the long history of observations on its territory (over 25 years) and a unique spatial research design that allows for experimentation and comparison.

¹⁵ The main features of the Aliment'Actions project presented in the article of Berthet et al. (2023).

I also carried out participatory observation by attending seminars, conferences and workshops organised by the members the French network of Zones Ateliers. For example, I took part in the seminar ‘Ecological restoration of the Rhône river’ organised by the ZA Bassin du Rhône (23/11/2021). Moreover, I participated in several of the annual partners’ meetings organised by the Zone Atelier Alpes; in the thematic school ‘Resilience’ organised by the French network of Zones Ateliers in December 2019. I also took part in the thematic working groups organised by the network. Nevertheless, the context of the Covid-19 pandemic was a limiting factor for participatory observations, as many events were cancelled or postponed at the beginning of the pandemic.

Phase 4. Workshops

The final phase of data collection consisted of organising two workshops to share, discuss and refine the preliminary findings of our research with the project leaders. The first workshop took place in Autrans, in the Vercors range, on 30 November 2021. It was organised as part of the annual Labex ITTEM¹⁶ partners’ meeting and was open to a wide range of participants (researchers, natural resource managers, members of NGOs, etc.). This diversity of perspectives and interests enriched the discussion. The workshop took the form of a roundtable with three rounds of questions, which were shared with the project leaders beforehand and followed by discussions with the workshop participants. The questions concerned, in turn, the problems addressed by the projects, the methods used in the research projects to address these problems, and the modalities of collaboration between the research actors and their partners (see Annex 6 for the list of questions). This event brought together the leaders of four projects of our sample (RhônEco, Alpages Sentinelles, Refuges Sentinelles, Aliment’Actions), and one leader of a Swiss project called Mountaincraft. The workshop was held in French and lasted four hours.



Photo 3: The photo was taken during the annual partner’s forum of Labex ITTEM, 30 November 2021, Autrans.

Photo Credit: Leila Shahshahani

¹⁶ Labex ITTEM is the Laboratory of Excellence: *Innovations and Territorial Transitions in Mountain Regions* supported by the University of Grenoble Alpes (<https://labexittem.fr/en/>)

Another workshop was held online on 15 March 2022 as part of one of the RZA working group on transdisciplinarity. I invited the leaders of the 17 selected research projects - mostly ecologists, but also geographers and economists - to participate in this workshop and comment on my preliminary results. The goal of the workshop was to present the positioning of the 17 projects on the two grids related to the problem wickedness and project pluralism (see Chapter III of the results part) and then to discuss the results with the project leaders. The presentation of the results initiated a discussion on the role of problem wickedness in the choice of methods and research stances. The meeting was held in French and lasted about two hours.

- **Participation in the research project COLLAB²**

Last but not least, this thesis is part of a research project dedicated to the study of inter- and transdisciplinary collaborations in sustainability science (ANR COLLAB²)¹⁷. The project involves research actors from both human and life sciences at different stages of their careers (junior and senior researchers), as well as societal actors, such as a manager of a national park. The project is composed of a core team of research actors (10 members) and members of the research infrastructures under study (7 members).

Several activities have been carried out during the project. First, together with other team members, I conducted a series of semi-directive interviews with project members to explore their backgrounds and motivations for studying inter- and transdisciplinary collaboration. Secondly, tri-annual meetings have been organised throughout the duration of my thesis. In total, I participated in nine project meetings. During these meetings, I presented the progress of my work to the team members and initiated debates and common reflections on the topic. A variety of perspectives (deriving from both social and life sciences) enriched the discussions. Participating in these events contributed to a better understanding of the topic and allowed me to refine my research questions. Furthermore, a quantitative survey was carried within the project, which allowed us to obtain a broader view on TRSS in several national research infrastructures, including the French network of ZAs. Finally, a series of book discussion events were organised among the team members to share and reflect on the recent literature on inter- and transdisciplinary collaborations. Overall, my participation in the COLLAB² project and the shared reflections on TRSS, integrating both insider and outsider perspectives, has contributed significantly to my understanding of the practical issues of TRSS.

3. Concluding remarks

The initial plan was to combine a meta-level analysis of i) the 15 Zones Ateliers and ii) a sample of transdisciplinary projects with an in-depth analysis of two Zones Ateliers (ZA Alpes and ZA Plaine & Val de Sèvre) and three projects (Aliment'Actions, RhônEco, Spare) selected from the sample of transdisciplinary projects. This would have made it possible, on the one hand, to identify trends that remain invisible when studying a very limited number of cases

¹⁷ ANR-19-CE03-19-0002

and, on the other hand, to develop an in-depth understanding of the processes and interactions at work in the organisations involved in TRSS and in transdisciplinary projects. The material collected in the course of the thesis allows for these two complementary approaches (see Table 5). However, time constraints prevented me from analysing the rich ethnographic material collected on the two Zones Ateliers and the three projects mentioned. The results presented in the rest of this thesis are therefore mainly based on the meta-level analysis of the 15 Zones Ateliers and two nested samples of transdisciplinary projects.

Although I have not been able to do full justice to the rich and varied material collected during this thesis, the time spent studying two ZAs and three projects has certainly been beneficial. In addition to providing data for further analysis, the ethnographic study, participant observation and workshops I conducted deepened my understanding of the functioning and dynamics of these ZAs and clarified the factors that determine the choices made by the research actors (methodological choices and choices related to the selection of collaborators).

Table 5: Research questions and empirical material

Source/Research question (RQ)	RQ1: To what extent and in what ways are research communities reorganising in the face of rising calls for inter- and transdisciplinarity?	RQ2: What roles do all the actors involved in TRSS projects perform and how are these roles distributed among them?	RQ3: What is the relationship between the wickedness of the problems and the research stances and methods adopted to address these problems?
Semi-directed interviews	with the ZA leaders (n = 18)		
Email exchanges		With the project leaders, when necessary	
Documentary analysis	<ul style="list-style-type: none"> - Accreditation and renewal documents - ZA websites 		
		<ul style="list-style-type: none"> - Scientific articles - Grey literature (reports, etc.) - Responses to project calls - Master's theses 	
Ethnographic observations	Participatory observations (Annual meetings of the Zone Atelier Alpes; Thematic school 'Resilience')	Ethnographic study of three research projects: Aliment' Actions (17 interviews), RhônEco (10 interviews), SPARE (5 interviews)	
Workshops		Workshop organised by Labex ITTEM (Autrans, 30/11/2021)	
			Workshop organised by the RZA Transdisciplinarity working group (online, 15/03/2022)

Part III: Results

Chapter I. Organisational issue: setting up an organisational context adapted to the characteristics of TRSS

This chapter is based on a paper published in *Environmental Science and Policy*, entitled 'Organising inter- and transdisciplinary research in practice. The case of the meta-organisation French LTSER platforms'. Authors: Arpin I., Likhacheva K., Bretagnolle V. DOI: 10.1016/j.envsci.2023.03.009

Preamble

Most current scientific research is organised in departments and units that are disciplinary and maintain a rather clear boundary with the rest of society, even if some relationships are necessarily established with societal actors, for example to obtain funding or to disseminate results. In contrast, transdisciplinary research in sustainability science (TRSS) is defined as an unconventional scientific approach that promotes collaboration between research actors from different disciplines, as well as between research actors and societal actors, to address sustainability problems. Research communities engaging in TRSS can therefore be expected to establish organisational arrangements that differ from conventional scientific organisations and that facilitate collaboration between a variety of actors, both in research and the rest of society. As we have seen in the introductory part, the establishment of organisational arrangements that meet the characteristics of TRSS is seen as one of the major concerns of the research infrastructures committed to promoting inter- and transdisciplinarity.

While considerable attention has been paid to the study of institutional barriers to transdisciplinarity in universities (see Russell et al. 2008; Yarmine et al. 2012; Gianni Baptista and Vilsmyer 2022), the level of research infrastructures has been little investigated so far. We therefore decided to dedicate this chapter to the organisational issues at the research infrastructure level and to examine to what extent and in what ways research communities are reorganising themselves in the face of rising calls for inter- and transdisciplinarity. Do their governing bodies, research projects and written productions reflect a specificity in terms of their capacity to bring together a variety of actors and help them to work together? What kind of organisations do they favour? In terms of our research design, the organisational issue with which we begin the presentation of our findings is a practical issue that arises at the community level and during the design phase of TRSS (see Figure 2).

The French Zones Ateliers (ZAs) present an appropriate case study to address the organisational issues empirically for the two main reasons: first, ZAs were explicitly created to promote place-based inter- and transdisciplinary research and address sustainability problems; second, ZAs are relatively free to organise themselves as they wish. As a result, ZA leaders are experimenting with the organisational arrangements of their sites and provide us with various examples of governance settings.

1. Introduction

Disciplinary academic research, which is conducted in universities and research centres in relative isolation from the rest of society, is increasingly considered ill-suited to addressing many problems facing contemporary societies (Hirsch-Hadorn et al. 2008). Indeed, a growing number of these problems are complex, interconnected and present a high degree of uncertainty. They cut across scientific disciplines and affect a broad range of societal actors with diverse and often conflicting interests, knowledge and perspectives on these problems. Because of these characteristics, such problems have been labelled ‘wicked problems’, a term proposed by urban planners in the 1960s and 70s (Rittel and Weber 1973) and now widely adopted. Many scientists share the conviction that wicked problems can only be tackled by bringing together research actors from various scientific disciplines, as well as societal actors interested in or affected by the problems at hand, i.e., through inter- and transdisciplinary research.

According to the widely accepted definition, interdisciplinarity (ID) refers to production of scientific knowledge that integrates information, data, methods, perspectives, concepts and/or theories from multiple disciplines (Kates et al. 2001; National Academy of Sciences 2004). The notions of transdisciplinarity (TD) and transdisciplinary research (TDR) have been the subject of much more discussion (Klein 2001; Jahn 2012) and have generated academic debates. However, TDR has increasingly referred to collaboration between academic actors and people outside academia to investigate and address so-called real-world problems (Wickson and Carew 2006; Lang et al. 2012), especially in the English-language literature. This is the definition we adopt herein.

Calls for inter- and transdisciplinary research (ITDR) emerged as early as the 1970s (OECD, 1972) and multiplied in the early 1990s with the publication of highly influential books (e.g., Gibbons et al. 1994) and papers (e.g., Funtowicz and Ravetz 1993). Since the 2000s, they have been gaining even more ground (Bozeman and Boardman 2014). For example, handbooks of inter- (Frodeman et al. 2010) and transdisciplinary research (Hirsch-Hadorn et al. 2008) have been published to provide newcomers to the field with concepts, approaches and case studies to help them engage with these modes of research. Examples of publications promoting ITDR now abound in environmental science and emerging scientific fields oriented towards tackling environmental problems, such as sustainability science (Kates et al. 2001; Komiyama et al. 2006; Lang et al. 2012). Beyond academic literature, science policies have also increasingly encouraged and expected researchers to develop inter- and transdisciplinary projects. Many funding processes at local, national and international levels now foster such projects (Cundill et al. 2015; for an example, see Horizon 2020: <https://ec.europa.eu/programmes/horizon2020/en/h2020-section/excellent-science>).

However, scientific disciplines have meanwhile remained the basic unit of academic structure and functioning (Hirsch-Hadorn et al. 2008). For example, scientists are still mostly

evaluated by disciplinary committees according to disciplinary agendas and criteria, at least in France. There is therefore a major tension between the promotion of ITDR and the mainly disciplinary structure of academia (Guimarães et al. 2016). Several studies have explored this tension by investigating how research actors respond to calls for ITDR and seek to become inter- and transdisciplinary within a predominantly discipline-based framework (Augsburg 2014; Guimarães et al. 2016; Fam et al. 2016). Research communities also deserve close attention, since organisations, infrastructures and platforms committed to ITDR have been created. The growth of ITDR is therefore not just about individuals, but also about research communities (Grove and Pickett 2019).

Studies at the research community level have chiefly focused on processes such as trust building and mutual learning (e.g., Scholz 2001; Jahn et al. 2012; Cundill et al. 2015; Mascarenhas et al. 2021), and have paid less attention to organisational issues. In general, the impact of organisation on research content is poorly understood (Gläser and Laudel 2016; Leahey and Barringer 2020). In her study of nanomedicine, Louvel (2021) showed that the sociopolitical order produced by interdisciplinary policies has only some of the characteristics of full-fledged sociopolitical orders and complements rather than replaces or contradicts the disciplinary organisation of contemporary science. Leahey and Barringer (2020) found that universities' commitment to ITDR has a positive effect on the quantity of interdisciplinary research but no effect on its quality. We seek to contribute to this body of work by documenting and analysing to what extent, in what ways and with what effects research communities are reorganising in the face of rising calls for ITDR.

We base our analysis on an empirical study of French organisations – Zones Ateliers (ZAs) – which aim to promote ITDR to investigate the functioning and dynamics of social-ecological systems¹⁸ facing global changes. We specifically investigate the following research questions: What kind of organisations are ZAs? Does the way they organise themselves influence the level of inter- and transdisciplinarity of the research projects¹⁹ they support and their outputs? Clarifying the type of an organisation is important not only from a theoretical perspective but also from an operational one. Indeed, it helps in understanding its functioning and dynamics, e.g., at what rate it can change, the type of challenges it is likely to face and what it can and cannot achieve.

We first introduce two concepts – boundary organisation and meta-organisation – that have been used for analysing organisations bringing together heterogeneous actors around environmental issues and we discuss their similarities and differences. We then present the characteristics of ZAs that matter for investigating organisational issues and the mixed methods we used to collect and analyse the data. The next two sections present and discuss

¹⁸ Developed in the 1990s, the notion of social-ecological systems (Berkes and Folke 1998) expresses the idea that social systems and ecological systems are closely interconnected and cannot be studied separately. It invites a focus on their interactions and the complex adaptive systems they form (Preiser et al. 2018).

¹⁹ Research projects are 'temporally, financially and staff-wise limited units of activities in relation to one or more related research goals' (Newig et al. 2019, p. 149).

our findings on the organisational arrangements of ZAs and the level of inter- and transdisciplinarity in their advisory and governing bodies, research projects and publications.

2. Literature review: Boundary organisations and meta-organisations

Designing organisations that can facilitate collaboration between research actors and other societal actors, in particular public policy communities, has been identified as a powerful means of achieving ITDR (Parker and Crona 2012). Such organisations have been referred to as boundary organisations (BO, Guston 1999, 2001) by science and technology scholars. Derived from principal-agent theory, the concept of BO aims to provide an understanding of processes taking place at the interface between science and policy. Guston (1999) proposed this concept to account for forms of organisation aiming to create collaborative processes that allow both science and policy to achieve their goals while stabilising the boundary between them. According to his definition, BOs must meet three criteria. First, they must facilitate the creation and use of boundary objects²⁰ and standardised packages²¹. Second, they must involve the participation of actors from both sides of the boundary. Third, they are accountable to each social world according to its own criteria. The concept has been widely taken up and enriched to render it more dynamic, complex and sensitive to power imbalances (Gustafsson and Lidskog 2018). BOs have been increasingly described as involving several blurred and moving boundaries rather than a single clear-cut and fixed boundary between science and policy and having to navigate contradictory demands and tensions between a long-term and a short-term focus, basic and applied research, disciplinary and interdisciplinary research and autonomy and consultancy (Parker and Crona 2012).

However, the concept of BO does not refer to a specific form of organisation, and it is silent on crucial organisational issues such as membership and leadership (Gustafsson and Lidskog 2018). As a result, BOs encompass a wide variety of organisational arrangements. This lack of attention to organisational issues is a serious limitation of the BO concept for studying how research communities reorganise to respond to calls for ITDR. To overcome this limitation, we mobilised the concept of MO that was developed by two organisation scholars, Göran Ahrne and Nils Brunsson.

First, Ahrne and Brunsson (2008, 2011) clarify what is and what is not an organisation: an organisation is an attempt to establish a decided order to achieve a certain goal (in our case promoting ITDR, seen as a condition for addressing the wicked environmental problems facing contemporary societies). Full-fledged organisations have members, a hierarchy, rules, positive and/or negative sanctions and ways of monitoring their activities to track their progress towards their goal. Because they are based on explicit decisions that can always be

²⁰ In a seminal article, Star and Griesemer (1989) defined boundary objects as ‘both adaptable to different viewpoints and robust enough to maintain identity across them’. Boundary objects play a key role in the capacity of different social worlds to cooperate.

²¹ ‘Standardised package’ is another concept used for analysing collective action. It involves standardised methods aiming to produce relatively stable facts across social worlds (Fujimura 1992).

questioned, organisations are more fragile and exposed to contestation than other types of social orders, such as networks and institutions (Ahrne and Brunsson, 2011). Networks consist of informal structures of non-hierarchical relationships between social actors, and institutions are built by common beliefs and norms and are taken for granted (Ahrne and Brunsson, 2011).

Second, Ahrne and Brunsson (2005, 2008) distinguish between individual-based organisations, whose members are individuals, and meta-organisations (MOs), whose members are organisations themselves. Being an individual-based organisation or a meta-organisation has important implications for the functioning and dynamics of organisations. For example, MOs have access to resources through their member organisations from the outset and are therefore immediately operational: they are a cheap way to set up collective action (Berkowitz and Dumez 2016). They tend to have a small and stable membership, which may lead to a monopolisation of decisions and low capacity for change. Other characteristics of MOs such as a culture of consensus increase their tendency to inertia (König et al. 2012). Moreover, members of MOs generally have as much power as the MO itself – or sometimes more – and can initiate the same type of activities, which may generate competition between MOs and their members.

The concept of MO was originally developed to account for organisational processes in sectors where MOs bring together one single type of members, such as firms in the same industry (Berkowitz et al. 2020). As a result, similarity among members was considered a key characteristic of MOs (Cropper and Bor 2018). This assumed homogeneity of MOs was a major weakness of the concept for the study of organisational arrangements in ITDR, which is precisely predicated on the idea that a wide range of actors should collaborate to address wicked problems. However, MOs have proliferated (Berkowitz and Dumez 2016) and are increasingly found in sectors that rely on the collaboration of heterogeneous actors, including research actors, to tackle wicked sustainability problems such as climate change (Chaudhury et al. 2016), ocean degradation (Berkowitz et al. 2020) and poverty (Pradilla et al. 2022). The concept of MOs has thus been extended to organisations whose members hold different and potentially contradictory views on the problems to be addressed (Berkowitz et al. 2020; Berkowitz et al. 2022b).

Drawing on the case of ocean degradation, Berkowitz et al. (2020) identified four conditions for a MO to effectively address sustainability problems: 1) it should be a governing MO, i.e., it should have at least some of the attributes of a full-fledged organisation (rules, hierarchy, leadership, monitoring, rewards and sanctions) and offer a neutral inter-organisational space; 2) its governance should involve multiple, cross-sectoral stakeholders who each contribute their expertise and views on the problem at hand; 3) it should be spatially embedded, to be able to attend to local social-ecological specificities; and 4) it should gain actorhood, i.e., be considered responsible for its decisions and accountable to its members and to external actors.

The BO and MO concepts have therefore both been used to account for and analyse organisations designed to facilitate collaboration between research actors and societal actors in order to address wicked sustainability problems. While they were developed separately and emanate from two distinct bodies of literature (science and technology studies for the BO concept and organisation studies for the MO concept), they have recently converged in some works, which note that multi-actor MOs can act as BOs (Berkowitz et al. 2016, p. 151; Berkowitz et al. 2020). As for BOs, they are often, but not necessarily, MOs. Analysing BOs as MOs, when applicable, helps to understand the limits of their ability to achieve ITDR by focusing on organisational aspects that are otherwise ignored.

Well-known empirical examples in the environmental field include Birdlife International and the International Whaling Commission (Berkowitz et al. 2022a) for MOs, and the IPCC and the IPBES for BOs. MOs and BOs cover a wide range of scales from local to global. We focus here on local organisations, the French Zones Ateliers (ZAs).

3. Methodology

3.1. The Zones Ateliers as organisations committed to place-based and long-term ITDR

ZAs were named after the objective they seek to achieve: ‘zones’ refers to the fact that they are spatially bounded and embedded, and ‘ateliers’ (from the Latin *astula*, meaning a small piece of wood) designate places where people work together. ZAs are a major tool used by the French national centre for scientific research (CNRS) to promote place-based and long-term ITDR (Lévêque et al. 2001; Lagadeuc and Chenorkian 2009; Bretagnolle et al. 2019). They are the French representatives of the long-term social-ecological research (LTSER) sites at the international level (iLTER) (Dick et al. 2018). 14 ZAs have been created in diverse social-ecological contexts over the last two decades, some of them having pre-existed their official recognition. They are widely distributed in space and vary considerably in size and shape²². A national ‘network’ of ZAs was created by CNRS in 2000 to encourage exchanges and synergies between them.

ZAs are ideal for studying the reorganisation of research communities. Indeed, they are bottom-up initiatives that their leaders submit to CNRS to be recognised as ZAs and admitted to their national ‘network’. CNRS gives them few organisational guidelines in return, i.e. they are relatively free to organise themselves as they wish to achieve ITDR. This allows identifying and comparing the organisational decisions of different research communities. Additionally, their longevity allows observation of how research communities change their organisation over time and how they may experiment with successive organisational arrangements.

²² For a detailed description of the ZAs, see Bretagnolle et al. 2019.

Another reason for investigating ZAs is that we are deeply involved in their management: two of us have each been co-leading a ZA (ZA PVS for many years and ZA Alpes since 2020) and one of us also led the national ‘network’ of ZAs from 2014 to 2020. We therefore have in-depth knowledge of the organisation, activities and outputs of two ZAs and their national ‘network’, as well as easy access to detailed data on the other 12 ZAs through their ‘network’.

3.2. Data collection and analysis

Following Gläser and Laudel (2016), we used a mixed-methods design, inspired by science policy studies, science and technology studies and bibliometrics, to investigate the relationship between research organisation and research content.

We conducted semi-directed remote interviews with the leader(s) of each ZA during spring 2020²³. We asked them about the human and financial resources of their ZA, its governing and advisory bodies, and the goals and composition of these bodies. We also asked them about the level of ID and TD in the projects and publications of the ZA. Most informants distinguished between two types of ID: narrow or restricted ID between research actors from scientific domains they consider to be close, and what they called extended or radical ID between human and social scientists (HSSs) on the one hand, and life or earth scientists on the other hand. We focus here on extended ID (EID) because it is easier to identify than narrow ID (informants disagree about when ID begins), and because informants generally considered EID to be more important and difficult to achieve. We recorded and transcribed the interviews, which lasted approximately two hours. We used qualitative analysis software (MaxQDA) to analyse them, coding all passages relating to organisational aspects of the ZAs as well as to the levels of EID and TD in the ZA bodies, projects and publications.

In addition, we collected the last application for creation or renewal submitted to CNRS by each ZA. These applications covered five-year periods and dated from 2017 to 2020 depending on the ZA. Following a template developed by CNRS, they consisted of four parts: i) a two-page overview indicating the members, bodies, academic and societal partners and the spatial extent of the ZA; ii) a ten-page summary of the past period, if applicable; iii) a ten-page project for the coming period and iv) appendices including lists of publications and projects associated with the ZA during the past period, if applicable.

Drawing on this material, we first identified the number and types of governing and advisory bodies of each ZA. We then evaluated their level of EID and TD, distinguishing three levels (low, intermediate and high). We considered that the TD level of a ZA governing and advisory bodies was low when none of these bodies involved societal actors or if one of them involved only societal actors; intermediate when some of them involved both research actors

²³ Out of the 22 ZA leaders we interviewed in total, 15 are men and 18 have a background in natural sciences (13 in life sciences, 5 in earth sciences).

and societal actors; and high when most or all of them did. We followed a similar logic to evaluate the level of EID, by focusing on the proportion of advisory and governing bodies involving both HSSs and life and/or earth scientists. We did a similar exercise to evaluate the level of EID and TD in the ZA research projects, basing our evaluation both on the interviews and on the applications for creation or renewal. We considered the level of EID (or TD) to be low when only a minority of projects involved both life or earth scientists and HSSs (or academic actors and societal actors), intermediate when this was the case for around half of the projects and high when this was the case for a majority of the projects. We based our evaluation of the level of EID in the publications on the list included in the applications for renewal. We considered the level of EID in publications to be low when less than 10% of peer-reviewed articles were co-authored by life or earth scientists and HSSs. All ZA leaders were given the opportunity to respond to our preliminary results, which led us to slightly modify our evaluation of EID in the research projects of one ZA.

Using univariate linear regression models (lm procedure in R), we analysed the existence of relationships between the following EID and TD levels: EID and TD levels in ZA bodies; EID and TD levels in ZA projects; EID levels in ZA bodies and projects; TD levels in ZA bodies and projects.

4. Results

4.1. [Tinkering with organisational arrangements](#)

All ZAs had one or several leader(s) and, except for ZA Plaine & Val de Sèvre, convened an annual general assembly. Otherwise, they had very diverse organisational features. The number and titles of their governing and advisory bodies varied greatly (for a detailed presentation, see Table 6). Some ZAs had up to five bodies beyond the leading team, others only two, one of which may have been dormant, such as the governing board of the ZA Alpes in 2020. The number of advisory and governing bodies also changed over time for a given ZA. For example, the ZA Terres Uranifères had recently set up a stakeholders' committee; simultaneously, the ZA Loire had decided not to set up a planned monitoring committee, which should have included local managers and stakeholders, because 'their involvement at the project and workshop site level has increased significantly in recent years and this level no longer seemed relevant' (except from the renewal application of ZA Loire). Thus, no single organisational arrangement prevailed over the others: each ZA established and tested its own organisational arrangements.

Table 6: The ZAs and their organizational arrangements

Name (year of official creation, year of last renewal)	Main topics	Members	Societal partners	Advisory and governing bodies		
ZA Alpes (2008, 2017)	Trajectories and functioning of mountain social-ecological systems in the Anthropocene	8 labs including 2 interdisciplinary labs and 1 lab in HSS	Protected areas, national alpine botanical conservatory, Grenoble Alpes Metropolis	Leading team Before 2020: 2 ecologists Since 2020: 1 soil scientist + 1 sociologist	Board of directors (“comité de direction”) Lab directors + directors of local scientific federations + representatives of supervising scientific authorities	Governing committee (“comité de pilotage”) Representatives of member labs + representatives of societal actors
ZA Antarctique et sub-Antarctique (2000, 2020)	Long-term dynamics of biodiversity and ecosystems of the French Antarctic and sub-Antarctic Territories	15 research programmes (including 1 in HSS)	Natural reserve (Terres australes et antarctiques françaises)	Leading team 2 life scientists	Scientific council (“conseil scientifique”) The PI of each research programme + leading team	Governing committee (“comité de pilotage”) Scientific council + scientific director of Institut Paul Emile Victor (IPEV) + director of the natural reserve
ZA Arc Jurassien (2013)	Impacts of the past and present evolution of climate and landscape on populations and communities, and on relationships between the	9 labs including 1 in HSS	Organisations for the study and prevention of zoonoses, Organizations promoting local cheese production, Hunting organizations, local water authorities, environmental authorities, farming authorities, conservationist NGOs, protected areas, national botanical	Leading team 2 life scientists	Steering and governing council (“conseil d’orientation et de pilotage”) Under construction Leading team + coordinators of scientific axes and of the « Observatories and modeling » workshop	Scientific committee (“comité scientifique”) Leading team + observatory coordinators + theme coordinators + directors of member and associate research units

	environment, ecology and human health in the Jura range		conservatory of Franche-Comté, communities					
ZA Armorique (2002, 2017)	Climate, agricultural and environmental policies, changes in land uses	9 labs including 1 in HSS	Farming organisations, regional environmental NGOs, local and regional communities, protected areas, local water authorities	Leading team 3 life/earth scientists	Scientific steering committee (“conseil d’orientation scientifique”) A new body designed to involve actors more strongly in scientific discussions and the definition of the ZA research strategy	Governing committee (“comité de pilotage”) Leading team + 1 representative per lab + 1 referent for the ZA urban site		
ZA Bassin du Rhône (2001, 2018)	Functioning, dynamics and restoration of the heavily transformed Rhône hydro-sociosystem	24 labs including 4 in HSS	Water authority (agence de l’eau Rhône-Méditerranée-Corse), Compagnie nationale du Rhône, Electricité de France, French biodiversity agency (OFB), protected areas, regional environmental authorities, Lyon metropolis, etc.	Leading team 2 vice-presidents elected by the governing board (one life scientist and one water scientist) + 1 director nominated by the board of directors	Board of directors (“comité de direction”) 20 representatives of member labs, including a minority of human and social scientists	<table border="1"> <tr> <td>Scientific coordination commission (“commission de coordination scientifique”) Members of governing board + persons in charge of scientific themes + persons in charge of key sites</td> <td>Advisory committee (“comité consultatif”) Scientific coordination commission + societal partners Each key site has its own advisory committee</td> </tr> </table>	Scientific coordination commission (“commission de coordination scientifique”) Members of governing board + persons in charge of scientific themes + persons in charge of key sites	Advisory committee (“comité consultatif”) Scientific coordination commission + societal partners Each key site has its own advisory committee
Scientific coordination commission (“commission de coordination scientifique”) Members of governing board + persons in charge of scientific themes + persons in charge of key sites	Advisory committee (“comité consultatif”) Scientific coordination commission + societal partners Each key site has its own advisory committee							
ZA Brest Iroise (2012, 2017)	Functioning and evolution of the coastal social-ecological system, in a context of change and with a view to	6 labs, mainly in life and earth sciences	Companies (Terra Maris), Océanopolis, Parc Naturel Marin d’Iroise, Brest Metropolis	Leading team – 1 bio-geo-chemist and 1 geomorphologist	Towards a scientific or a steering committee (“comité d’orientation”)? The creation of this committee was under discussion at the period	Governing committee (Comité de pilotage) Leading team + coordinators of scientific themes and transversal axes + representatives of scientific supervising authorities + societal partners		

	integrated management				of the last application for renewal. It was finally not created.	
ZA Environnement Urbain (2010, 2020)	Functioning of the urban social-ecological system centred on the Strasbourg conurbation and its relations with neighbouring social-ecological systems	12 labs including 3 in HSS and 2 interdisciplinary	Strasbourg Eurometropolis, Water agency, Environment and energy authorities, Local and regional communities, Environmental NGOs	Leading team 2 researchers + 2 representatives of Strasbourg Eurometropolis	Scientific council (“conseil scientifique”) 1 representative per lab (12) + 2 referents of thematic groups and transversal axes (coordinated by 2 people, if possible one research actor and one person from the Strasbourg Eurometropolis)	Governing committee (“comité de pilotage”) Leading team + scientific supervising authorities + representative of Strasbourg Eurometropolis
ZA Hwange (2010, 2020)	Functioning of the social-ecological system including Hwange national park	22 labs with a low involvement of labs in HSS (involved in general discussions rather than projects)	Zimbabwe national park, Forestry commission, Hwange Rural District Council, Zimbabwean farming authorities and veterinary services, NGOs: CAMPFIRE, conservation NGOs, French Embassy, Foundations, FAO	Leading team – 2 life scientists	Governing committee (“comité de pilotage”) Researchers particularly involved in the ZA activities (mostly ecologists)	Stakeholder meetings The ZA participates in i) a research platform called “Produce and conserve in partnership” (RP-PCP) that involve French research institutes and Zimbabwean universities, ii) stakeholder meetings, which are organized in the frame of collaborative projects and which involve societal actors (traditional chiefs, prefects, forestry agencies, conservation and development agencies, mining industries, tourism companies)
ZA Loire (2001, 2019)	Loire hydrosystem and human societies in the Loire watershed and their co-evolution	15 labs including 6 in HSS, and 1 interdisciplinary	Environment/Culture authorities/Water/Navigation/Hunting authorities, Local and regional communities, protected areas, French biodiversity agency, environmental NGOs, botanical national services, etc.	Leading team – 3 life scientists	Bureau (“bureau”) leading team + coordinators of structuring projects	Board of directors (“comité de direction”) lab representatives + bureau

ZA Moselle (2000, 2020)	Impact of human activities on the quality of water resources in the Moselle watershed	14 labs including 1 in economy, 1 in agronomy and 1 in geography	Farming organizations, Local and regional communities, Water/Forest authorities, Water agency, NGOs	Board of directors (“comité de direction”) – 4 life and earth scientists	Partnership committee (“comité partenaria”) Board of directors + coordinators of research axes + representatives of scientific supervising authorities + societal actors	Scientific council (“conseil scientifique”) Board of directors + coordinators of research axes + representatives of member labs
ZA Plaine & Val de Sèvre (2009, 2017)	Design and implement socio-ecological experiments to conserve biodiversity and investigate impacts of human activities on the functioning of agro-ecosystems	9 ecology labs including 1 research team in ecology that manages the ZA	Local communities, water syndicates, Hunting federations, organic farming federation, Environment/Farming authorities, NGOs, schools, local representatives, farmers, beekeepers, citizens	Leading team – 2 life scientists	Board of directors (“directoire”) Leading team + 5 other scientists deeply involved in the ZA Designed in 2017 but abandoned by 2020	A scientific and technical committee (“comité scientifique et technique”) involving researchers from the ZA managing team, other researchers and societal partners was envisaged in 2020.
ZA Pyrénées Garonne (2017)	Dynamics of interactions between human societies and the functioning of ecosystems in the Pyrenees and the Garonne watershed	17 labs, including 4 in HSS and one interdisciplinary	Water companies, Adour-Garonne Water agency, Water/Forest/Farming/Environment/Hunting/Culture authorities, farming organisations, local and regional communities, Toulouse metropolis, botanical services, protected areas, environmental NGOs.	Leading team – 2 life and earth scientists	Scientific committee (“comité scientifique”) Coordinators of structuring research questions + coordinators of main research sites + coordinators of the ZA observatories	Governing committee (“comité de pilotage”) Board of directors + heads of each member lab + representatives of scientific supervising authorities représentants des tutelles + societal partners
ZA Seine (2001, 2020)	Seine watershed : functioning of the watershed as a social-	Comprises 3 programmes (PIREN-Seine,	Example of PIREN Seine : Seine-Normandie water agency ; water sanitation syndicate, local communities (Large Paris Metropolis, Paris municipality,	Leading team – 3 scientists including 1 in HSS	Scientific council (“conseil scientifique”) One for each programme	Council of institutional partners (“conseil des partenaires institutionnels”) One for each programme

	ecological system (PIREN-Seine), flows of urban micropolluants (OPUR), restoration of the ecological functioning of an anthropised estuary (Seine-Aval)	OPUR, Seine-Aval) involving 64 labs ; each programme has its own sites, topics and sites.	etc.), Regional water syndicate, Water/Navigation authorities, Water companies						
ZA Terres Uranifères (2015, 2019)	Short and mid-term risks of low-dose radionuclides for people and ecosystem services	26 labs and a multidisciplinary environmental research federation Recent arrival of some labs in HSS	Nuclear safety authority, regional environmental authorities, manager of radioactive springs, company owning regulated area, natural regional park, 3 local communities, local NGO for the control of radioactivity	Leading team 3 CNRS researchers (physics and life sciences)	Governing committee ("comité de pilotage") One representative per member lab ; project and axis coordinators , data management coordinator	Supervisory committee ("Comité des tutelles") representatives of CNRS and of research partners	Scientific council ("conseil scientifique") 5 people in 2019, including 1 in HSS	Coordinators of overarching projects	Committee of stakeholders (comité des parties prenantes) Under construction

4.2. Quasi boundary organisations

All ZAs clearly stood at the interface between science and policy. They encouraged using what can be considered boundary objects to facilitate collaboration between research actors and societal actors. This is visible in the social-ecological systems they identified. For example, the ZA Arc Jurassien considered the meadows used to produce a local cheese (*comté*) as a key social-ecological system; this social-ecological system was meaningful for both research actors and societal actors (farmers, cheese producers and local representatives), but they related to it in different ways. Another example of a boundary object was the very perimeter of the ZAs, which in most cases had been delineated to include important research sites and to ensure that the ZAs were relevant entities for societal actors. This was notably the case for ZAs associated with a mountain range (the Alps, the Pyrenees or Jura) or a large watershed (the Seine, Loire, Rhône or Moselle); their extension allowed research actors to take into account various gradients and fitted territorial units, such as mountain range committees or watershed agencies, that were relevant for societal actors. Moreover, all ZAs involved both societal and research actors, albeit to very different extents, as well as individuals who straddled science and policy (e.g., individuals with a robust scientific background working in protected areas, local communities or water agencies). In turn, they submitted their outcomes and project to CNRS only: they were essentially accountable to the research world, rather than to both science and policy, as the definition of boundary organisations would require. Thus, ZAs fully met the two first criteria defining BOs (boundary objects and involvement of actors from both worlds), and only partly the third one (accountability to both science and policy).

4.3. Research-based meta-organisations

During the interviews, the ZA leaders designated the people participating in their activities as their 'members'. Some had established a list of individual members of their ZA, for example by drawing on the list of participants in the annual general assembly: 'Membership is relatively flexible, well, you had to know who was a member of the general assembly. However, this is very difficult to determine, so we have a real problem of governance, which we are having trouble resolving' (interview with a leader of a ZA)²⁴. The leaders of a ZA envisaged establishing such a list and asking their 'members' to agree to a charter indicating their rights and duties. The CNRS institute in charge of ZAs, entitled *Institut Ecologie et Environnement* (INEE), also encouraged them to indicate how many 'members' they actually had. In other words, their leaders and supervising authorities saw ZAs as individual-based organisations.

However, the creation and renewal applications clearly showed that the members of ZAs were not individuals, but research labs (or research programmes in the case of ZA

²⁴ Unlike the excerpts from creation and renewal documents, interview excerpts are anonymised.

Antarctique et sub-Antarctique). Indeed, these documents started with a list of the research units that were members of the ZA at the date of application. As their members were themselves organisations, ZAs can be defined as MOs, and their national 'network' as a meta-meta-organisation (Ahrne and Brunsson 2005; Berkowitz et al. 2022b). This has several important implications. First, there was little turnover in membership; in particular, member labs seldom left a ZA. Second, some member labs were more powerful than others for various reasons: because they had played a major role in the creation of a ZA; because they were larger, had more resources or managed major research sites; or because they were closer to INEE. The ZA leaders were almost always from these labs; INEE required that at least one co-leader of the ZAs belong to a lab affiliated with INEE. The few member labs with a strong HSS orientation had joined the ZAs only recently and had less weight than the member labs with a strong life sciences orientation that had contributed to the creation of ZAs. Third, with few exceptions (e.g., ZA Bassin du Rhône), ZAs tended to have far fewer human and financial resources than their members. ZAs received very limited annual financial support from INEE, which only some of them managed to supplement, for example through partnerships with societal actors interested in their activities or through the organisation of joint research calls with organisations sharing similar goals. Most ZAs had insufficient financial means to hire staff to help them achieve ITDR; in fact, their status did not allow them to recruit, receive funds or establish partnerships, so they necessarily depended on their member labs to carry out these activities. Fourth, any member of the member labs could participate in and benefit from the activities of the ZAs, even if they did not share their goals. ZA leaders had to accept that participants in the ZA activities were not always interested in ITDR: 'We try to find gentle ways for people to adhere to the collective approach of the ZA; if we impose it with a steamroller, the risk is that no one will be behind us when we turn around'.

Another important point is that societal actors were not members but partners of the ZAs. This means that they were not on an equal footing with the member labs and did not have the same rights. For example, the ZA Alpes could only fund projects that were led by a member of one of its member labs. ZAs were therefore research-based meta-organisations, although some of them had established and maintained strong partnerships with a variety of societal actors. Thus, they fulfilled only some of the conditions identified by Berkowitz et al. (2020) for meta-organisations to deal effectively with wicked environmental problems: they were formal, spatially embedded, but not multi-stakeholder, meta-organisations and they were not accountable to societal actors, as mentioned earlier when discussing them as boundary organisations.

4.4. [A limited level of ITD in the ZA bodies, projects and peer-reviewed articles](#)

We found the level of TD to be low in 10 ZAs (see Table 7), in particular in their governing bodies (see Table 6 for a detailed presentation). It was high in only one ZA (ZA Environnement Urbain), the leaders of which had decided that research actors and societal actors would sit equally on all the ZA bodies, including the leading team. Societal actors

participated in a governing body and played a significant role in decision-making in few ZAs. This was the case for ZA Alpes, and it was not by accident: protected area managers had played a major role in its creation, and a strong collaborative culture had been nurtured for decades among protected area managers and research actors. The level of EID in ZAs tended to be higher than the level of TD. However, it was low in two ZAs, and medium in most. Importantly, a large majority of the ZA leading teams did not include HSSs.

Table 7: Levels of extended interdisciplinarity in the ZA bodies, projects and peer-reviewed publications and levels of transdisciplinarity in the ZA bodies and projects

(1 = low, 2 = intermediate and 3 = high)

Name of ZA	Level of extended interdisciplinarity in			Level of transdisciplinarity in	
	advisory and governing bodies	projects	peer-reviewed articles	advisory and governing bodies	projects
Alpes	2	1	1	2	3
Antarctique et sub-Antarctique	1	1	1	1	1
Arc jurassien	2	2	1	1	2
Armorique	3	3	1	2	3
Bassin du Rhône	2	1	1	1	3
Brest Iroise	2	1	1	1	2
Environnement urbain	3	3	1	3	2
Hwange	2	2	1	1	3
Loire	2	1	1	1	1
Moselle	2	1	1	1	1
Plaine & Val de Sèvre	2	2	1	1	3
Pyrénées-Garonne	2	2	NA	1	1
Seine	2	1	1	2	2
Terres uranifères	1	2	1	1	1

Concerning the levels of TD and EID in the ZA projects, we found much variation across the ZAs. They were high in the projects supported by five and two ZAs, respectively. The level of TD tended to be higher than the level of EID in the projects, contrary to what we found in the ZA bodies. In other words, the research projects supported by ZAs more often involved societal actors than HSSs, whereas the opposite was true for the ZA bodies.

We found that the level of EID in all the ZA peer-reviewed publications was low, which is consistent with the results found by Dick et al. (2018) for the three ZAs included in their international study of LTER platforms' outputs (Armorique, Bassin du Rhône, Environnement

Urbain). Focusing on peer-reviewed articles is known to lead to underestimation of ID productions (Katz and Martin 1997; Roux et al. 2010). However, the consideration of other types of written publications in the publication lists, including reports, did not change the overall picture. It should also be noted that some applications went back several years. The interviews suggested that the level of EID in publications had recently increased, without changing the situation radically. Overall, the publications associated with the ZAs remained mainly disciplinary or narrowly interdisciplinary.

We found a statistically significant positive relationship between the level of EID and the level of TD in the ZA bodies (adjusted $R^2 = 0.535$, $F_{1,12} = 15.96$, $P = 0.002$), and between the level of EID in the ZA bodies and projects (adjusted $R^2 = 0.526$, $F_{1,11} = 14.30$, $P = 0.03$). No other tested relationships were significant.

In the interviews, the ZA leaders identified a number of obstacles to EID and TD. Some of these obstacles may be related to the organisational characteristics of the ZAs and their societal partners, although our informants did not mention this relationship.

4.5. Obstacles to EID and TD associated with organisational issues

We observed an enduring difficulty in opening up the ZAs to HSSs. Most ZA leaders reported having struggled to involve HSSs in the ZA bodies and projects: ‘We still have difficulty in mobilising HSSs, certainly because we are doing it the wrong way. Personally, I did not know these sciences well. We don't have the same protocols, we don't have the same publication strategies, we don't really have the same way of working at the moment. We are getting closer little by little, but there is still a lot of work to do.’ ZA leaders identified the fear of being instrumentalised by natural scientists and turned into social engineers as one major reason for the HSSs’ reluctance to get involved in a ZA. The ZAs mainly oriented towards natural sciences particularly faced this difficulty. However, it was also the case for the ZA Plaine & Val de Sèvre, which had increasingly sought to open up to HSSs and experiment with ways of transforming its territory, and where attempts to closely and sustainably involve sociologists and economists sharing this goal had so far failed.

Concerning TD, the ZA leaders mentioned different obstacles depending on the type of societal organisations involved. They reported that research actors were often reluctant to involve politically and economically powerful societal actors out of fear of jeopardising the ZA’s scientific autonomy: ‘We had a debate about involving the SNCF [*national railway company*]. When this possibility was raised, the scientific council objected on the grounds that it might impair our way of working and our results’. The leaders of another ZA decided not to involve two powerful organisations in their ZA’s field of investigation until the ZA had defined its own scientific strategy: ‘since this year, we have integrated [*the two organisations*] into the scientific projects, now that we have a robust academic scientific strategy, and insofar as we have been able to show that we remain neutral with regard to these aspects and that we are here to do science and not to proselytise for one side or the other’. Involving weak societal

actors raised other types of challenges. Politically weak actors might fear that the ZA research projects would challenge and threaten their legitimacy: 'On some issues, it was and is sometimes a bit difficult because they [*a public service managing natural resources*] are always afraid of being contested.' Economically weak organisations demanded financial compensation for the participation of their staff in ZAs: 'Bringing in protected area managers for one or two days cost me €20,000 in a €200,000 project. It's horribly expensive!' Finally, some ZA leaders found it almost impossible to involve citizens who were not part of a formal organisation: 'Research actions involving citizens cannot be funded, at least not easily. Funders ask us for letters from partners, which can be NGOs, but registered NGOs. Citizens' collectives are not NGOs, they are not trade unions, they are not declared, they exist but are not recognised.'

5. Discussion and conclusion

ZAs were explicitly established to spur environmental ITDR in France (Levêque et al. 2000). They have played an important role in bringing together research actors from distant scientific domains and societal actors. They have initiated many encounters and contributed to mutual learning and trust building (Mauz et al. 2012), which are crucial to ITDR (e.g., Cundill and Roux 2015).

In this article, we focused on organisational issues in ZAs, which have received little attention in research. In the following, we discuss 1) the limited impact of ZAs on the reorganization of research communities; 2) the relatively limited level of EID and TD in their bodies, projects and publications; and 3) the contribution of boundary organisation and meta-organisation concepts to our study and vice versa. We conclude with a plea for enhanced reflexivity on organisational issues in organisations committed to addressing wicked environmental problems through ITDR.

5.1. [A limited impact on the reorganisation of research communities](#)

The reorganisation of research communities in ZAs to achieve ITDR has so far been limited. Undeniably, both research actors and societal actors are involved in the functioning and dynamics of ZAs, and sometimes in their creation. However, they generally consider that they belong to two distinct social worlds and that maintaining the boundary between them is important, even if this boundary is moving or blurred and other boundaries between societal actors and between research actors are also relevant. As for the ZAs, they regard research labs, but not other societal organisations, as their direct members. Moreover, a marked imbalance persists among research actors, to the detriment of HSSs.

The limited impact of ZAs on the reorganisation of research communities suggests that the calls for ITDR have not been sufficient to counterbalance the weight of the discipline-based

structuring of scientific research. In the tension between discipline-based science and ITDR, the former continues to be stronger, at least in research-based MOs such as ZAs. The discrepancy we have highlighted between the ideals of ITDR and what is actually achieved is not restricted to French LTSER platforms but applies to LTSER platforms internationally (Zimmerman and Nardi 2010; Mauz et al. 2012; Dick et al. 2018; Holzer et al. 2018).

However, things have recently started to change (Dick et al. 2018). For example, there are now more HSSs in the ZA governing bodies and even leading teams, including in ZAs originally restricted to natural sciences. Moreover, the leaders of several ZAs have recently become more openly engaged in ITDR, and the current and former leaders of the national 'network' of ZAs have even become ITDR champions (see Ragueneau 2020; Bretagnolle 2021; Berthet et al. 2022). The high proportion of inter- and transdisciplinary contributions to the colloquium of the 'network' in 2020 (Falk and Charpentier 2021) is another sign of this evolution, which seems to have been strongly encouraged by the recent adoption of a common conceptual framework centred on the notion of social-ecological ecosystem (Bretagnolle et al. 2019) and the emergence of sustainability science in France. Although they share the inertia common to MOs (König et al. 2012), it is becoming increasingly difficult for ZAs to only pay lip service to ITDR.

5.2. Limited levels of EID and TD

The levels of EID and TD we found in bodies, projects and publications were surprisingly low for organisations committed to ITDR. A question logically comes to mind here: is this a consequence of the limited impact of ZAs on the reorganisation of research communities? Arguably, the fact that ZAs are research-based MOs reduces the range of organisational arrangements available to them. In particular, they cannot try out arrangements in which societal actors are members and not just partners. Moreover, their historical roots in natural sciences make it difficult to involve HSSs. In other words, the fact that they are anchored in natural sciences frames and limits their capacity to achieve ITDR. However, the case of ZAs only enabled us to shed some light on the relationship between organisation and research content. Clarifying this relationship further would require extending the investigation to other types of organisations, beyond the case of research-based MAs such as ZAs. This would allow for study of the effect of considering societal actors as genuine members of an organisation aiming to promote ITDR, rather than involving them as partners of a research-based MO.

It is important to note that there were both similarities and differences between levels of EID and TD in the ZA bodies and projects. The positive relationship between EID and TD in governing and advisory bodies may be due to the HSSs' capacity to convince their colleagues that these bodies should be more open to societal actors. It is probably no accident that a social scientist was co-leading the sole ZA with systematically transdisciplinary bodies (ZA Environnement Urbain). EID in bodies and EID in projects are positively related, but this is not the case for TD. Research actors can clearly collaborate with societal actors without involving

them robustly in advisory and governing bodies, which is the path taken by at least some ZAs (e.g., ZA Plaine & Val de Sèvre, ZA Hwange). As to the low level of EID in publications irrespective of the organisational arrangement, which may come as a surprise, it may be partly due to the very recent rise of EID in bodies and projects in most ZAs: achieving publications co-authored by natural scientists and HSSs takes more than a few years (Dick et al. 2018).

5.3. Contribution of boundary organisations and meta-organisations concepts to our study and vice versa

The BO and MO concepts enabled us to define the kind of organisations that ZAs are (quasi BOs and research-based MOs) and to understand their limitations as organisations committed to ITDR. Indeed, both fields of literature have identified a set of conditions that organisations should fulfil to effectively bring together research actors and societal actors around environmental issues. This has helped us grasp that ZAs meet only some of these conditions: they are formal, place-based, meta-organisations that involve a variety of actors and rely on boundary objects. On the other hand, they are not accountable to societal actors, a condition highlighted by both concepts. Furthermore, they do not consider societal actors as members, but as partners. Because it pays special attention to organisational issues and distinguishes between membership and partnership, the MO concept enabled us to highlight this aspect more clearly than the BO concept.

The distinction between membership and partnership, which we found particularly illuminating for our study, has recently been discussed in the MO literature. In their study of the compositional dynamics of a health MO, Cropper and Bor (2018) underline the major contribution of partners, not just members, to the functioning and dynamics of the MO. They consider that Ahrne and Brunsson (2005) have overemphasised the distinction between members and partners and suggest that it should be toned down. On the contrary, we believe that drawing this distinction is an important advantage of the MO concept in clarifying organisational issues and understanding one source of limits to the ability of organisations to achieve ITDR. Our study also underlines the importance of examining power asymmetries between members. In our case, early members were clearly more influential than late ones, but further studies are needed to clarify the influence of seniority as there may be confounding factors (early members happen to be natural sciences labs).

Despite its analytical value in examining organisational issues, the MO concept has intriguingly not been mobilised thus far in the literature on LTSER platforms. In contrast, we regularly encountered the BO concept in this literature and in our interviews with ZA leaders. Thus, it seems that ZAs are readily recognized as BOs but ignored as MOs. Far from being specific to ZAs, this ignorance is common in MOs (Ahrne and Brunsson 2008, pp. 9-12). We offer three explanations for this difference in the use of the two concepts, two of which are

related to their respective dynamics and characteristics and the third to the roles and positions of ZA leaders.

First, the BO concept has had both the time and ease to spread in the LTSER community as it dates back to the early 2000s, and was developed from the outset for organisations bringing together research actors and societal actors. In contrast, the MO concept emerged a few years later and was initially developed for homogeneous MOs. As a result, the use of the MO concept for organisations committed to ITDR is still in its infancy. Second, the MO concept may be considered 'boring' (Ahrne and Brunsson 2005; Berkowitz and Dumez 2016), whereas the BO concept has a high capacity to convey positive value (Gustaffson and Lidskog 2018). It is easily appropriated by ZA leaders, not so much because it accurately describes their organisation, but because it is rhetorically effective in portraying ZAs in a positive way: as organisations that help bring science and policy together, without pointing out organisational issues such as hierarchy between members or the distinction between members and partners. Third, ZA leaders are also leaders and members of projects that involve both research actors and societal actors, so the BO concept fits with their perception of ZAs as organisations that bring together different communities. In turn, the fact that the members of ZAs are labs and not individual research or societal actors remains minimally visible at the level of the ZA leaders, and even less so at the level of the mere participants in ZA activities. The invisibility of these organisational issues makes discussing them all the more important.

5.4. [Need for pragmatic reflexivity](#)

Organisational issues are rarely discussed collectively in ZAs, either at a national or individual ZA level. This lack of collective reflection and debate prevents a full understanding of the consequences of ZAs being research-based MOs and of organisational issues more generally. ZA leaders do not associate obstacles to ITDR with the kind of organisation ZAs are. Enhanced collective reflection could also help them take full advantage of the range of organisational arrangements they can experiment with. The idea is certainly not to identify an organisational arrangement that would be suitable for all ZAs. Rather, it is to draw on a diversity of experiments at work to feed a pragmatist approach to reflexivity regarding the organisation of ZAs, in line with the open-ended and adaptive character of ITDR (Popa et al. 2015).

Finally, it is important to recall that ITDR is a means to help face contemporary wicked environmental problems rather than an end in itself. To what extent it contributes to achieving this goal is a question we did not address here, but which is of paramount importance.

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This chapter has explored how research communities are reorganising themselves in the face of increasing calls for inter- and transdisciplinarity. We have applied a pragmatic lens to study the French network of ZAs. Our results show that ZAs are not only quasi boundary organisations, but also research-based meta-organisations, which has important implications for their functioning and dynamics. In particular, the focus on the concept of meta-organisations has allowed to shed light on the issues associated with membership and leadership. We have shown that societal actors are not members, but partners of ZAs and do not have the same rights as research actors. Our results also show that the level of inter- and transdisciplinarity in ZAs' advisory and governing bodies, projects and peer-reviewed articles has recently increased, but remains relatively low, except for the projects. Overall, we highlight the obstacles associated with the organisational arrangements that research communities can experiment with and call for pragmatic reflexivity related to organisational issues. Our findings suggest that the type of organisations with which ZAs are associated has an impact on research productions and should not be neglected.

Whereas this chapter has focused on a practical issue that arises at the level of the community level, the next two chapters focus on practical issues at the level of research projects. In particular, the next chapter examines the distribution of roles among all the actors involved in TRSS projects.

Chapter II. Participation issue: Involving actors and distributing roles in TRSS processes

This chapter is based on a paper to be submitted to *Sustainability Science*, entitled 'Actors and their roles in transdisciplinary research in sustainability science: an exploratory study of research projects in the French LTSER network'.

Preamble

The previous chapter has focused on a practical issue at the community level and suggested, based on the case of the French Zones Ateliers (ZAs), that research communities engaged in transdisciplinary research in sustainability science (TRSS) have so far reorganised themselves to a limited, albeit increasing, extent.

The next chapter proposes to shift attention to the practical issues that arise at the level of the research projects carried out in these communities and, more specifically, to focus on the societal actors involved and the distribution of roles between all actors (see Figure 2 of the Introduction). Indeed, the involvement of societal actors is a main characteristic of TRSS, which is expected to bring various benefits: increasing the effectiveness of research by bringing together different types of expertise and knowledge (Lang et al. 2012; Wiek et al. 2012), increasing the legitimacy of the research and its outputs, and empowering societal actors (Scholz and Steiner 2015). Much of the literature has therefore emphasised the need to involve all relevant actors in TRSS projects at the right time. TRSS projects can therefore be expected to involve a wide range of societal actors and allow them to perform a large number of roles in these projects. To what extent is this the case? What kind of societal actors are involved in TRSS projects, and what roles does each category of actors actually perform? These questions remain unexplored.

Again, the Zones Ateliers present an appropriate case study, as they host a large number of transdisciplinary projects that bring together a variety of research actors and societal actors around diverse sustainability problems. They therefore allowed for the construction of a sample of TRSS projects to explore the involvement of actors and the distribution of roles between them.

1. Introduction

Contemporary societies are plagued by numerous interrelated, complex and pressing problems such as war, sanitary and food crises, climate change or biodiversity loss. As early as the 1960s, urban planners (Churchman 1967; Rittel and Webber 1973) qualified such problems as ‘wicked’ and defined them as ‘a class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing’ (quoted in Churchman 1967, p. B141). Since then, wicked problems have been identified as being particularly prevalent in the areas of health, the environment, new technologies, and sustainability. We focus here on sustainability problems, which have given rise to a new discipline in the early 2000s, sustainability science (Kates et al. 2001). Sustainability science is committed to producing knowledge that will enable contemporary societies to move towards more sustainable futures (Komiyama and Takeuchi 2006; Kates 2011).

It is commonly assumed that addressing sustainability problems, especially when they are wicked, requires the participation of researchers from different disciplinary backgrounds as well as actors interested in, or affected by the problems at hand (Funtowicz and Ravetz 1993; Hirsch-Hadorn et al. 2008; Jahn et al. 2012; Brandt et al. 2013). The participation of societal actors in research processes is expected to bring a series of benefits (Polk 2014; Musch and von Streit 2020): increasing the effectiveness of research by bringing together different kinds of expertise and knowledge (Lang et al. 2012; Wiek et al. 2012), increasing the legitimacy of the research and its outputs, and empowering societal actors (Scholz and Steiner 2015). Defined as ‘a reflexive research approach that addresses societal problems by means of interdisciplinary collaboration as well as the collaboration between researchers and extra-scientific actors’ (Jahn et al. 2012, p. 4), transdisciplinarity has therefore been a cornerstone of sustainability science since its inception (Komiyama and Takeuchi 2006). In particular, knowledge co-production, ‘an iterative and collaborative process involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future’ (Norström et al. 2020, p. 183), has become an ideal for sustainability science over the last two decades (Clark and Dickson 2003; Beiluch et al. 2017; Mielke et al. 2017; Caniglia et al. 2020; Musch and von Streit 2020).

Many studies have examined how research actors should engage with societal actors in transdisciplinary research in sustainability science (TRSS) in order to achieve societally and scientifically relevant outcomes. They have highlighted the importance of factors such as trust (Harris and Lyon 2013), careful selection and preparation of case studies (Horcea-Milcu et al. 2022), early involvement of all relevant societal actors in the projects (Lang et al. 2012), and the formulation of operational concepts to open up design spaces and engage with a wide range of stakeholders (Berthet et al. 2022). Some studies have focused on the respective concrete contributions of research actors and societal actors to transdisciplinary projects, often using the concept of roles (Pohl et al. 2010; Enengel et al. 2012; Wittmayer et al. 2017;

Hilger et al. 2021; Kruijf et al. 2022). As conceptualised in interactionist and constructionist sociology, roles can be defined as the ‘set of recognizable activities and attitudes used by an actor to address recurring situations’ (Wittmayer et al. 2017, p. 51). Two characteristics of roles are important to keep in mind here. First, actors do not only play predefined roles, but also actively adopt roles and adapt them to their specific situations. Roles are therefore performed rather than played. For example, the roles of research actors have been shown to shift from objective observers to reflexive researchers and change agents (Wittmayer and Schöpke 2014) when engaging in TRSS (Pohl et al. 2010; Lang et al. 2012; Popa et al. 2015; Schneider et al. 2021). Second, actors negotiate their roles with other actors with whom they interact, so that the roles of actors involved in a situation are not independent of each other and form a dynamic system. These two characteristics also apply in the case of TRSS, where research actors interact with societal actors. They invite us to consider the roles of all of them as open-ended rather than predetermined, and to study them simultaneously rather than separately. However, this has rarely been the case in the literature: most studies have tended to focus on the roles of either research actors or societal actors, assigning them a limited number of predefined roles (but see Mobjörk 2010; Hilger et al. 2021).

In this paper, we not only seek to identify the roles performed by the different actors involved in TRSS, but also to go a step further by analysing how these roles are distributed among them. Analysing the distribution of roles is important because it clarifies which actors are involved in TRSS, and to what extent and in what ways. Our empirical analysis is based on a sample of transdisciplinary research projects selected from a French research infrastructure with a strong sustainability science orientation. The paper is structured as follows: first, we start with a literature review on actors and their roles in TRSS. We then present our sample of research projects and the method we used to identify the actors involved, the roles they performed and the distribution of roles among them. In the results section, we show that societal actors have become major role performers in this sample of TRSS projects, but to very different extents depending on the category of actor. In particular, citizens appear to perform a limited number of roles in a limited number of projects, pointing to an important weakness of TRSS projects. Finally, we discuss the contribution and limitations of our analysis of TRSS projects in terms of roles and role distribution, as well as perspectives for future research.

2. Literature review: actors and their roles in transdisciplinary research in sustainability science

2.1. Typologies of actors

TRSS involves researchers, i.e. people who conduct research as their main profession and act as ‘certified experts’ in their function in a given field (Fritz and Meinherz 2020, p. 43), as well as students and technicians, the latter supporting researchers and students in research processes in crucial but often little visible ways (Shapin 1989). Students and early-career researchers have been shown to make a crucial contribution to TRSS (see e.g. Engengel et al.

2012; Deutsch et al. 2021; Sellberg et al. 2021; Horcea-Milcu et al. 2022; Pachoud et al. 2023). We therefore find the term researcher restrictive and prefer to speak of research actors. Deciding what to call the other actors involved in TRSS is more difficult. The literature offers a wide range of terms that can be divided into three groups. In the first group, these actors are negatively referred to as what they are not: 'non-scientists' (Walter et al. 2007, p. 325), 'non-academic actors', 'non-certified experts' (Di Giulio and Defila 2017) or 'extra-scientific actors' (Felt et al. 2012; Jahn et al. 2012). On the other hand, the second group refers to them in a positive way, as endowed with specific attributes, skills or competences: 'experience-based experts' (Di Giulio and Defila 2017), 'practitioners' (Klein et al. 2001, p. 4) or stakeholders (Bracken et al. 2015; Thompson et al. 2017). Finally, they are sometimes referred to as 'co-researchers' (Hartley and Benington 2000; Paganini and Stöber 2021). The latter term underscores that the boundary with research actors becomes blurred when the other actors are involved in all, or at least many, stages of the research process: for example, they may participate in the elaboration of research questions, the selection of research methods, the discussion of the preliminary results and the dissemination of the final results. Here, we rather follow Mobjörk (2010) and refer to them as societal actors, a term that has the advantage of leaving open the roles they can perform. We define a societal actor as an individual or institution outside academia that is formally or informally involved in a transdisciplinary research process by participating in any activity of this process.

Different approaches to the participation of societal actors in sustainability science have been identified, leading to several typologies (Mielke et al. 2017; Musch and von Streit 2020). In a review of 31 studies in TRSS, Musch and von Streit (2020) have shown the dominance of a functional and competitive approach to participation, characterised in particular by an over-representation of actors regarded as experts, to the detriment of other societal actors and 'ordinary' citizens.

2.2. Typologies of actor roles

Much of the literature on knowledge co-production has distinguished between the roles of research actors and of societal actors in TRSS (Pohl et al. 2010; Felt et al. 2012; Wittmayer et al. 2017; Caniglia et al. 2020). For example, Wittmayer and Schöpke (2014) identify five ideal-typical roles of research actors: change agent, knowledge broker, reflective scientist, self-reflexive scientist and process facilitator. Through a study of projects in a funding programme for participatory sustainability research, Felt et al. (2012) identify four main roles that researchers expect societal actors to perform: providing or facilitating access to information or data for research actors; supplying data; providing feedback on the knowledge produced; and disseminating research results.

The above studies tend to focus on either research actors or societal actors and then typify the roles they perform or attribute to others. In contrast, Mobjörk (2010) has examined the involvement of both research actors and societal actors in TRSS, distinguishing between

participatory transdisciplinarity, where societal actors and research actors are equally involved in the knowledge production process, and consulting transdisciplinarity, where societal actors simply respond and react to the research conducted. More recently, Hilger et al. (2021) have conducted a systematic literature review to identify all the activities that can take place in TRSS. On this basis, they have defined 15 roles, each corresponding to a subset of these activities. For example, the role of data supplier includes two activities: i) responding to surveys or interviews, and ii) providing information or data and supporting data collection. Only in a second step do the authors consider which actors fulfil which roles. They find that some roles are more typical of the research actors (e.g. knowledge collector and scientific analyst) or societal actors (e.g., data supplier), while others (knowledge co-producer or results disseminator) are often shared by both types of actors. However, they do not pre-determine the roles of the different actors, which allows them to highlight the variety of roles, including unexpected ones, that both research actors and societal actors can perform in TRSS. Their approach seems particularly relevant not only to identify the roles performed by each actor, but also to empirically investigate the distribution of roles among all actors involved in TRSS projects, as illustrated below.

3. Research method

3.1. Focus on the French network of Zones Ateliers

To examine the distribution of roles in TRSS projects, we focused on the French network of Zones Ateliers (Bretagnolle et al. 2019). In addition to facilitating data collection, constructing a sample from a single national network facilitated the development of a consistent typology of actors, the analysis of their roles in research projects, and the comparison of projects. This network was created in the early 2000s by the French National Centre for Scientific Research (CNRS) to promote place-based research on social-ecological systems²⁵ under global change (Lévêque et al. 2000; Bretagnolle et al. 2019). As the French version of the international LTSER sites, the Zones Ateliers (ZAs) aim to bring together research actors from different disciplines and societal actors around problems of interest to them all. To date, there are 15 ZAs in different social-ecological contexts, offering a wide range of TRSS projects.

3.2. Selection of a sample of research projects

Here, research projects are defined as a ‘temporally, financially and staff-wise limited unit(s) of activities in relation to one or more related research goals’ (Newig et al. 2019, p.

²⁵ The concept of social-ecological systems, which emerged in the 1990s, emphasises the need for a systemic approach to the study of social and ecological systems (Berkes and Folke 1998).

149). They are relatively easy to identify, meaningful to their participants and therefore, despite some limitations (Pregernig 2006), a convenient unit of analysis for TRSS. We used the sample of projects that we had constructed for a previous study of TRSS, based on interviews with the leaders of each ZA. However, we had to exclude three projects for which, despite our efforts, we were unable to obtain sufficient information about the actors involved and their activities in the project. We thus ended up with a sample of 14 projects, spread across all but three ZAs.

3.3. Analysis of actors, actor roles and role distribution

Building on Hilger et al. (2021), we identified the actors involved, the roles performed by each of them, and analysed the distribution of roles in each project and in our overall sample.

In terms of actors, we used the four broad categories of societal actors identified by the OECD (OCDE 2020) in its study on the use of transdisciplinary research to address complex societal challenges: public sector, private sector, civic sector, and citizens/communities. For the first three categories, we further distinguished between different types of actors that were commonly represented in our sample, in order to get a more accurate picture of their diversity. We divided the public sector category into three subcategories (nature managers, authorities at different spatial levels, consular chambers²⁶), the private sector into two subcategories (private and semi-public companies, primary and tertiary sector professionals) and the civic sector also into two subcategories (nature users and NGOs with a primary environmental focus, other nature users and NGOs). We did not divide citizens into subcategories. We thus obtained eight subcategories of societal actors, nested within the four OECD categories. We looked at the number of subcategories of societal actors involved in each project. We considered the diversity of societal actors to be low if this number was one or two, medium if it was three or four, and high if it was more than four. We also looked at the diversity of societal actors in the overall sample. Note that we did not distinguish between different types of research actors.

In terms of actor roles, we adapted the typology developed by Hilger et al. (2021) to our case study, by merging the roles of i) choreographer and coordinator, ii) facilitator and intermediary, and iii) results disseminator and communicator, as they systematically involved the same actors in our sample. We also decided to eliminate the roles of self-reflexive participant and troublemaker, for which we lacked information across all projects. We therefore ended up with a typology of ten roles (see Table 8). We identified the roles performed by each i) actor and ii) broad category of actors in each project.

²⁶ Consular Chambers, which include Chambers of Commerce and Industry, Chambers of Crafts and Chambers of Agriculture, aim to promote economic development.

Table 8: Typology of actor roles adapted from (Hilger et al. 2021)

	Roles	Examples of activities
1	Choreographer-coordinator	Organise and structure the process, lead the process
2	Facilitator-intermediary	Facilitate and encourage knowledge integration through e.g. the organisation and moderation of meetings or workshops; mediate between different perspectives and viewpoints
3	Knowledge Collector	Collect data (e.g. interviews, observations, surveys)
4	Knowledge Co-Producer	Engage in knowledge co-production processes from the first phases of research process (define research goals and research question; select, discuss, or develop methods and tools; discuss (final) results and/or derived recommendations)
5	Field Expert	Contribute context-specific knowledge
6	Data Supplier	Respond to surveys or interviews; provide information or data
7	Results Disseminator-communicator	Translate and disseminate results and raise awareness; engage in formal/informal communication
8	Practice Expert	Contribute expertise and application-oriented knowledge; engage in or support and experiment/real-life change
9	Scientific Analyst	Contribute to scientific knowledge ; evaluate the process; carry out a system or actor analysis
10	Application Expert/change agent	Test and adapt the project results in the application context; apply process results or potentially introduce them into the decision-making process

In terms of role distribution, we looked at which actors performed which roles in each project, and then calculated the number of roles performed by the broad categories of actors (i.e., research actors and OECD categories of societal actors). We calculated the mean and variance of the number of roles performed by the broad categories of actors for each project, and arbitrarily defined five levels of role distribution: The distribution of roles was considered to be very low if the mean of the number of roles was less than 2,5; low (or medium) if the mean of the number of roles was between 2,5 and 4 and the variance of the number of roles performed by the broad categories of actors was higher (or lower) than the median of the variances; high (or very high) if the mean of the number of roles played was more than 4 and the variance of the number of roles performed by the broad categories of actors was higher

(or lower) than the median of the variances. We used Spearman correlation (cor procedure in R) in order to test for the existence of a relationship between the diversity of societal actors, measured as the number of subcategories of societal actors (eight levels) and the distribution of roles (five levels). We also looked at the distribution of roles across the broad categories of actors in the full sample.

To better visualise the roles in the projects, we also performed a multivariate analysis on the 14 projects and 6 explanatory variables, i.e. the number of roles played by research actors and the OECD categories of societal actors. The variables included the respective number of roles performed by research actors, public actors, private actors, civic actors and citizens. The number of roles for each category was based on Table 10 (see below). In addition, we used the total number of roles performed by all societal actors (values are available in Table 11 in Annex to this Chapter). We used principal component analysis (PCA) (using the FACTOMINE package in R) with standardised variables. The PCA was used for illustrative purposes only, to visualise the respective positions of the 14 projects and the correlations between the variables.

4. Results

4.1. Diversity of societal actors

The number of subcategories of societal actors involved in the projects ranged from one to six out of a total of eight (see Table 9). The diversity of societal actors was high in five projects (Aliment'Actions, Prosuli, BioMareau, Alpages sentinelles and Alice), medium in six projects (Refuges sentinelles, RhôneEco, CARELI, SPARE, ONDINE, TortuEES), and low in three projects (Sensei, Ocean Sentinel and EcoFlux). Public actors were most frequently represented. They were involved in twelve projects and made up the majority of the societal actors in the overall sample. However, there were significant differences between the types of public actors: nature managers and public authorities were involved in twelve and eight projects respectively, while a chamber of agriculture was involved in only two projects. Private actors were involved in nine projects and were the second most represented group of societal actors in the overall sample. The companies involved were very heterogeneous, with several small companies specialising in naturalist inventories or facilitation activities in rural areas (e.g., Entomotec, a consultant in botany, SCOP Wision) on the one hand, and large national companies (EDF, Compagnie nationale du Rhône) on the other hand. Farmers made up the bulk of the primary and tertiary sector professionals involved. Eight projects involved civic actors, with significant differences between nature users and NGOs with a primary environmental focus (seven projects) and other nature users (three projects). Finally, eight projects involved citizens, most of whom were local residents.

Table 9: Societal actors involved in the projects

(Broad typologies of societal actors are indicated in colours: blue = public actors; red = private actors; green = civic actors; yellow = citizens).

OECD categories of societal actors	Public actors			Private actors		Civic actors		Citizens	Number of subcategories of societal actors per project
Subcategories of societal actors	Nature and environment managers (e.g., water agencies, national and regional parks)	Local authorities at regional, departmental, and municipal level	Consular chambers (e.g., chamber of agriculture)	Private and semi – public companies (e.g., SNCF, EDF)	Primary and tertiary sector professionals (e.g., farmers, professional hunters and fishermen)	Nature users and NGOs with a primary environmental focus	Other nature users and NGOs (e.g., recreational hunters and fishermen, hikers), foundations		
Aliment'Actions	Water agency (Syndicats d'eau)	Regional and municipal authorities		SCOP Wision, SoliNiort	Farmers	Colibris, InPACT		Local residents	6
ProSuLi	Protected area managers	Local authorities		Private tourist companies	Farmers, professional hunters	International and local NGOs		Local residents	6
Refuges Sentinelles	Protected area managers				Mountain guides, refuge keepers	CREA Mont-Blanc	Association of mountain guides; French Alpine Club, Petzl foundation		4

RhônEco	Water agency of Rhône-Méditerranée-Corse	Local authorities, Syndicat du Haut-Rhône, Syndicat Mixte Intercommunal Rhône Court Circuité Loire Ardèche Isère Drôme (SMIRCLAID)		Compagnie nationale du Rhône, Electric utility company (EDF)				Local residents	4
BioMareau	Loire Nature Environment, national botanic conservatory	Local authority, environmental regional authority		Private company (L'avion jaune)		Environmental NGO (Entomotec)		Local residents	5
Alpages Sentinelles	Protected area managers		Chamber of agriculture	Consultant in botany	Farmers, shepherds		Pastoral services		5
Alice	Water development and management plan (SAGE)	Local authorities (Pays de Fougères)	Chamber of agriculture	Private consultant	Farmers	Environmental NGO (Eau et Rivières de Bretagne)			6
CARELI					Farmers	2 environmental NGOs (LPO, FNE)	Departmental federation of farmers, Departmental federation of hunters, FREDON Bourgogne Franche-Comté		3

SPARE	Syndicat mixte de la rivière Drôme	Water local commission						Local residents	3
ONDINE	Conservatory of Natural Spaces of Auvergne	Local authority						Local residents	3
TortuEES	Park managers	Representative of the city of Strasbourg						Park users	3
Sensei	Nature resource managers					Environmental NGO (Friends of Cooper Island)			2
Ocean sentinel	Nature resource managers				Professional fishermen				2
EcoFlux								High school students and teachers	1
Number of projects per (sub)category of societal actors	13	11	2	7	10	8	7	8	

4.2. Role pluralism

All ten of the roles we have retained for this article were performed in seven of the projects in our sample, nine roles in one project, eight roles in two projects, seven roles in three projects and six roles in one project. In other words, most, if not all, of the roles were present in the projects. The roles that were performed by at least one actor in all the projects were those of choreographer-coordinator, knowledge collector, knowledge co-producer, data supplier, results disseminator-communicator and scientific analyst. The roles of field expert, application expert/change agent, practice expert and facilitator-intermediary were missing in two, four, five and six projects respectively.

4.3. Role distribution

Clearly, the roles were not evenly distributed among the different types of actors.

Table 10: Distribution of the ten roles between the broad categories of actors in each project and in the overall sample

Projects	Actors		Roles										Total
			1	2	3	4	5	6	7	8	9	10	
Aliment'Actions (1)	Research actors		1	1	1	1	0	1	1	0	1	1	8
	Societal actors	Public actors	0	1	0	0	1	1	0	1	0	1	5
		Private actors	0	1	0	1	0	1	1	1	0	1	6
		Civic actors	1	0	0	1	0	0	1	0	0	1	4
		Citizens	0	0	0	1	1	1	0	0	0	1	4
		Societal actors across categories	1	1	0	1	1	1	1	1	0	1	8
ProSuli (2)	Research actors		1	1	1	1	0	0	1	0	1	0	6
	Societal actors	Public actors	0	1	0	1	1	1	1	1	0	1	7
		Private actors	0	0	0	1	1	1	0	1	0	1	5
		Civic actors	0	1	1	1	1	1	1	1	0	1	8
		Citizens	0	0	0	1	1	1	0	0	0	1	4
		Societal actors across categories	0	1	1	1	1	1	1	1	0	1	8
Refuges sentinelles (3)	Research actors		1	1	1	1	0	1	1	0	1	1	8
	Societal actors	Public actors	1	1	0	1	1	0	1	0	1	1	7
		Private actors	0	0	1	0	1	1	1	0	0	1	5
		Civic actors	0	1	1	1	1	1	1	1	1	1	9
		Citizens	0	0	0	0	0	1	0	0	0	0	1

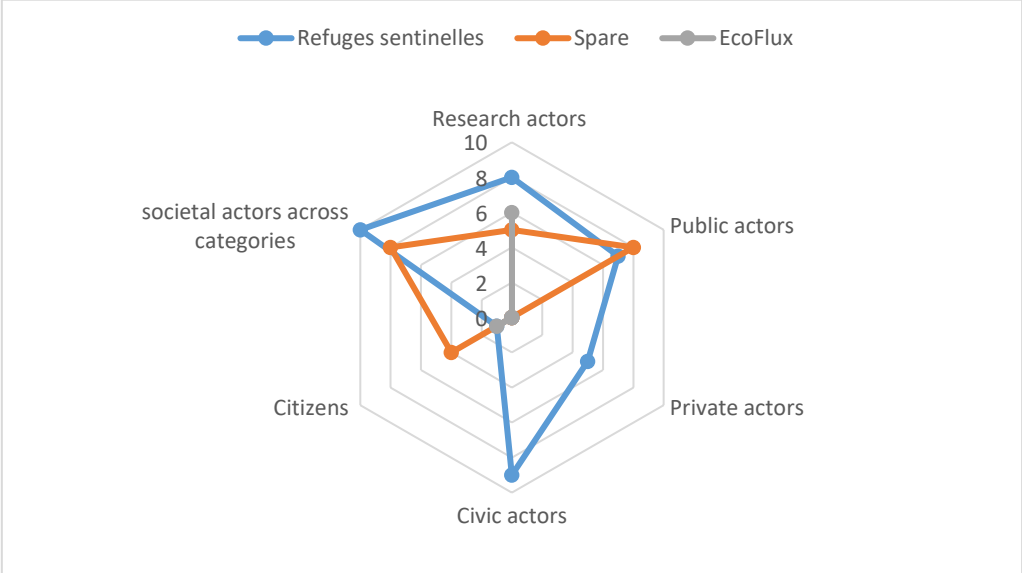
		Societal actors across categories	1	1	1	1	1	1	1	1	1	1	1	10
RhônEco (4)	Research actors		1	1	1	1	0	1	1	0	1	0	7	
	Societal actors	Public actors	1	0	1	1	1	1	1	1	0	1	8	
		Private actors	0	0	0	1	1	1	1	1	0	1	6	
		Citizens	0	0	0	0	0	1	0	0	0	0	1	
		Societal actors across categories	1	0	1	1	1	1	1	1	0	1	8	
BioMareau (5)	Research actors		1	0	1	1	0	1	1	0	1	0	6	
	Societal actors	Public actors	1	0	0	1	1	0	1	0	0	1	5	
		Private actors	0	0	1	0	0	0	0	0	0	0	1	
		Civic actors	0	0	1	0	0	0	0	0	0	0	1	
		Citizens	0	0	0	1	1	1	0	0	0	0	3	
		Societal actors across categories	1	0	1	1	1	1	1	0	0	1	7	
Alpes sentinelles (6)	Research actors		1	1	1	1	0	1	1	0	1	0	7	
	Societal actors	Public actors	1	1	1	1	1	1	1	1	0	1	9	
		Private actors	0	0	1	0	1	1	0	1	0	1	5	
		Civic actors	0	0	1	1	1	1	1	1	1	1	8	
		Societal actors across categories	1	1	1	1	1	1	1	1	1	10		
Alice (7)	Research actors		1	1	1	1	0	1	1	0	1	0	7	
	Societal actors	Public actors	1	0	0	1	1	0	1	1	0	1	6	
		Private actors	0	1	0	0	0	1	0	0	0	0	2	
		Civic actors	0	0	1	0	0	0	1	0	0	0	2	
		Societal actors across categories	1	1	1	1	1	1	1	1	0	1	9	
CARELI (8)	Research actors		1	1	1	1	0	0	1	0	1	0	6	
	Societal actors	Private actors	0	0	0	0	0	1	0	0	0	0	1	
		Civic actors	0	0	1	1	1	1	1	1	0	1	7	
		Societal actors across categories	0	0	1	1	1	1	1	1	0	1	7	
SPARE (9)	Research actors		1	1	1	1	0	0	0	0	1	0	5	
	Societal actors	Public actors	1	1	1	1	1	1	1	0	0	1	8	
		Citizens	0	0	0	1	1	1	0	0	0	1	4	
		Societal actors across categories	1	1	1	1	1	1	1	0	0	1	8	
ONDINE (10)	Research actors		1	0	1	1	0	1	1	1	1	0	7	
	Societal actors	Public actors	0	0	0	1	0	1	0	0	0	0	2	
		Citizens	0	0	0	0	0	1	0	0	0	0	1	
		Societal actors across categories	0	0	0	1	0	1	0	0	0	2		
TortuEES (11)	Research actors		1	0	1	1	0	1	1	0	1	0	6	
	Societal actors	Public actors	0	0	0	1	1	1	1	1	0	1	6	
		Citizens	0	0	0	0	0	1	0	0	0	0	1	
		Societal actors across categories	0	0	0	1	1	1	1	1	0	1	6	

Sensei (12)	Research actors		1	0	1	1	0	0	1	0	1	0	5
	Societal actors	Public actors	0	0	0	1	1	1	0	0	0	0	3
		Civic actors	0	0	0	0	0	0	1	0	0	0	1
		Societal actors across categories	0	0	0	1	1	1	1	0	0	0	4
Ocean sentinel (13)	Research actors		1	0	1	1	0	0	1	0	1	0	5
	Societal actors	Public actors	0	0	0	1	1	0	0	0	0	0	2
		Private actors	0	0	0	0	0	1	0	0	0	0	1
		Societal actors across categories	0	0	0	1	1	1	0	0	0	0	3
EcoFlux (14)	Research actors		1	0	1	1	0	1	1	0	1	0	6
	Societal actors	Citizens	0	0	1	0	0	0	0	0	0	0	1
		Societal actors across categories	0	0	1	0	0	0	0	0	0	0	1
Total for the overall sample	Research actors		14	8	14	14	0	9	13	1	14	2	89
	Societal actors	Public actors	6	5	3	11	11	8	8	6	1	8	67
		Private actors	0	2	2	2	4	7	3	5	0	5	30
		Civic actors	1	2	5	5	4	4	7	4	2	5	39
		Citizens	0	0	1	3	4	8	0	0	0	3	19
		Societal actors across categories	7	6	9	13	12	13	11	8	3	10	92

At the project level, societal actors performed more roles than research actors in eight projects (ProSuli, Refuges sentinelles, RhôneEco, BioMareau, Alpes sentinelles, Alice, Careli, SPARE), while the opposite was true in three projects (Ondine, Ocean Sentinel, EcoFlux) (see Figure 3). Research actors and public actors performed an equal number of roles in three projects (Aliment'Actions, TortuEES, Sensei). However, research actors often performed more roles than any broad category of societal actors. Public actors performed the highest number of roles in three projects (RhôneEco, Alpes sentinelles, Spare) and shared the highest number of roles performed with research actors in one project (TortuEES). Civic actors performed the highest number of roles in three projects (ProSuli, Refuges sentinelles, Careli). Private actors sometimes performed a high number of roles (e.g., six roles in Aliment'Actions and RhôneEco), but never the highest. Citizens performed the lowest number of roles in all but one project (BioMareau), and never more than four roles.

Figure 3: Number of roles performed by each broad category of actor in three projects of our sample

(Only three examples are given for the sake of clarity).

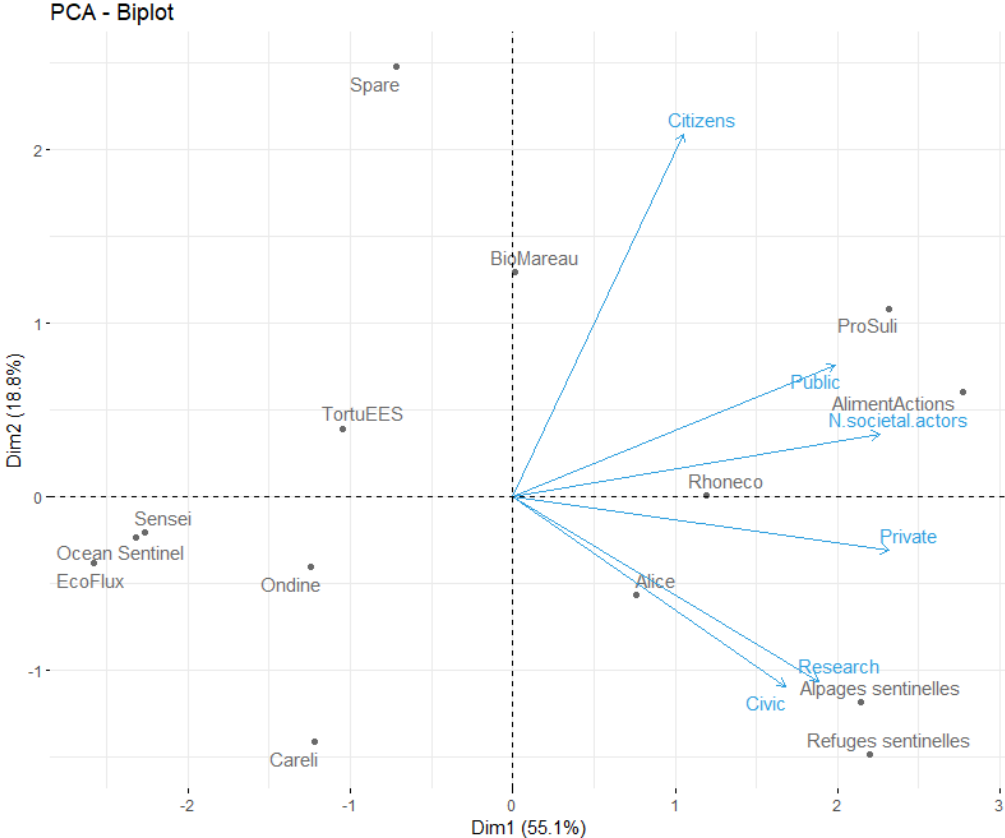


The results of the PCA are shown in Figure 4 for the first two dimensions. The first dimension varies with the number of actors and the number of roles they perform in the projects, and is thus mainly a quantitative axis. The second dimension correlates with the number of roles performed by citizens. As can be seen in Figure 4, the roles performed by the subcategories of actors were correlated with each other (and with Dimension 1, horizontal axis), except for the citizens’ roles, which mainly explained Dimension 2 and was orthogonal to the number of roles performed by research and civic actors. The 14 projects were distributed in the space defined by the first two axes, with the multivariate analysis contrasting, on the one hand, the projects with a low number of roles (left part; EcoFlux, Ocean Sentinel, Sensei) with projects with a much higher number of roles (ProSuli, Aliment’Actions, Alpages sentinelles, Refuges sentinelles), and, on the other hand, the projects in which citizens performed several roles (upper part; Spare, BioMareau, ProSuli, Aliment’Actions) with projects in which they performed none or only one role (Careli, Refuges sentinelles, Alpages sentinelles).

Figure 4: Principal component analysis of the 14 projects

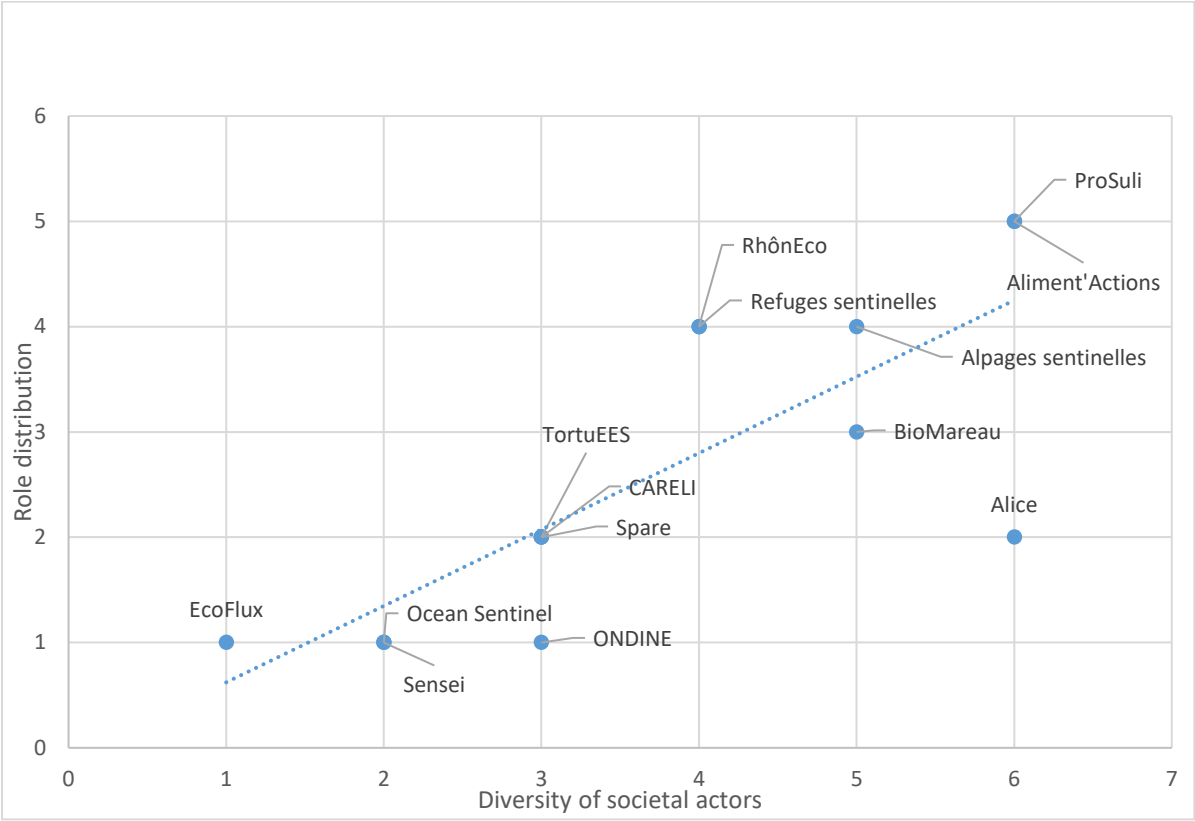
The projects are analysed according to six quantitative variables representing the number of roles (out of ten possible roles) performed by each broad category of actors (see methods for the list of variables).

(Only the first two dimensions are shown, with their respective contributions in % of explained variance. Dimension 1 represents the horizontal axis, and explains 55.1% of the total variance).



The distribution of roles was very high in two projects (ProSuli, Aliment’Actions), high in three projects (Refuges sentinelles, RhônEco, Alpages sentinelles), medium in one project (BioMareau), low in four projects (Alice, Spare, CARELI, TortuEES), and very low in four projects (Ondine, Sensei, Ocean sentinel, EcoFlux) (see Table 10 and Figure 5). We found a statistically significant positive relationship between the diversity of societal actors (taken from Table 9) and the distribution of roles ($\rho=0.83$, $S=75.5$, $p=0.0002$), i.e. actors tend to perform more roles as the diversity of societal actors increases. In the projects with a low diversity of societal actors, societal actors performed only one to four roles, which often revolved around data collection or supply and the contribution of context-specific knowledge. Research actors also tended to perform a limited number of conventional roles for research actors, such as choreographer-coordinator, knowledge collector or scientific analyst.

Figure 5: Relationship between the distribution of roles and the diversity of societal actors in our sample of projects



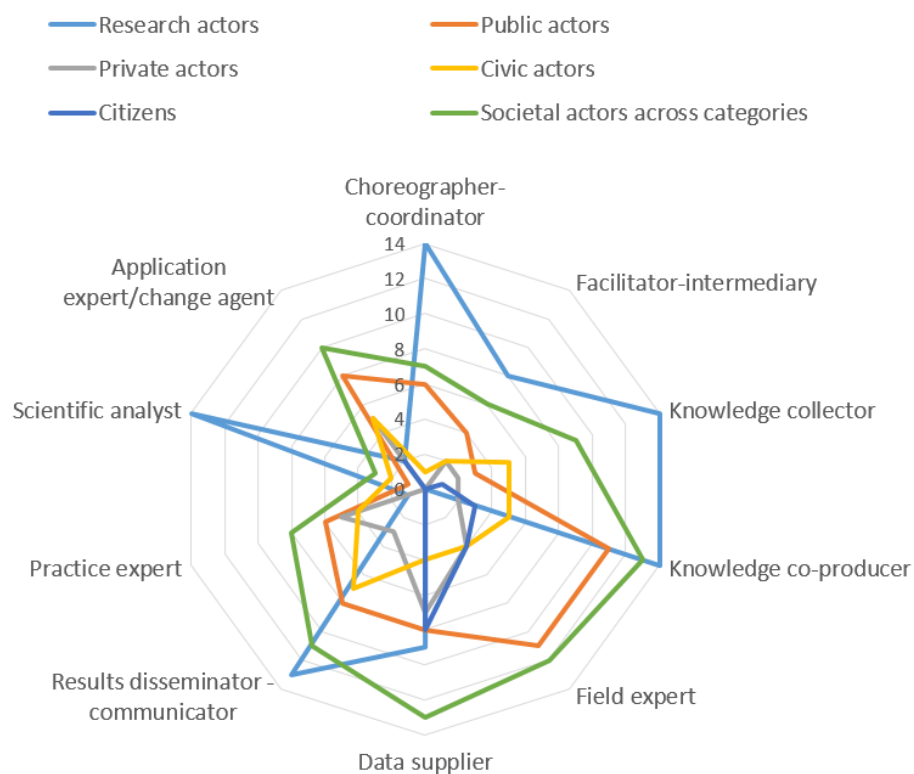
Across the whole sample, research actors and societal actors performed a similar number of roles, with 89 and 92 role performances for the research actors and societal actors respectively (see Table 10). Among the latter, public actors stood out as the main role performers, with 67 role performances. Civic actors and private actors ranked third and fourth, with 39 and 30 role performances respectively. Citizens came last, with only 19 role performances.

The roles of scientific analyst and, to a lesser extent, choreographer were mainly performed by research actors. The only societal actors who contributed to these roles were public or civic actors. The roles of field expert, practice expert and, to a lesser extent, application expert/change agent were frequently performed by societal actors, and very rarely by research actors. Several broad categories of societal actors performed these roles, with public actors always in first place. The roles of data supplier, knowledge co-producer and results disseminator/communicator were more evenly distributed between research actors and societal actors. It is also striking that some actors were highly specialised in some roles, while others tended to contribute to a greater diversity of roles. For example, research actors systematically performed the roles of choreographer-coordinator, knowledge collector, knowledge co-producer, scientific analyst and rarely or never performed the roles of field expert, practice expert and application/change agent. In contrast, public actors often contributed to all but two roles (scientific analyst and knowledge collector). Citizens

performed few roles, and the only role they frequently performed was that of data supplier (see Figure 6).

Figure 6: Role distribution in our sample of projects

The number on each axis of the spider diagram indicates the number of projects in which each of the ten roles were performed by each broad category of actor. For example, the role of choreographer-coordinator was performed by research actors and societal actors across categories in 14 and 7 projects respectively. It was performed by public actors, private actors, civic actors and citizens in 6, 0, 1 and 0 projects respectively.



5. Discussion and perspectives

Building on recent literature using the concept of roles in TRSS, we examined the roles performed by research actors and societal actors, and the role distribution between all the actors, in a sample of selected transdisciplinary projects in a French research infrastructure with a strong sustainability science orientation. An important advantage of analysing TRSS projects in terms of roles and role distribution is that it considers jointly how research actors and societal actors contribute to TRSS projects. As the identification of actors' roles is based on the activities they carry out, it provides a detailed view of what the different actors involved in TRSS projects actually do and do not do. It thus usefully complements previous studies that have focused, for example, on the type of knowledge that the different actors contribute at different stages of TRSS projects (Enengel et al. 2012).

Unpacking the respective roles of research actors and societal actors highlights the huge heterogeneity of TRSS projects in terms of the number and diversity of societal actors involved (Hilger et al. 2021) and the distribution of roles. Thus, defining projects as transdisciplinary or based on knowledge co-production is clearly not sufficient and needs to be complemented by a detailed analysis of the roles performed by all the actors involved and of the distribution of these roles. We believe that the visualisations of the distribution of roles proposed in this article are particularly useful to clarify and collectively reflect on who actually participates in TRSS, at the level of research projects and at the level of research infrastructures.

In contrast to Hilger et al. (2021), we found that societal actors performed a wide variety of roles in our sample of TRSS projects, and often even more roles than research actors. This difference may be partly due to a selection bias, as Hilger et al. (2021) have analysed a sample of transformative processes around a sustainability problem described in peer-reviewed articles in English. Such selection may have returned projects that are more research-oriented and research-driven than those in our sample. Furthermore, the roles performed by societal actors may be less visible in peer-reviewed articles than in the more diverse material we collected. However, we have highlighted that only some categories of societal actors have become major role performers in our sample of TRSS projects. This was particularly the case for nature managers and, to a lesser extent, environmental NGOs. In contrast, other public actors, such as chambers of agriculture, private actors and, above all, citizens, perform a much more limited number of roles in a limited number of projects. The low presence of citizens in TRSS projects, which is consistent with the results of previous studies (Musch and von Streit 2020; Hitziger et al. 2021), appears to be a major limitation of TRSS projects.

Several reasons could explain why societal actors contribute to TRSS projects to very different extents. First, the fact that the main role performers are linked to the environmental sector (nature managers, environmental NGOs) suggests that epistemic and social proximity matters. These actors and research actors often share a common disciplinary background, similar interests and goals, and some of them have the competence and ability to act as knowledge brokers (Meyer 2010) between research actors and societal actors. For example, the nature managers involved in Alpages sentinelles have established a long tradition of collaboration with several research labs and, in particular, with the research actors involved in this project. Second, institutional and financial reasons hinder the involvement of some societal actors in TRSS projects. Civic and private actors, such as farmers, generally have financial constraints and little time and may prefer not to get involved or, alternatively, perform roles that are not time-consuming. As for citizens, it is generally difficult to find out how to reach them, as they do not have representatives, and then to finance their participation in TRSS projects. Conducting interviews with all the actors involved in TRSS projects would make it possible to sort out and complement these different reasons.

One striking finding concerns the role of change agent, which is crucial for engagement in transition processes (Wittmayer and Schöpke 2014). While contributing to the improvement of unsustainable situations is supposed to be at the core of TRSS (see e.g. Hirsch-Hadorn et al.

2008; Hirsch-Hadorn et al. 2010; Lang et al. 2012), the role of change agent was not present in all the projects, and was far more often performed by societal actors than by research actors. This finding confirms that actors, and especially research actors, engaged in TRSS are not necessarily willing to act as change agents in the situation they are studying (Wittmayer and Schöpke 2014).

Another interesting finding of our study concerns the relationship between the diversity of societal actors and the distribution of roles. We found that the more societal actors are involved in TRSS projects, the more roles they and the research actors tend to perform, leading to rather strong overlap between actors and role distribution. This suggests the existence of an amplification effect of the involvement of societal actors in TRSS. Conversely, one might have expected a tendency towards specialisation as a result of competition or complementarity between the actors. Why, then, do the number and distribution of roles tend to increase with the diversity of actors involved in TRSS projects? There are at least three possible explanations for the amplification effect we observed, which are not mutually exclusive. First, it may be due to the social learning dimension of TRSS projects, understood as an 'open-ended process of inquiry geared towards a broadening of the community of practice through social innovation and experimentation' (Popa et al. 2015; Herrero et al. 2019). Indeed, TRSS projects can offer their participants the opportunity to learn from each other and, in particular, to try out the roles performed by others. Second, the involvement of different societal actors may reflect the openness of research actors to share roles with societal actors. Third, each type of actor brings its own expectations and skills to the project, making it possible to undertake activities that none of the actors would be able to carry out alone, thus making new roles available to all. Given the strength of the signal we detected in our sample, further research is clearly needed to disentangle these three hypotheses.

Finally, we would like to highlight the limitations of our study and the perspectives it opens up. A major limitation concerns the difficulty of identifying the roles performed by the different actors in the projects. First, obtaining a detailed description of the respective activities of the actors in the projects required a significant effort to collect sufficiently detailed data (see methodological section), which limited the size of our sample of projects and, consequently, the robustness of our findings. Second, the roles of the actors were sometimes difficult to identify, even for the projects we knew best, and interviewing the project leaders was not always sufficient to clarify the distribution of roles. TRSS projects are inherently messy (Wittmayer and Schöpke 2014) and evolving (see e.g. Berthet et al. 2022), making it difficult to get a clear picture of the distribution of roles. Some of the roles identified by Hilger et al. (2021) were particularly difficult to document. For example, we were unable to obtain information on the roles of troublemaker and self-reflexive participant across all the projects and had to exclude them from the analysis, despite the importance of the role of self-reflexive participant for TRSS (Popa et al. 2015). In addition, it was easier to have detailed knowledge of the activities carried out by the research actors, and we may therefore have underestimated the number of roles performed by the societal actors in some cases. However,

we are confident that the general picture we have given is robust. Another important limitation of our exploratory study is that we did not distinguish between different categories of research actors, despite their diversity. We believe that a distinction based on two criteria would be particularly fruitful in clarifying the distribution of roles among research actors: disciplinary background on the one hand, and stage in the research career on the other hand.

We offer three further perspectives for deepening this exploratory analysis: i) to increase the size of the project samples by extending the study to other research infrastructures committed to TRSS. This would make it possible to refine the results by examining more diversified cases, and to strengthen them by reinforcing the robustness of the statistical analyses; ii) to conduct an ethnographic study of the interactions between research actors and different types of societal actors in projects characterised by contrasting role distributions, in order to analyse the practices and representations that influence the negotiation and distribution of roles. This would allow a better understanding of the relationship between the distribution of roles and the interactions between actors in TRSS, and to analyse the conflicts that may arise between the different roles that each group of actors performs (Wittmayer and Schöpke 2014), as well as between the different actors performing the same roles; iii) to analyse the temporal dynamics of the roles and their distribution in TRSS. Roles and their distribution are clearly not fixed, but we know little about how and why they evolve, and about the consequences of this evolution for the outcomes and impacts of TRSS projects. We therefore believe that studying the distribution of roles in TRSS is a rich research agenda and hope that this study will contribute to its realisation.

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Table 11: Distribution of the ten roles between the actors involved in each project

Projects	Actors		Roles										Total
			1	2	3	4	5	6	7	8	9	10	
Alpages sentinelles	Research actors		1	1	1	1	0	1	1	0	1	0	7
	Societal actors	Protected area managers	1	1	1	1	1	1	1	1	0	1	9
		Chamber of agriculture	0	0	0	0	1	0	0	0	0	0	1
		Private consultant	0	0	1	0	1	0	0	0	0	0	2
		Farmers, shepherds	0	0	1	0	1	1	0	1	0	1	5
		Pastoral experts	0	0	1	1	1	1	1	1	1	1	8
Aliment'Actions	Research actors		1	1	1	1	0	1	1	0	1	1	8
	Societal actors	Water agency	0	0	0	0	0	1	0	1	0	0	2
		Regional and municipal authorities	0	1	0	0	1	1	0	0	0	1	4
		SCOP Wision, SoliNiort	0	1	0	1	0	1	1	0	0	1	5
		Farmers	0	0	0	1	0	1	0	1	0	1	4
		Colibris, InPACT	1	0	0	1	0	0	1	0	0	1	4
		Local inhabitants	0	0	0	1	1	1	0	0	0	1	4
ProSuli	Research actors		1	1	1	1	0	0	1	0	1	0	6
	Societal actors	Protected area managers	0	1	0	1	1	1	1	1	0	1	7
		Local authorities	0	1	0	1	1	1	1	1	0	1	7
		Private wildlife industry	0	0	0	0	0	0	0	0	0	1	1
		Farmers, hunters	0	0	0	1	1	1	0	1	0	1	5
		International and local NGOs	0	1	1	1	1	1	1	1	0	1	8
		Local inhabitants	0	0	0	1	1	1	0	0	0	1	4
Refuges sentinelles	Research actors		1	1	1	1	0	1	1	0	1	1	8
	Societal actors	Protected area managers	1	1	0	1	1	0	1	0	1	1	7
		Mountain guides and refuge keepers	0	0	1	0	1	1	1	0	0	1	5
		Local environmental NGO	0	0	1	1	0	0	1	1	1	0	5
		Association of mountain guides, French Alpine Club, Petzl foundation	0	1	1	1	1	1	1	1	1	1	9
		Tourists	0	0	0	0	0	1	0	0	0	0	1
RhônEco	Research actors		1	1	1	1	0	1	1	0	1	0	7
	Societal actors	Water agency	1	0	1	1	1	1	1	1	0	1	8
		Syndicates of the Rhône river	0	0	0	1	1	0	1	0	0	1	4
		Compagnie nationale du Rhône	0	0	0	1	1	1	1	1	0	1	6
		Public electricity company	0	0	0	0	1	0	0	1	0	0	2
		Local inhabitants	0	0	0	0	0	1	0	0	0	0	1
BioMareau	Research actors		1	0	1	1	0	1	1	0	1	0	6
	Societal actors	National botanic conservatory	1	0	0	1	1	0	1	0	0	1	5
		Local authority	0	0	0	0	1	0	0	0	0	1	2
		Private company	0	0	1	0	0	0	0	0	0	0	1
		Environmental NGO (Entomotec)	0	0	1	0	0	0	0	0	0	0	1
		Local inhabitants	0	0	0	1	1	1	0	0	0	0	3

Alpages sentinelles	Research actors		1	1	1	1	0	1	1	0	1	0	7
	Societal actors	Protected area managers	1	1	1	1	1	1	1	1	0	1	9
		Chamber of agriculture	0	0	0	0	1	0	0	0	0	0	1
		Private consultant	0	0	1	0	1	0	0	0	0	0	2
		Farmers, shepherds	0	0	1	0	1	1	0	1	0	1	5
		Pastoral experts	0	0	1	1	1	1	1	1	1	1	8
Alice	Research actors		1	1	1	1	0	1	1	0	1	0	7
	Societal actors	Water development and management plan	1	0	0	1	0	0	1	1	0	1	5
		Local authorities (Pays de Fougères)	0	0	0	0	1	0	0	0	0	0	1
		Chamber of agriculture	0	0	0	0	1	0	0	0	0	0	1
		Private consultant	0	1	0	0	0	0	0	0	0	0	1
		Farmers	0	0	0	0	0	1	0	0	0	0	1
		Environmental NGO	0	0	1	0	0	0	1	0	0	0	2
CARELI	Research actors		1	1	1	1	0	0	1	0	1	0	6
	Societal actors	Farmers	0	0	0	0	0	1	0	0	0	0	1
		Environmental NGOs (LPO, FNE)	0	0	1	1	0	0	1	0	0	0	3
		Federation of hunters, hunters	0	0	0	1	1	1	1	1	0	1	6
SPARE	Research actors		1	1	1	1	0	0	0	0	1	0	5
	Societal actors	Syndicat mixte	1	1	1	1	1	0	1	0	0	1	7
		Water local commission	0	0	0	1	1	1	0	0	0	1	4
		Local inhabitants	0	0	0	1	1	1	0	0	0	1	4
ONDINE	Research actors		1	0	1	1	0	1	1	1	1	0	7
	Societal actors	Conservatory of natural areas of Auvergne	0	0	0	1	0	1	0	0	0	0	2
		Local authority	0	0	0	0	0	1	0	0	0	0	1
		Local inhabitants	0	0	0	0	0	1	0	0	0	0	1
TortuEES	Research actors		1	0	1	1	0	1	1	0	1	0	6
	Societal actors	City park managers	0	0	0	0	1	1	1	1	0	1	5
		Representative of the city of Strasbourg	0	0	0	1	0	0	0	0	0	1	2
		Park users	0	0	0	0	0	1	0	0	0	0	1
Sensei	Research actors		1	0	1	1	0	0	1	0	1	0	5
	Societal actors	Nature resource managers	0	0	0	1	1	1	0	0	0	0	3
		Environmental NGO	0	0	0	0	0	0	1	0	0	0	1
Ocean sentinel	Research actors		1	0	1	1	0	0	1	0	1	0	5
	Societal actors	Nature resource managers	0	0	0	1	1	0	0	0	0	0	2
		Professional fishermen	0	0	0	0	0	1	0	0	0	0	1
EcoFlux	Research actors		1	0	1	1	0	1	1	0	1	0	6
	Societal actors	High school students and teachers	0	0	1	0	0	0	0	0	0	0	1

Table 12: Number of roles performed by the broad categories of actors in our sample

The 'mean' and 'variance' columns show the mean and variance respectively of the number of roles performed by the research actors, public actors, private actors and citizens. The median of the variances is 8,65.

Projects	Research actors	Public actors	Private actors	Civic actors	Citizens	Societal actors across categories	Mean	Variance
Aliment'Actions	8	5	6	4	4	8	5,4	2,8
ProSuli	6	7	5	8	4	8	6	2,5
Refuges sentinelles	8	7	5	9	1	10	6	10
RhônEco	7	8	6	0	1	8	4,4	13,3
BioMareau	6	5	1	1	3	7	3,2	5,2
Alpages sentinelles	7	9	5	8	0	10	5,8	12,7
Alice	7	6	2	2	0	9	3,4	8,8
Careli	6	1	0	7	0	7	2,8	11,7
Spare	5	8	0	0	4	8	3,4	11,8
Ondine	7	2	0	0	1	2	2	8,5
TortuEES	6	6	0	0	1	6	2,6	9,8
Sensei	5	3	0	1	0	4	1,8	4,7
Ocean Sentinel	5	2	1	0	0	3	1,6	4,3
EcoFlux	6	0	0	0	1	0	1,4	6,8

Based on a sample of TRSS projects provided by the French network of ZAs, this chapter has examined the roles performed by both research actors and societal actors, and the distribution of roles between these actors. Our work suggests that societal actors have become major role performers in TRSS, and that all actors tend to perform more roles as the diversity of the societal actors involved in the projects increases, which we refer to as an amplification effect. However, we also found that the distribution of roles across categories of societal actors is very uneven. In particular, citizens appear to perform few roles and to be often limited to a role of 'data supplier' (responding to interviews or surveys). By allowing us to explore the concrete activities of both research actors and societal actors in TRSS projects, this chapter has highlighted the practical issue of involving some types of societal actors, and in particular citizens, in this type of research.

The following chapter further explores the practical issues of TRSS at the project level by focusing on the issue of adapting research methods and stances to the level of wickedness of the problems addressed. More specifically, it focuses on the influence of problem wickedness on project pluralism. This allows us to extent our focus of interest and to consider jointly the diversity of the actors involved and the diversity of the methods used in TRSS projects.

Chapter III. Methodological issue: adapting research methods and stances to the level of wickedness of the problems

This chapter is based on a paper published in *Sustainability Science*, entitled 'An exploration of the influence of problem wickedness on project pluralism in sustainability science'. Authors: Likhacheva K., Bretagnolle V., Arpin I. DOI: [10.1007/s11625-023-01373-6](https://doi.org/10.1007/s11625-023-01373-6)

Preamble

The previous chapter has focused on the different categories of actors involved in TRSS projects and the distribution of roles among them. Here we remain interested in the actors involved, but extend our interest to the methods used.

Transdisciplinary research in sustainability science (TRSS) brings together research actors and societal actors in order to address wicked sustainability problems. It is the wickedness of the problems that justifies the involvement of a variety of actors, who are expected to bring their respective perspectives and interests on problems with different dimensions and facets, as well as their respective skills and knowledge. Pluralism in the methods used to address the problems becomes possible as participants master different skills and competences, and is seen as necessary to involve societal actors in transdisciplinary research processes. Pluralism of actors involved and pluralism of methods thus appear to be two interrelated conditions for dealing effectively with the wickedness of sustainability problems.

One might expect a positive relationship between the degree of wickedness of the problems at hand and the degree of pluralism of the actors involved and the methods used to address these problems. Surprisingly, however, this relationship has not been analysed, at least to our knowledge. This is the aim of this third chapter.

As in the previous chapter, we base our empirical analysis on a sample of TRSS projects in the French Zones Ateliers (ZAs), consisting of the same projects and three others addressing problems with different levels of wickedness.

1. Introduction

In the 1960s and 1970s, urban planners identified a new type of problem, which they described as particularly complex, open-ended, and intractable (Churchman 1967; Rittel and Webber 1973). They termed these problems ‘wicked’ as there was no consensus on the definitions of and solutions to these problems (Roberts 2000) and attempts to solve them often tended to have irreversible consequences and negatively impact the overall situation (Xiang 2013). The term ‘wicked problems’ has become increasingly popular, especially in environmental studies, and has been used to the point of losing some of its meaning (Alford and Head 2017; Peters 2017). As a result, degrees of wickedness have been introduced (Head and Alford 2015; Termeer et al. 2019). In particular, Alford and Head (2017) have proposed a typology of wickedness based on the level of the intractability of the problem and the distribution of problem knowledge, interests, and power among affected actors.

Another idea gained ground in the 1990s: ecological and social systems are deeply intertwined, and scholars should focus on their interrelationship (Berkes and Folke 1998; Collins et al. 2011). This argument gave birth to the concept of social-ecological systems, now defined as complex adaptive systems formed by interacting social and ecological systems (Preiser et al. 2018). Social-ecological systems have been found to teem with wicked problems (Xiang 2013; Head and Xiang 2016), with climate change, biodiversity loss, and waste used as classic examples (Russell 2010; Chan 2016). In fact, wicked problems and social-ecological systems share common characteristics such as scale sensitivity, path dependence, context dependence, and non-linear relationships (Akamani et al. 2016). They may be seen as two faces of the same coin and have become core concepts of an emerging scientific discipline: sustainability science.

Sustainability science has been defined in various ways (see Komiyama and Takeuchi 2006; Kates 2011; Spangenberg 2011; Shahadu 2016; Fang et al. 2018; Mino and Kudo 2020). We retain the definition by Fang et al. (2018, p. 12), based on an extensive literature analysis: ‘Sustainability science is a use-inspired basic science of sustainable development, which focuses on understanding human-environment interactions and linking the understanding to actions by promoting a place-based, multi-scale, and transdisciplinary approach’. Beyond minor differences, all definitions emphasise that sustainability science is problem-driven and aims to tackle ‘real-world’ problems, especially wicked ones.

However, the literature on the influence of problem wickedness on the practice of sustainability science is curiously sparse. Regarding its influence on the participation of non-academic actors, Bieluch et al. (2017) found that the preferences of local government officers for different participation strategies were significantly impacted by problem wickedness, except for environmental problems (as opposed to economic and policy problems). Schneider and Buser (2018) identified the level of contestation of a problem as one of six criteria impacting stakeholder interaction processes. As for the influence of problem wickedness on the methods used, to our knowledge, it has not been investigated so far. Here we intend to

help fill this gap by investigating the relationship between the wickedness level of the problems addressed and how scientists handle these problems in practice.

More specifically, we address the following question: what is the relationship between the wickedness of the problems and the research stances and methods adopted to address these problems? We explored this relationship by analysing a sample of research projects from a national network designed to foster long-term and place-based inter- and transdisciplinary environmental research in France. In brief, we expected a positive relationship between the wickedness of the problems, the variety of research methods, and the plurality of non-academic partners in the research project (see the rationale for these expectations below).

First, we review the literature about research stances and methods in sustainability science. Then, we explain how we constructed our sample, and how we investigated and compared the wickedness of the problems addressed and the research stances and methods adopted. After presenting our results, we offer interpretations for the more limited than expected correspondence we found between them.

2. Literature review: Research stances and methods in sustainability science

Here we understand a research stance as a strategy used to deal with a given wicked problem. A classical research stance is reductionism, which consists of simplifying the complexity of a problem as much as necessary to be able to solve it (Hazard et al. 2020). Reductionism often entails bringing a real-world problem into a place (typically, a laboratory or a model) where the scientists can reduce its complexity and then export the solution to the real world. It is thus based on a series of displacements between the real world and a 'truth-spot' (Gieryn 2002, 2006), as shown by numerous social studies of science in recent decades (e.g. Latour 1983). This reductionist stance has resulted in the gradual distancing of scientists from the rest of society and the emergence of a growing number of disciplines.

In contrast, sustainability scientists working on social-ecological systems seek precisely to account for their complexity. They consider reductionism to be ill-suited to the characteristics of wicked problems and doomed to failure when attempting to tackle them (Pahl-Wostl et al. 2013; Head and Xiang 2016b; Preiser et al. 2022). Wicked problems cannot be detached from the real world and integrating their complexity, rather than reducing it, is seen as crucial to addressing them in a more appropriate manner (Klenk and Meehan 2015). Furthermore, sustainability scientists propose bringing together research actors with various disciplinary backgrounds and societal actors to conduct inter- and transdisciplinary research on wicked problems (Lang et al. 2012; Jahn et al. 2012; Brandt et al. 2013). Defined as 'iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future' (Norström et al. 2020, p. 183), knowledge co-production is considered crucial for integration and transdisciplinary research as they are understood in sustainability science (Holzer et al. 2018; Wyborn et al. 2019; Norström et al. 2020).

Such calls for renewed research stances have pushed for a re-thinking of research methods. We define a research method as a ‘codified way of producing knowledge of a focus of interest’ (de Vos et al. 2019, p. 2). Research methods are the concrete means by which researchers produce knowledge and are at the very heart of scientific practice and innovation (Koppman and Leahey 2019). As their design and implementation usually require specific skills and entail risks and rewards, research methods are crucial for defining who can engage in the research process and who is left out. They also strongly influence the results and outcomes of research. The research strategies promoted to address wicked problems in social-ecological systems are expected to entail major changes in classical research methods²⁷, if not their complete overhaul (Preiser et al. 2018).

In fact, there has been a recent burst of publications on the methodological issues and challenges of sustainability science (Poteete et al. 2010; Spangenberg 2011; Caniglia et al. 2017; von Wehrden et al. 2017; Preiser et al. 2018; Caniglia et al. 2020; Jerneck and Olsson 2020; Biggs et al. 2021). Researchers have emphasised the wealth of methods that may be useful in tackling wicked problems and stressed the value of methodological pluralism, i.e. ‘the use of different methods with the aim of investigating a common phenomenon but from different perspectives’ (Biggs et al. 2021, p. 52). Over the last decade, various lists and typologies of methods targeted at newcomers to the field (e.g. Biggs et al. 2021²⁸) have been developed to encourage sustainability scientists to broaden their range of research methods and help them select methods appropriate to the specific problems they seek to address. For example, de Vos et al. (2019) identified more than 300 methods that they grouped into 28 categories (Biggs et al. 2021).

Collaborative pluralism and methodological pluralism are, therefore, two cornerstones of sustainability science. Our goal here was not to provide sustainability scientists with an additional toolkit on how to achieve this dual pluralism but to study the level of pluralism scientists adopt when dealing with diversely wicked sustainability problems in social-ecological systems. To do so, we interviewed all the leaders of a distributed national network of research infrastructures designed to promote inter- and transdisciplinary environmental research. We asked them to describe at least one ongoing (or recently completed) research project in this field. Drawing a sample of projects from a single national research network had two important advantages: first, the commonality of language facilitated the collection of information on the projects; second, the fact that the projects took place in the same context, or at least very similar, scientific and administrative contexts, made it easier to explore the

²⁷ These include collecting naturalist data through field inventories or sociological data through interviews, carrying out ecological experiments in the field or in the lab, and modelling the past or future evolution of social or ecological systems.

²⁸ See also td-net toolbox: https://naturalsciences.ch/co-producing-knowledge-explained/methods/td-net_toolbox, and the sustainability methods wiki: https://sustainabilitymethods.org/index.php/Main_Page

relationship between the complexity of the problems and the research positions and methods adopted.

For each project, we then investigated three core aspects. First, we analysed the wickedness level of the problem addressed by decomposing wickedness into two dimensions, as suggested by Alford and Head (2017): i) the difficulty of defining both the problem and its solution(s) (cognitive complexity); ii) the heterogeneity of the actors affected by this problem and the level of conflict among these actors (political complexity of the problem). We expected a positive relationship between these two dimensions, i.e. that the difficulty in defining the problem and its solution(s) would increase alongside the heterogeneity of the actors affected and the level of conflict over the problem (or vice versa). Second, we also decomposed project pluralism into two dimensions: the diversity of the research partners (collaborative pluralism of the project) and the diversity of methods used (methodological pluralism of the project). We again expected a positive relationship, i.e. that the diversity of methods would increase with the diversity of partners. Finally, we analysed the relationship between problem wickedness and project pluralism.

We expected that i) the diversity of research partners involved in the projects (collaborative pluralism of the project) would reflect the diversity of actors affected by the problem addressed (political complexity of the problem); ii) the diversity of methods used (methodological pluralism of the project) would reflect the cognitive complexity of the problem. Our overarching hypothesis was, therefore, that researchers addressing more wicked problems would consider it necessary to resort to a wider range of methods and partners than researchers addressing less wicked problems.

3. Methods

3.1. The French network of 'Zones Ateliers' as a case study

Zones Ateliers (ZAs) are the French version of long-term social-ecological research (LTSER) sites at the international level (Haberl et al. 2006; Angelstam et al. 2019). They are place-based research infrastructures that were initiated by the French National Centre for Scientific Research (CNRS) in the early 2000s to promote long-term inter- and transdisciplinary research at the interface between nature and society (Lévêque et al. 2000). The 14 current ZAs address a broad array of sustainability problems, including the impacts of industrial agriculture on biodiversity and human health, of large-scale facilities on the functioning of rivers, or of climate change on farming practices²⁹. They have recently placed social-ecological systems at the core of their common conceptual framework (Bretagnolle et al. 2019). As they cover a wide range of social-ecological systems across the country, they provided us with a diversity of research projects aimed at tackling diversely wicked sustainability problems.

²⁹ For a synthetic description of ZAs, see Bretagnolle et al. (2019), table 1.

3.2. Selecting a sample of research projects from the LTSEr network

Following others (e.g. Bammer 2008; Hirsch Hadorn et al. 2008; Wiek et al. 2012; Newig et al. 2019), we analysed research projects as the basic unit for conducting our investigation. Indeed, research projects, i.e. 'temporally, financially and staff-wise limited units of activities in relation to one or more related research goals' (Newig et al. 2019, p. 149), are relatively easy to identify and constitute meaningful entities for research actors and their partners.

In spring 2020, we conducted remote interviews with the ZA leaders to identify at least one transdisciplinary research project underway or recently completed. The selected research projects had to tackle a complex environmental issue (we deliberately did not use the term 'wicked problem'). We asked our informants to specify the objectives and stage of development of these projects and the partners involved. We defined research partners as individuals or institutions formally engaged in the projects through their participation, e.g. in the design of research questions and methods, the collection and analysis of data, or the dissemination of results. We also relied on project websites and available documents (responses to research calls, reports, and published papers) and, where necessary, email exchanges and interviews with project leaders to complete the project information. We selected all projects for which we had sufficient information on the problem addressed, the project members and partners, and the methods used. The sample of 17 projects we obtained included at least one project from each ZA. We asked the project leaders to validate a synoptic presentation of their project (see Table 13).

3.3. Project classification and positioning

Based on the material collected, we analysed for each project i) the cognitive complexity of the problem addressed; ii) its political complexity; iii) the methodological pluralism of the project; iv) its collaborative pluralism. We developed two analysis grids, one with the two dimensions corresponding to the wickedness of the problems addressed (grid 1) and the other with the two dimensions corresponding to the pluralism of the projects (grid 2). We then proceeded in two steps.

First, we developed a coarse-grained classification of the 17 projects and corresponding problems by implementing a three-level gradation (low, medium and high) for each dimension in the two grids, resulting in nine boxes in each grid (three boxes per dimension). We placed all projects and corresponding problems in the appropriate box of the two grids. Two of the authors proceeded separately and compared their results, seeking agreement with the third author in the few cases where they had assigned different boxes to a project or a problem. We then presented our preliminary results to the project leaders through email and in an online meeting, asking them to check that we had positioned their project and the problem it

addressed in the correct box of each grid according to their knowledge and understanding of our work. The project leaders validated our positioning of the vast majority of projects and corresponding problems (86% agreement, n=34). Discussions based on additional information on the projects led us to move them to a neighbouring box in one case (#17) for grid 1 and four cases (#2, 4, 5, 16) for grid 2.

Then, we refined this preliminary classification by positioning each problem (grid 1) or project (grid 2) in relation to its neighbours within a cell. Each project or problem was thus assigned not only a specific cell but also a specific position within that cell. This allowed us to assign coordinates to each project (problem) on the x- and y- axes of grid 1 (2). We did not ask the project leaders to validate this second step, as it required comparative knowledge of the different projects. Below we detail the criteria we used to assign the level of complexity of the problems and the pluralism of the projects.

3.4. [Grid 1: Problem wickedness](#)

The cognitive and political complexity of the problems addressed appear on the y- and x- axes, respectively, of grid 1. We adapted the criterion proposed by Alford and Head (2017) to evaluate the cognitive complexity of the problem addressed in each project (see Table 14). Indeed, we found it challenging to evaluate the clarity of the problem and the clarity of the solution(s) separately, as suggested by these authors. Instead, we considered the cognitive complexity low when both the problem and its solution(s) appeared to be clear, intermediate when they were moderately clear, and high when they were unclear. In turn, we used the criterion they proposed to evaluate the political complexity of the problem. We considered the political complexity to be low when access to relevant knowledge about the problem was relatively easy, and conflict over the problem was limited; intermediate when access to relevant knowledge was difficult but the level of conflict was limited; and high when access to knowledge was difficult, and the level of conflict was high.

3.5. [Grid 2: Project pluralism](#)

The methodological and collaborative pluralism of the projects are represented on the y- and x- axes, respectively, of grid 2. To evaluate methodological pluralism, we considered the number of methods used and the number of research approaches to which they relate (see Table 15). Biggs et al. (2021) distinguished between three types of research approaches: analytical/objective approaches, which are grounded in empirical measurements that are quantified and aim to generate objective descriptions of the phenomena studied; interpretive/subjective approaches, which focus on the meanings, experiences, feelings, and interpretations that people attach to phenomena; and collaborative approaches, which aim to co-produce knowledge and elicit or integrate different types of knowledge. Considering not only the number of research methods but also the number of research approaches to which

they relate is crucial because it encompasses the epistemological distance among them. Using two methods associated with distinct approaches might entail a similar or even higher level of methodological pluralism than using more methods associated with a unique research approach.

We considered the diversity of methods to be low if the methods used in a project related to a single research approach, regardless of the number of methods used; intermediate if two research approaches were used, with one or two methods for each research approach; and high when two research approaches were used with more than two methods for each research approach, or when all three research approaches were used, regardless of the number of methods used. Regarding collaborative pluralism, we split project partners following the OECD typology of non-academic actors that distinguishes among four categories: the private sector (i.e. business and industry), the public sector (i.e. government and civil service), the civic sector (i.e. civil society and non-governmental organisations), and citizens/communities (OECD, 2020). We considered the diversity of project partners to be low when only academics were involved in the project, intermediate when at most two categories of non-academic actors were also involved, and high when this was the case for at least three categories.

We tested the correlations between the political complexity (x-coordinate on grid 1) and the cognitive complexity (y-coordinate on grid 1) of the problems, and between the collaborative pluralism (x-coordinate on grid 2) and the methodological pluralism of the corresponding projects (y-coordinate on grid 2). We also compared the respective positions of the political complexity of the problem (x-coordinate on grid 1) and the collaborative pluralism of the project (x-coordinate on grid 2), as well as the respective positions of the cognitive complexity of the problem (y-coordinated on grid 1) and the methodological pluralism of the project (y-coordinated on grid 2). Finally, we projected each of the 17 problems (projects) onto the diagonal ($y=x$) of grid 1 (2). This gave us new coordinates (projectGrid1 and projectGrid2), which represent the wickedness of the problem and the pluralism of the project. We then tested the correlation between these coordinates. Given the small sample size, all correlations were tested using non-parametric Spearman tests. All statistical tests were performed using RStudio.

Table 13: Sample of projects in the ZA network focusing on a real-world problem

No.	Name (year of creation, ZA involved)	Short description of the project and its goal(s)	Project partners	Project leader (gender, disciplinary background, career stage)	Sources in addition to interviews with the ZA leaders, when relevant
1	Alpages Sentinelles (2008-present, ZA Alpes)	A long-term project in the French Alps to investigate climate change, its impact on summer mountain pastures and associated grazing systems, and strategies of adaptation of farmers and shepherds. Field measurements are carried out in >30 alpine pastures to produce reference data and enrich the knowledge co-production process among partners.	Researchers (agronomists, ecologists, sociologists), protected area managers, farmers, shepherds, pastoral experts, botanists, farming and pastoral organisations, and local and regional authorities	Female, sustainability science, mid-career	https://www.alpages-sentinelles.fr/ Dobremez et al. 2014; Nettier 2016
2	Refuges Sentinelles (2016-present, ZA Alpes)	Long-term research-action programme using >30 mountain huts as places to reflect on the transformation of high mountain areas under climate change.	Researchers, mountain refuge keepers, mountain guides, protected area managers, NGOs	Male, human geography, late-career	https://refuges-sentinelles.org/ Mahieu 2020
3	RhônEco (1998-present, ZA Bassin du Rhône)	Long-term monitoring programme studying the ecological and hydrological responses to the restoration operations on the Rhône river.	Researchers (hydrologists, ecologists, biologists), managers of the Rhône river (Compagnie nationale du Rhône, Agence de l'eau Rhône-Méditerranée-Corse, Syndicat du Haut - Rhône), local authorities, public electric utility company (EDF), protected areas, environmental NGOs	Male, hydroecology, late-career	http://restaurationrhone.univ-lyon1.fr/ http://www.graie.org/graie/graiedoc/doc_telech/brochure_RhonEco_restoration_ecologique.pdf ; Olivier et al. 2014
4	SPARE, 2015-2018, ZA Bassin du Rhône	Improving river management practices and increasing awareness and knowledge about the ecosystem services of healthy rivers. It united partners from six Alpine countries to experiment with new forms of citizen	The French case: researchers, Syndicat mixte de la rivière Drôme (SMRD), local inhabitants, NGOs	Female, human geography, mid-career	https://www.alpine-space.org/projects/spare/en/home Muhar et al. 2018; Ratouis 2021

		participation in water management.			
5	ProSuLi (2018-2022, ZA Hwange)	Triggering societal transformations to support the long-term sustainable management of TransFrontier Conservation Areas in southern Africa (Botswana, Mozambique, Zimbabwe) through a multi-stakeholder participatory process.	Researchers (ecologists, social scientists), NGOs, local and national governments, technical institutions, private sector	Male, ecology and sustainability sciences, mid-career	https://umr-astre.cirad.fr/en/research/projects/pro-suli
6	Aliment'Action (2018-present, ZA Plaine et Val de Sèvre)	Ten-year research-action project using a set of diversified methods to experiment with the transformation of food consumption and production practices in an agricultural territory comprising 40 villages and 34,000 inhabitants to enhance the resilience of the agrifood system.	Researchers (ecologists, agronomists, human and social scientists), farmers, local communities, NGOs, citizens	Male, ecology, late-career	https://aliment-actions.fr/?PagePrincipale Berthet et al. 2020 Berthet et al. 2022
7	PACSE (2018-2020, ZA Pyrénées-Garonne)	Ensuring the best compromise between the ecosystem services provided by agricultural landscapes (water quality, pollination, and pest regulation).	Researchers, farmers, an agricultural cooperative, and an NGO	Male, economy, mid-career	https://www.dynafor.fr/single-post/2019/04/18/projet-pacse Ouin et al. 2020
8	Ocean Sentinel (2018-2020), ZA Antarctique et Sub-Antarctique)	Monitoring seabirds equipped with biologgers to detect illegal fishing boats in remote seas of the Southern ocean.	Researchers in oceanography and ecology	Male, ecology, late-career	Weimerskirch et al. 2020
9	Sensei (<i>Sentinels of the sea ice</i>) (2017-2023, ZA Terres Antarctiques)	Assessing the impact of the melting of sea ice on polar ecosystems in the Arctic and Antarctic by making predictions for eight predator species based on long data sets.	Researchers specialised in sea ice evolution and species ecology, NGOs, private sector (BNP-Paribas foundation)	Male, ecology, late-career	https://www.projetsensei.com/fr/ https://sites.google.com/view/senseicebc/home
10	Biomareau 1 (2012-2015) and 2 (2016-2019) (ZA Loire)	Studying the consequences of fluvial maintenance operations on four components of biodiversity (vascular flora; coleopteran insects; shore birds; European beaver) (BioMareau I) and landscape	Researchers (biologists, geologists, ecologists), public authorities, natural resource managers, environmental NGOs	Male, ecology, late-career	https://www6.val-de-loire.inrae.fr/biomareau/Page-d-accueil/BioMareau-I-and-II Chevalier et al. 2021; Final report of the project BioMareau Supplementary Interview, 20/12/2021

		dynamics (BioMareau II) in the Mareau-aux-Prés islands.			
11	CARELI (2018, ZA Arc jurassien)	A ten-year research-action project to reconcile conflicting views about the management of fox populations by engaging all interested actors in a large-scale experiment to compare two management strategies (hunting versus protection of the fox) in the department of Doubs, France.	Researchers (ecologists, sociologists), environmental NGOs, hunting federations, farming organisations, regional authorities	Male, ecology, late-career	https://zaaj.univ-fcomte.fr/spip.php?article115
12	ALICE (2017-2021, ZA Armorique)	Promoting sustainable investments in blue-green infrastructure networks by identifying the benefits of ecosystem services delivered at the terrestrial-aquatic and land-sea interfaces in the Atlantic Region. The French case study includes the Couesnon river catchment in north-western France in the Armorican massif.	French case: researchers, water development and management planners (SAGE), local communities (Pays de Fougères)	Male, geography, late-career	https://project-alice.com/alice-project/ Houet 2015; Houet et al. 2016; Terêncio et al. 2021 Couesnon 2050 – Evolution des paysages et impacts possibles sur la biodiversité et les ressources en eau (https://hal.archives-ouvertes.fr/hal-03474398/file/COUESNON_2050_presentation.pdf). Supplementary Interview, 14/12/2021
13	Ecoflux (1998, ZA Brest Iroise)	Long-term citizen science project aiming to monitor river water quality in western Brittany.	Researchers (hydrologists, biogeochemists), volunteers, high school students and teachers	Female, research assistant, mid-career	https://www-iuem.univ-brest.fr/ecoflux Abbott et al. 2018
14	ONDINE (2021-2022, ZA Territoires Uranifères)	An exploration of the co-evolution of the natural environment and societies around naturally radioactive mineral springs.	Researchers in ecology, radiology, biology, sociology, anthropology, and geomorphology; the Conservatory of Natural Spaces of Auvergne; the town hall of Joze	Female, hydroecology, mid-career	https://msh.uca.fr/content/ondine-les-sources-min%3a9rales-des-co-%c3%a9volutions-homme-environnement-atypiques
15	TortuEEES 2017-2020, ZA Environnement urbain)	An exploratory study investigating the presence of exotic freshwater turtles in Strasbourg public parks, its perception by park users and managers, and potential management strategies.	Researchers in zoology and ethnology, natural resource managers, and representatives of the city of Strasbourg	Female, human geography, late-career	Philippot et al. 2019; Glatron et al. 2021 Supplementary Interview, 20/12/2021

16	Rustic (2013-2015, ZA Moselle)	Implementing and evaluating the purifying capacity of rustic drainage filtering devices to identify and understand pollution mitigation mechanisms.	Researchers, water managers, farmers, national (ANSES) and regional authorities (the regional chamber of agriculture of Lorraine)	Female, geology, late-career	Vallée 2018
17	Project CONSACRE - Ecological continuity of the Seine river and interest of stakeholders in its Restoration (2018-2021, ZA Seine)	A three-year action research project to analyse the ecological continuity of the Seine river. Its objective was to propose possible actions that concern, on the one hand, the possibilities of development for the preservation and restoration of natural environments and, on the other hand, the involvement of different stakeholders in problem resolution.	Researchers (ecology, hydrology, geography, history), migratory fish NGO, water managers, the Fish Observatory of the Seine-Normandy basin, regional authorities	Female, hydroecology, mid-career	https://consacre.inrae.fr/ Le Pichon et al. 2020

Table 14: Characterising the degree of wickedness of the real-world problems addressed in our sample

No.	Clarity of the problem and its solutions	Diversity of human actors directly affected by the problem, distribution of knowledge and interests, level of conflict
1	Multiple responses have been collectively identified, depending on the type of mountain pasture, with some knowledge about their feasibility and effectiveness.	Intermediate diversity of actors (farmers, shepherds, grazing organisations, protected area managers, researchers) with a broad distribution of knowledge and interests. Low level of conflict.
2	High mountains and related human activities are heavily affected by climate change. Affected actors implement individual responses; a collective reflection is just beginning.	Intermediate diversity of actors (mountain guides, shelter keepers, tourists, local residents). No conflicting values or interests.
3	The Rhône river has been heavily transformed due to hydroelectric production; the physical and chemical degradations affecting it are relatively well understood. Ecological restoration operations have been carried out and improved the situation, but the extent to which the Rhône river can be restored is unclear.	Very high diversity of actors (managers of the Rhône river, local communities, inhabitants of the Rhône valley, managers of protected areas, fishers); very broad distribution of knowledge and interests; potentially severe conflicts.
4	Multiple responses can be considered, with little knowledge about their feasibility and effectiveness.	High diversity of actors (managers of the Drôme river, inhabitants, public authorities, private companies, environmental NGOs) with a very broad distribution of knowledge and interests.
5	TransFrontier Conservation Areas in southern Africa face pressures and threats of multiple sorts (e.g. climatic and ecological hazards, economic crises, political instability, and conflicts). Solutions are unclear.	Extremely high diversity of actors involved (local communities, managers of conservation areas, local and national governments) with highly divergent knowledge and knowledge systems and conflicting interests.
6	Agrifood systems have become ecologically, economically, and socially unsustainable. Several ways of transforming food production and consumption practices can be envisaged, with little knowledge about their feasibility and effectiveness.	Very high diversity of actors involved (e.g. food consumers, farmers, farming organisations, local representatives, agrifood businesses, environmental NGOs) with highly diverging knowledge and knowledge systems and conflicting interests.
7	Agricultural landscapes provide multiple ecosystem services (e.g. maintaining water quality, pollination and pest regulation) that cannot be all maximised. Multiple solutions can be envisaged, with little knowledge about their feasibility and effectiveness.	High diversity of actors (farmers, farming organisations, water authorities) with diverging and conflicting interests.
8	Illegal fishing in remote seas threatens vulnerable species. Solutions exist but have not been implemented.	A wide variety of actors are affected by the problem, including fishers, researchers, nature reserve managers, and NGOs; high level of conflict.
9	Polar ecosystems are affected by the rapid melting of sea ice. Solutions are unclear.	Few actors are directly affected by the problem; low level of conflict.
10	Fluvial maintenance operations impact the Loire's biodiversity. Solutions are unclear.	High diversity of actors (water authorities and services, local communities, inhabitants, NGOs, protected areas) and an intermediate level of conflict.
11	How can fox populations be managed sustainably? Contradictory solutions have been proposed.	High diversity of actors (hunters, farmers, NGOs) with conflicting interests.
12	Changes in land use and climate change compromise biodiversity and ecosystem service provision in Atlantic landscapes, especially at terrestrial-aquatic and land-sea interfaces. Solutions are unclear.	High diversity of actors living in coastal areas (farmers, citizens, local authorities, local communities, water managers); conflicting interests between farmers and water managers concerning water pollution.
13	The quality of river water in western Brittany is seriously degraded. Solutions exist but are difficult to implement.	High diversity of actors involved (farmers, farming organisations, citizens, environmental NGOs, water authorities, local authorities), with highly conflicting interests.
14	Measures to restrict the uses of spring water with high natural radioactivity may be considered.	Intermediate diversity of actors; low level of conflict.
15	European and national regulations prevent the spread of exotic invasive species, but the general public often appreciates encountering Florida turtles in urban public parks. How should the populations of invasive exotic species of the Florida turtles (<i>Trachemys scripta elegans</i>) be managed in public parks? Contradictory solutions exist.	Intermediate diversity of actors; low level of conflict.
16	Pesticides contribute heavily to the degradation of water quality. Different solutions can be considered, with some knowledge about their feasibility and effectiveness.	High diversity of actors (farmers, water managers, regional authorities, environmental NGOs, citizens); high level of conflict.
17	There has been a drastic decrease in fish abundance and diversity in the Seine river. Recent measures such as the implementation of fish passes have slightly improved the situation.	High diversity of actors affected (water authorities and agencies, fishermen) and a high level of conflictuality.

Table 15: Characterising the pluralism in our sample of projects

No.	Diversity of research methods	Heterogeneity of research partners
1	A broad set of quantitative methods (e.g. evaluation of biomass at the beginning of the grazing season, monitoring of vegetation, and air and soil temperatures) and qualitative methods (interviews, focus groups, working groups)	High diversity of research partners: protected area managers, pastoral services, farmers, shepherds
2	Mostly qualitative methods (interviews, focus groups, participatory hikes, participant observation) but also integrating quantitative data into the project	High diversity of research partners: mountain shelter keepers, mountain guides, protected area managers
3	Mostly predictive modelling of physical and biological changes induced by ecological restoration actions and biological monitoring	High diversity of research partners: Rhône-Méditerranée-Corse water agency, Electricité de France (national electricity company), protected areas
4	Qualitative and participatory approaches that involve citizens in the discussion of management strategies of the Drôme river through workshops, fieldwork, and interviews	High diversity of research partners: public water authorities (Syndicat mixte de la rivière Drôme), citizens
5	Collaborative scenario building – mixed methods (Godet 1986, 2010)	Very high diversity of research partners: local NGOs, private sector, local communities and inhabitants, public authorities
6	Long-term ecological monitoring of agrosystems, qualitative studies based on interviews and questionnaires, and social-ecological experimentations of transformation methods based on a broad range of theories and tools (theatre plays, conception workshops, animation techniques – six thinking hats)	Very high diversity of research partners: local communities, NGOs, farmers, citizens
7	Modelling (3 types of models used)	High diversity: a farming organisation (Groupement des Agriculteurs de la Gascogne Toulousaine), an agricultural cooperative (Val de Gascogne), and a local NGO (Arbre & Paysage 32)
8	Monitoring of seabirds equipped with biologgers	Low diversity
9	Ecological modelling based on extensive data sets about the species studied	Low diversity
10	Mainly ecological field data collection: inventorying and mapping the compartments of biodiversity studied before and after works	Intermediate diversity: nature resource managers
11	A social-ecological experiment comparing two ways of managing fox populations; statistical analysis of quantitative data and qualitative analysis through observations and interviews	High diversity of research partners: NGOs, hunting and farming organisations, hunters, farmers
12	Prospective modelling of land use, the use of GIS data and modelling to map aquatic and terrestrial vegetation formations and hydrological modelling, and scenario building based on participatory approaches	High diversity of stakeholders involved in the construction of long-term scenarios: water managers, local elected representatives, farming organisations, consumers' associations, land use planners (urbanisation), environmental authorities (DREAL)
13	Long-term observations of water quality	Citizen science (principally high school students) to collect field data about the quality of river water
14	Analyses of radioactivity in water, vegetation, and soils; a historical study based on the examination of archives; scenario building, based on interviews and a questionnaire	The Conservatory of Natural Areas of Auvergne (Rhône Alpes), a local community
15	Sociological survey based on interviews with park visitors and managers; a photo-interpretation and naturalist study of turtle species	Managers of the green spaces of the Strasbourg metropolitan area
16	Several types of devices were proposed: ditches of varying lengths, ditches with a straw bale, ponds, and a succession of ponds	Diversity of research partners, including farmers, agricultural advisers, regional and departmental Chambers of Agriculture, water agency
17	Long-term historical study of the transformation of the Seine river; ecological connectivity modelling; studying the role of communication, awareness-raising, and collaboration in the construction of restoration projects	Fishers organisations and federation; regional urbanism and environment agency

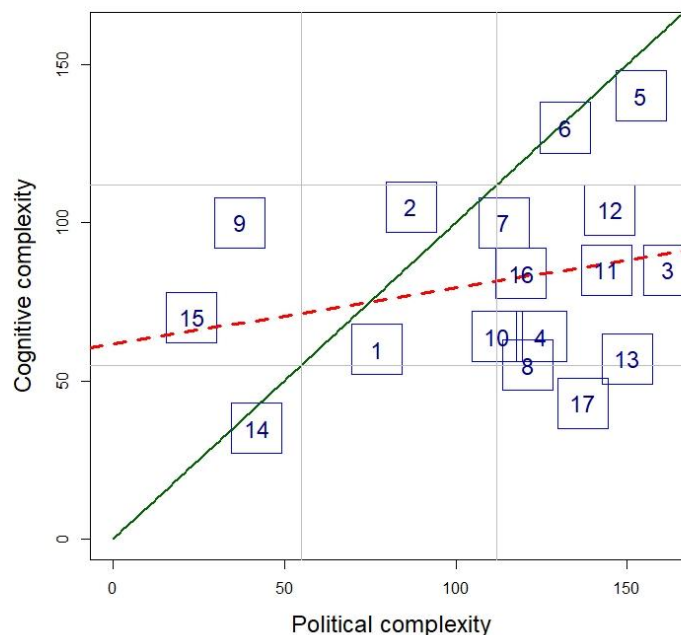
4. Results

4.1. Problem wickedness

In line with our expectations, there was an overall slightly positive ($r=0.21$) albeit non-significant ($p=0.4$, $n=17$) trend within our sample of projects regarding the cognitive and political complexity of the problems addressed (see Grid 1 in Figure 7). In other words, the problems addressed and their solutions were more difficult to define as the range of actors affected grew. Indeed, no projects that addressed a very unclear problem affected a narrow range of actors, nor, symmetrically, did a problem affect a wide range of actors and address a clear problem with clear solutions. However, there were many exceptions, as underlined by the non-significant relationship, since several projects were not aligned on the diagonal, with a majority of them positioned below it (Figure 7). This finding reveals that the political complexity of the problem addressed in these projects contributed more to the overall problem wickedness than its cognitive complexity. The opposite was true for only three projects (#2, 9, 15). It can also be noted that a large majority of projects in our sample addressed moderately wicked problems, two of them (#5, 6) very wicked problems, and one a weakly wicked problem (#14).

Figure 7: Degree of wickedness of the problems in 17 research projects

Grid 1, showing the degree of wickedness of the problems addressed in our sample of projects. The green line corresponds to the diagonal ($Y=X$), while the red line corresponds to the regression line between the two axes (the line is dashed because the correlation is not significant). Projects are numbered in blue. The nine boxes are represented in light grey. The scales chosen for the graphical presentation are arbitrary.

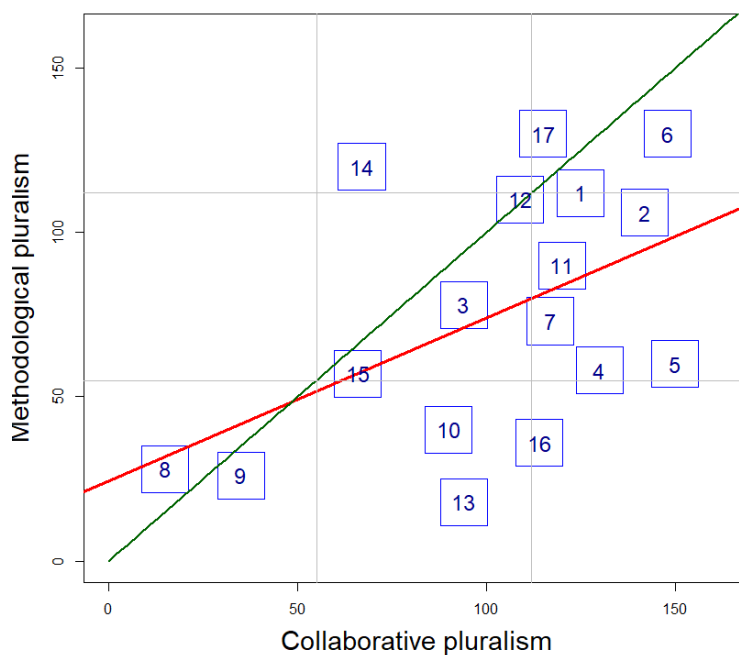


4.2. Project pluralism

Again as expected, we found an overall positive – and weakly significant ($r=0.49$, $p=0.04$, $n=17$; Figure 8) – relationship between methodological pluralism and collaborative pluralism within our sample of projects. In other words, the diversity of methods increased with the diversity of research partners. There were no projects with low heterogeneity of research partners and intermediate or high diversity of research methods, nor with a high diversity of research partners and low diversity of research methods. Five projects (#1, 3, 6, 9, 15) were very well aligned on the diagonal, which means that their collaborative and methodological pluralism contributed equally to their overall pluralism. Four projects (#2, 8, 11, 12) were almost aligned on the diagonal. Six projects (#4, 5, 7, 10, 13, 16) were substantially below the diagonal, which means that their collaborative pluralism contributed more to their overall pluralism than their methodological pluralism. The opposite was true for two projects (#14, 17).

Figure 8: Level of pluralism of the 17 projects

Grid 2, showing the level of pluralism of the projects in our sample of projects. The green line corresponds to the diagonal ($Y=X$), while the red line corresponds to the regression line between the two axes (the line is complete because the correlation is significant). Projects are numbered in blue. The nine boxes are represented in light grey. The values on axes are arbitrary.



4.3. Correspondence between problem wickedness and project pluralism

Only four pairs of project and associated problem (#4, 6, 7, 11) occupied the same box (out of nine possibilities) in both grids (Figures 7, 8), i.e. contrary to our initial expectations, the correspondence between problem wickedness and project pluralism was actually limited. As said, we refined these results by testing the correlation between the coordinates of the projects and their associated problems projected onto the diagonals of the two grids (Figure 9a) We found an overall tendency toward positive correlation, which was marginally significant ($r=0.41$; $p=0.08$, $n=17$; see Figure 9a), indicating that the relative positions of the projects in the two grids along the diagonals were more or less conserved. However, this held particularly true for the right part of the graph, i.e. the most wicked projects, while the level of correspondence between problem wickedness and project pluralism was more dispersed around the diagonal when problem wickedness was low (Figure 9). In weakly wicked projects, project pluralism was either slightly higher (#15), much higher (#1, 14), slightly lower (#9), or much lower (#8) than expected given the wickedness of the problem at hand. On the contrary, projects addressing highly wicked problems tended to have a level of pluralism that did not deviate much from the wickedness level of the problem addressed. Six projects (#4, 6, 7, 11, 12, 15) were almost perfectly aligned on the diagonal. Their levels of problem wickedness and project pluralism contrasted, ranging from low (e.g. #15) to high (e.g. #6). Main outliers (detected from their distance to the diagonal, in reference to Figure 9) were #1, 2, 14, and 17 above the diagonal, and #8, 9, and 13 below the diagonal (and to a lesser extent, #3, 5, 10, and 16). Conversely, by using the residual distance of each project from the corresponding diagonals, we found no relationships between the residuals in grid 1 versus grid 2 (Figure 9b).

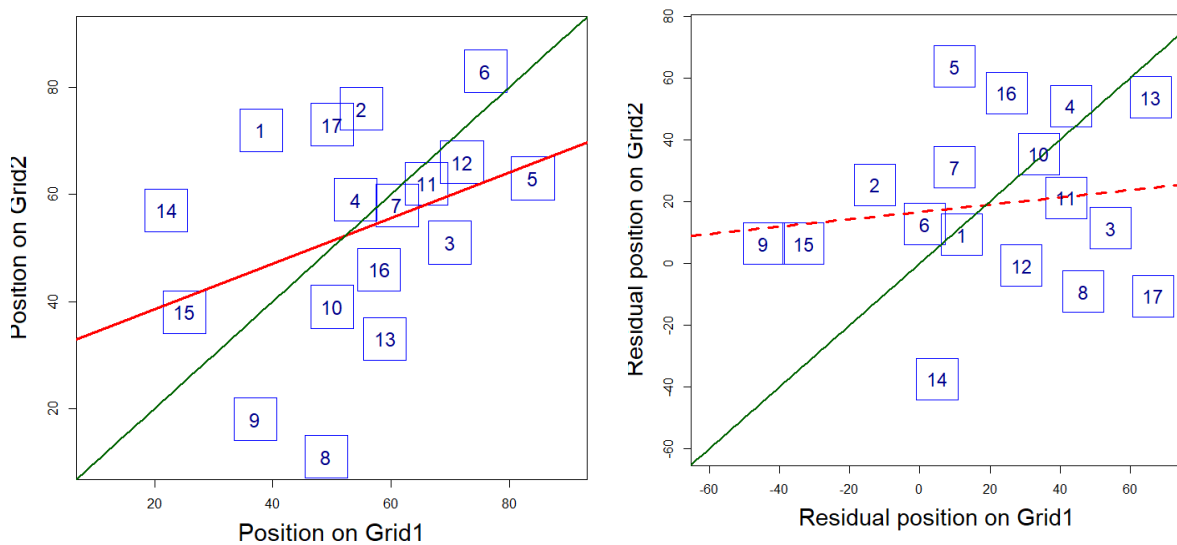
We designated the situations where the methodological (collaborative) pluralism was close to expected given the cognitive (political) complexity of the problem addressed as methodological (collaborative) correspondence, as methodological (collaborative) reductionism when it was lower, and as methodological (collaborative) integrationism when it was higher. We found that most projects presented at least one type of correspondence but that reductionism and integrationism were also well represented in our sample (Table 16). We found no project with methodological integrationism and collaborative reductionism or vice versa.

Table 16: Classification of the 17 projects according to their methodological and collaborative strategies

		Methodological		
		reductionism	correspondence	integrationism
Collaborative	reductionism	8, 10, 13	3, 12	
	correspondence	5, 9, 16	4, 6, 7, 11	17
	integrationism		2, 15	1, 14

Figure 9: Correspondance between problem wickedness and project pluralism in 17 research projects

a) The relative position of each of the 17 projects along the diagonal of Grid1 (X-axis) and Grid2 (Y-axis); b) the residual (orthogonal) distance of each project against the diagonal of Grid1 (X-axis) and Grid2 (Y-axis). The green line corresponds to the diagonal ($Y=X$), while the red line corresponds to the regression line between the two axes (dashed when the correlation is not significant). Projects are numbered in blue. The values on axes are arbitrary. Alignment with the diagonal means perfect correspondence. A position below (above) the diagonal indicates that project pluralism is lower (higher) than expected given problem wickedness.



5. Discussion

Sustainability science has been presented as ‘a different kind of science’ (Kates 2011, p. 19450; see also Clark and Dickson 2003). This claim is associated with its central objective, which is to tackle the wicked problems facing contemporary societies. Here we investigated the influence of problem wickedness on how scientists address wicked problems in practice. We analysed the relationship between the level of problem wickedness and project pluralism by documenting the research stances and methods adopted to address diversely wicked environmental problems in 17 research projects. We refined the approach by distinguishing between the political and cognitive complexity of the problem on the one hand and between the collaborative pluralism and methodological pluralism of the project on the other. We found overall positive correlations between cognitive complexity and political complexity, methodological pluralism and collaborative pluralism, and problem wickedness and project pluralism, but the levels of correlation were always, at best, weakly significant. We identified three research stances in our sample: correspondence, when there was a rather close match between collaborative (methodological) pluralism and political (cognitive) complexity; reductionism, when methodological or collaborative pluralism was lower than expected; and

integrationism, in the opposite case. Below we discuss the influence of problem wickedness on these strategies.

5.1. Problem wickedness

The dispersion of the level of correspondence between problem wickedness and project pluralism (Figure 9a) suggests that projects addressing highly wicked problems have less leeway regarding the level of pluralism than projects addressing weakly wicked problems. On the one hand, it is understandably difficult to involve more actors than those interested in or affected by a highly wicked problem or to use more methods and approaches than the cognitive complexity of the problem suggests. Strong integrationism, then, is a poor option when addressing a highly wicked problem. On the other hand, involving far fewer actors or using a limited number of methods and approaches can threaten project legitimacy and relevance, making strong reductionism equally difficult.

We found a tendency toward reductionism in projects addressing moderately wicked problems (see Figure 9a), which may have several explanations. Although strongly advocated in sustainability science (Poteete et al. 2010; Biggs et al. 2021), methodological pluralism faces practical obstacles that can be ‘formidable’ (Poteete et al. 2010). These include the need for the research team to master the specific skills required by each research method, which demands time and money; for some incumbent team members to acquire additional skills; or for new members with these skills to join the team. In addition, combining research methods from different approaches may cause misunderstandings and tensions between project participants, e.g. using qualitative methods when trained in quantitative methods. Research based on a mix of scientific approaches may also be more difficult to publish and valorise in research careers (Poteete et al. 2010).

Similarly, the literature on participation in sustainability science (e.g. Bammer 2008; Lang et al. 2012) has highlighted the many obstacles that can hinder actor involvement in a project. These include, on the actors’ side, a lack of interest in the project, a lack of confidence in its capacity to improve their or the overall situation, and a lack of energy to invest in time-consuming participatory processes; on the researchers’ side, impediments include a lack of facilitation and mediation skills. Finally, while the level of problem wickedness is likely to increase actors’ interest in the project, its influence on their confidence in the project’s capacity to improve the situation is more difficult to predict. This would require an in-depth analysis of how the various actors envisage the potential benefits and costs of (not) participating in the project.

While the obstacles to methodological and collaborative pluralism may explain the reductionist strategy, the integrationist strategy appears more counterintuitive. We found that projects characterised by methodological integrationism (#1, 14, 17) and collaborative integrationism (#1, 2, 14, 15) tended to address weakly to moderately wicked problems (Table 16). These strategies seem to be related to specific circumstances of the projects rather than generic factors. For example, project #1 focused on a moderately wicked problem (i.e. the

adaptation of mountain pastures and associated grazing systems to climate change) that brought together all the actors interested in mountain pastures. According to the project leader, this would have been impossible with a more controversial issue such as wolf predation, a highly wicked problem in the French Alps (Mounet 2007; Doré 2011). The project aimed to develop a 'space for dialogue' (Nettier 2016), and the wickedness level of mountain pastures' adaptation to climate change lent itself perfectly to this process. Each participant then developed their own methods and approaches, and additional methods were used to foster their interactions, leading to high methodological pluralism. Project #15 focused on the presence of exotic invasive species of turtles in urban parks, which most visitors have not considered a problem (Glatron et al. 2021). Interviewing these actors enabled the project leaders to open up a debate about the place of invasive exotic species in urban contexts and the possibility of adopting a more 'benevolent' attitude toward them (Glatron et al. 2021). In this case, collaborative integrationism could be seen as a strategy to counteract the dominant ecological perspective (i.e. invasive exotic species are problematic and should be eradicated).

5.2. Project duration and leadership

Project duration and leadership are two other factors that are well known to interfere with transdisciplinarity (Poteete et al. 2010; Lang et al. 2012; Hitziger et al. 2019). A short project duration seems to foster methodological reductionism, which is congruent with previous studies (Poteete et al. 2010). Notably, it takes time to master the skills associated with various methods, especially if they pertain to different scientific approaches. We sought to explore the impact of these two factors on project pluralism despite our small sample size, which precludes multivariate analyses and statistical testing. Out of the six projects characterised by methodological reductionism (#5, 8, 9, 10, 13, 16), four (#5, 8, 10, 16) had a short duration, one (#9) had an intermediate duration, and one (#13) was a long-term project. Therefore, the tendency is less clear than for problem wickedness. The pattern was even less clear for collaborative reductionism, with two long-term projects (#3, 13) out of five characterised by collaborative reductionism.

Interestingly, project #13, characterised by both methodological and collaborative reductionism, was a long-term citizen science project addressing the poor quality of river water and recurring algal blooms in western Brittany. It was based on the weekly monitoring of water samples collected by scientists and essentially one type of citizen (high school students). Methodological and collaborative reductionism may be a common strategy in long-term monitoring projects, as it facilitates the standardisation of data production protocols.

An equal number of short-term and long-term projects showed methodological or collaborative integrationism, whereas we expected the number of long-term projects meeting this criterion would be higher. One potential explanation is that short-term projects actually benefit from the long-term dimension of ZAs. Two- or three-year projects can build on a much longer history that has given the participants time to master a diversity of methods and to establish and maintain relationships with a broad range of actors. For example, its inclusion in

a long tradition of collaboration between researchers with various disciplinary backgrounds and local actors enabled project #14 to involve a wide range of actors and use various methods around the radioactivity of natural springs despite its short duration.

Finally, we found that projects characterised by reductionism were mostly led by male scientists trained in ecology or hydroecology, whereas projects characterised by integrationism were mostly led by women with more diverse disciplinary backgrounds (ecology, sustainability science, and human geography). Koppman and Leahey (2019) found that scholars with high status (i.e. men affiliated with a more prestigious discipline) were more likely to adopt high-risk, high-reward strategies and, in particular, unconventional methods, provided these were not too unconventional. Methodological and collaborative pluralism can be considered unconventional methods (Biggs et al. 2021), and they may be too unconventional to be adopted by high-status researchers, although there are exceptions in our sample. For example, projects #2 and 6 (addressing a highly wicked problem and characterised by methodological and collaborative correspondence) were led by two late-career male researchers, the former in human geography and the latter in ecology.

5.3. Limitations

Our results are exploratory and need to be confirmed and refined. The first limitation regards the positioning of the cases in the two grids, especially in grid 1 (problem wickedness). Assessing the wickedness of a problem is certainly not straightforward (Peters and Tarpey 2019). While we found really helpful to decompose problem wickedness into two dimensions, assessing the problems' cognitive complexity proved to be particularly challenging. Indeed, we could not strictly follow Alford and Head's (2017) proposal, i.e. distinguish between the level of clarity of the problem and the level of clarity of its solution(s). We found it more feasible to identify three levels of clarity of the problem and its solution(s), as explained in the method section. Despite this adaptation, we acknowledge that there is some subjectivity when positioning a problem's cognitive complexity. Positioning the political complexity of the problem was also problematic in some cases. For example, we discussed the extent to which the rapid melting of sea ice in polar ecosystems (project #9) is a politically complex problem (and eventually decided it directly affected a few actors and generated little conflict). As for the positioning in grid 2 (project pluralism), it could be biased by the heterogeneous level of information available for each project and our personal knowledge of some projects. We limited this bias as much as possible through discussion among ourselves and with the project leaders.

We are therefore confident that the positioning of the problems and projects is not arbitrary, although some slight changes could probably be considered (and would affect the statistical tests). Furthermore, we could have chosen the typology of methods proposed by von Wehrden³⁰ rather than that proposed by Biggs et al. (2021). However, there is significant

³⁰ See <https://sustainabilitymethods.org/index.php/Methods>

overlap between the two typologies, and the three categories of research approaches we have used are broad enough to be robust. Consequently, we believe that using another typology would not have changed our results, at least qualitatively.

The sample size is the second limitation of our study. On the one hand, we could not obtain statistically robust results with only 17 projects. A larger and more diversified sample would be necessary to further our understanding of the influence of problem wickedness on project pluralism and to test factors that we only started to explore here, such as project duration and leadership, or that we did not consider, such as financial resources. On the other hand, there were too many projects to give us in-depth knowledge of each of them. Therefore, we could not evaluate the influence of qualitative factors such as intensity of interactions or trust among project partners, which has often been underlined as an important factor for collaborative pluralism (e.g. Harris and Lyon 2013; Cundill et al. 2015).

6. Conclusion

Contemporary societies are faced with a growing number of diversely wicked environmental problems, including highly wicked or super wicked ones. Sustainability science has developed specific research stances and methods to tackle these problems. The textbooks about methods and participation in sustainability science that have recently flourished are undeniably useful in helping newcomers to the field choose methods and participation strategies that are appropriate to the problems they seek to address. However, we believe that there is also a need to clarify the factors that influence the research stances and methods adopted in projects addressing wicked environmental problems. Therefore, we adopted a pragmatic rather than prescriptive approach to exploring these factors, with particular attention to the level of problem wickedness. An original feature of our study is that we considered participation and methods as two types of project pluralism, whereas the literature tends to focus on one or the other.

We found that project pluralism tended to increase with problem wickedness. Moreover, projects addressing highly wicked problems have little room for manoeuvre and are more likely to have a level of methodological and collaborative pluralism that matches the wickedness of the problem at hand. Addressing such problems is therefore especially constraining. In contrast, projects addressing weakly to moderately wicked problems have more flexibility when choosing between the three strategies we have identified: correspondence, reductionism, and integrationism.

Beyond problem wickedness, our study enabled us to discern the influence of other factors such as project duration and leadership. Because the results presented here are preliminary and need to be strengthened, we hope that our paper will pave the way for studies based on larger and more diverse project samples. Such projects will contribute to a better understanding of the implications of addressing highly wicked problems for research stances and methods and, more generally, the factors influencing how sustainability science is concretely enacted.

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Part IV: Discussion and Conclusion

Calls for inter- and transdisciplinary research are rising (Toomey et al. 2015). Indeed, TRSS has gained popularity in recent decades and is considered the ultimate approach to tackle the wicked problems facing contemporary societies (Hirsch Hadorn et al. 2008, Jahn et al. 2012; Lang et al. 2012; Scholz and Steiner 2015). However, the transdisciplinary approach remains somewhat marginal and receives little support from universities and research institutions (Jahn et al. 2012; Yarmine 2012; Guimarães et al. 2019; Fam et al. 2019; Fam and O'Rourke 2021). Indeed, there is a persistent tension between the conventional ways of knowledge production based on disciplines, and the urgent need to address the wicked problems in sustainability science by applying transdisciplinary research. Proponents of transdisciplinary research propose to change the processes of knowledge production by applying methodological pluralism (Poteete et al. 2010; von Wehrden et al. 2017; Biggs et al. 2021) and involving societal actors in the research process (Hirsch Hadorn et al. 2008; Mobjörk 2010; Jahn et al. 2012). However, these success factors of TRSS are rather difficult to implement, and can raise a number of practical issues for those carrying out this type of research. In this work, we have unpacked some of the practical issues faced by research actors at the stage of organising the research process and its implementation. In this final part, we discuss the main findings, reflect on the contributions of this work, but also its limitations, and suggest a way forward for future research.

1. Overview of the main results

This thesis has focused on three practical issues of TRSS related to the phases of research design and research process (see Figure 2 of the Introduction): 1) setting up an organisational context adapted to the characteristics of TRSS; 2) involving actors and distributing roles in TRSS processes ; 3) adapting research methods and stances to the level of wickedness of the problems. To explore these issues, we have applied pragmatic lenses and provided empirical examples from the French network of Zones Ateliers. The following section aims to reflect on these issues and provide an overview of the major results of this work.

1.1. Creating collaborative spaces beyond science or society alone

In the first chapter of the results, we have explored the role of organisational arrangements at the research infrastructure level and their influence on the level of inter- and transdisciplinarity in the ZAs' governing bodies, projects and peer-reviewed articles. We have shown that the ZAs are research-based meta-organisations, which has some implications for their functioning and dynamics. Such organisational settings entail power inequalities among their members and a low turnover of members. In fact, societal actors had a limited decision-making capacity due to the lack of collaborative spaces and they were not members, but partners of the ZAs. Polk (2014) highlighted the role of such collaborative spaces that are both "embedded in" and "isolated from" science and practice itself. However, creating such spaces is not an easy task. ZAs are experimenting with their organisational arrangements to create

such spaces, and there is an ongoing reflection in the ZAs' direction on how to adjust their governing bodies to facilitate the involvement of societal actors. We have also shown that the ZAs are quasi-boundary organisations, incorporating two characteristics of boundary organisations (integrating actors from both sides of the boundary; using a SES framework as a boundary object). However, they are essentially accountable to the research institution (CNRS). According to Polk (2014), knowledge transfer and scalability are the major limitations of institutionalising transdisciplinarity in boundary organisations.

Overall, this chapter has shown that the type of organisational structure in a given national research infrastructure is important for its scientific productions. We have also highlighted the role of membership and differentiated it from partnership. Finally, we have underlined the limitations associated with the lack of accountability to societal actors in research infrastructures. Although the creation of such collaborative spaces is seen as a necessary step for the success of TRSS, their actual implementation is rather challenging. Mobilising the concept of meta-organisation and boundary organisation has allowed us to shed light on several limitations related to the organisation and functioning of ZAs. Table 17 provides an overview of these features in the ZAs.

Table 17: Organisational arrangements of the Zones Ateliers

Concept	Features of MO/BO	Presence of these features in the ZAs
Meta-organisation (MO): Ahrne and Brunsson (2008, 2011)	Members of MOs are organisations	Members of ZAs are research labs; societal actors were not members but partners of the ZAs
	Members of MOs are more powerful than the organisations themselves	Member labs have greater financial resources than the ZAs themselves
	Little turnover of members	Member labs seldom left a ZAs, unequal power distribution among labs
Boundary organisation (BO): Guston (1999)	BO facilitate the creation and use of boundary objects	SES framework (Bretagnolle et al. 2019) is used as a boundary object
	BO involve the participation of actors from both sides of the boundary	ZAs involve both societal and research actors
	BO are accountable to each social world according to its own criteria	ZAs are accountable only to the research institution (CNRS)

1.2. Beyond the duality of perspectives between research actors and societal actors

In the second chapter of the results, we have explored how roles are distributed among actors in TRSS projects. Focusing on the concept of roles has allowed us to overcome the conceptual dualism between research actors and societal actors. Jahn et al. (2021) argue that conceptual dualism exists in transdisciplinary approaches, when 'science' and 'society' are largely seen as complementary and often mutually exclusive categories (p. 352). The authors argue that transdisciplinary research requires a more nuanced understanding of actors'

involvement in TRSS processes. Accordingly, we have analysed the roles of all actors involved in the projects. Our results suggest that societal actors have become major role performers. Contrary to our expectations, they were performing a larger panel of roles than the research actors. However, we highlighted the marginal role of several types of actors. In fact, while some actors performed a vast diversity of roles, the role of citizens was limited to 'data supplier' in the majority of projects. Following Jahn et al. (2021), we suggest that sufficient resources should be allocated to compensate these 'disadvantaged' actor groups. In addition, we have explored factors such as actor pluralism and examined its relationship with role distribution. Musch and von Streit (2020) argue that in order to reach a faster consensus, actors from similar societal backgrounds are selected in TRSS projects. To overcome this homogeneity of actors, they suggest rethinking existing financing schemes that would favour long-term financing.

1.3. Choosing research strategies when addressing wicked sustainability problems

In the third and final chapter of the results, we have examined the relationship between the wickedness of the problems, the diversity of research methods and the plurality of societal actors in the TRSS projects. We expected the level of problem wickedness to be a determining factor in the choice of research strategies. However, our findings demonstrated a limited correspondence between the problem wickedness and both the methodological and actor pluralism in the projects. We identified three research strategies in our sample of projects: 1) a correspondence between project pluralism and problem wickedness; 2) reductionism, when methodological or actor pluralism was lower than expected; and 3) integrationism, in the opposite case. We highlighted several factors that influence the choices of these strategies. In particular, we discuss the practical obstacles to applying both methodological and collaborative pluralism, which are considerable and shouldn't be underestimated. In addition, we conclude that projects addressing highly wicked problems have less leeway in terms of the research stances and methods than projects addressing weakly wicked problems. Finally, we suggest that the project duration and leadership are among the factors influencing the choices of research strategies. Overall, we call for pragmatic reflexivity in the choice of research stances and methods, especially when addressing wicked sustainability problems (Hazard et al. 2019).

Table 18: An overview of the main results

Chapters	Research Questions	Key hypothesis	Main results
I	To what extent, in what ways and with what effects research communities are reorganising in the face of rising calls for TRSS?	What type of organisation ZA is influence the level of inter- and transdisciplinarity in its governing bodies, projects and peer-reviewed articles.	<ul style="list-style-type: none"> - Diverse organisational features of each ZA site; - ZAs are research-based meta-organisations: 1) little turnover of membership; 2) power inequalities among its members; 3) ZAs tend to have fewer financial and human resources than their members; - Societal actors are partners, but not members of the ZAs; - ZAs are quasi boundary organisations: 1) involve actors from both sides of the boundary; 2) use a SES framework as a boundary object; 3) accountable essentially to the research institution; - A limited level of inter- and transdisciplinarity in the ZA bodies, projects and peer-reviewed articles.
II	What roles do all the actors involved in TRSS projects perform and how are these roles distributed among them?	<p>Research actors perform more diverse roles than the societal actors do.</p> <p>The number of roles performed by all the actors and by each category of actor would increase with the diversity of actors involved in the projects.</p>	<ul style="list-style-type: none"> - Societal actors have become major role performers. However, role distribution depends on the type of actor; - Public actors perform a vast diversity of roles, when citizen perform a limited number of roles; - Positive relationship between the diversity of societal actors and the distribution of roles (actors tend to perform more roles as the pluralism of societal actors increases).
III	What is the relationship between the wickedness of the problems and the research stances and methods adopted to address these problems?	Positive relationship between the wickedness of the problems, the variety of research methods, and the plurality of societal actors in the research project.	<ul style="list-style-type: none"> - Limited correspondence between problem wickedness and project pluralism. - Three research stances in our sample: a correspondence between project pluralism and problem wickedness; reductionism, when methodological or collaborative pluralism was lower than

			expected; and integrationism, in the opposite case.
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2. Contributions of this work

We have contributed to the study of the practical issues of TRSS in several ways. First, our theoretical contribution lies in applying pragmatic lenses to TRSS through an empirical analysis of the French network of Zones Ateliers. In order to do so, we drew on various concepts adapted from different fields of literature. We have also provided methodological tools for the empirical study of our case. In the following section, we discuss the contributions of this work and suggest avenues for future research.

2.1. Pragmatic approach

We have seen in the Introductory chapter that there is a growing community of scholars, research centres and institutions interested in TRSS and providing a normative basis for its development (see TDAcademy, ITD Alliance, TD-net). A number of scholars have dedicated their work to providing theoretical foundations for TRSS (Lang et al. 2012; Jahn et al. 2012; Brandt et al. 2013; Scholz and Steiner 2015). The last decade has also marked a burst of methodological toolboxes aimed at providing newcomers to the field with a panel of methods to tackle wicked problems in sustainability science (see Table 1 in the Introduction). Instead, our aim was not to provide researchers with theoretical underpinnings of TRSS, nor to propose methodological tools. Rather, we aimed to demonstrate how researchers go about practicing TRSS by providing an empirical analysis of the French network of Zones Ateliers. Several authors have adopted a pragmatic approach to TRSS (Popa et al. 2015; Fam et al. 2016; Fam and O'Rourke 2021; Hilger et al. 2021). This work has contributed to this body of literature by adopting a number of concepts and providing methodological tools to study TRSS empirically.

We have highlighted the importance of several factors in TRSS processes, such as organisational arrangements, problem wickedness, methodological and actor pluralism. Wiek et al. (2012) highlight several success factors of TRSS, including advanced collaborative research settings, advances in transformative research methods, cross-case generalisation, and reduction of institutional barriers. However, our approach differs from that of Wiek et al. (2012). We have analysed how these success factors are implemented in practice. Therefore, our theoretical contribution is to examine these factors from a pragmatic perspective. We have shown that the creation of collaborative spaces for science and society at large, the application of methodological pluralism, and the equal distribution of roles among all actors in the TRSS process are desirable but therefore difficult to implement, and we have proposed several explanations for this.

2.2. Building on a diversity of concepts

In this work, we have drawn on various concepts taken up from diverse literature fields. First, to explore the organisational issues at the level of research infrastructures, we mobilised the concepts of boundary organisation taken from the field of science and technology studies (Guston 1999) and of meta-organisation from the sociology of organisations (Ahrne and Brunsson 2008, 2011). Second, the adoption of role theory (Biddle 1986; Hilger et al. 2021) allowed us to explore the roles performed by the different actors involved in TRSS and the distribution of roles among them. Finally, we empirically explored the research stances (Hazard et al. 2020) and methods in sustainability science (von Wehrden et al. 2017) and their relationships with problem wickedness. Therefore, we present a diversity of concepts and rely on extensive literature to explore them. By mobilising these concepts from diverse areas of the literature, we have not been constrained by the narrow scope of theoretical tools, but have been able to provide a broader perspective on the practical issues of TRSS.

2.3. Methodological pluralism in this work

As far as the methodological contributions of this thesis are concerned, the methodological pluralism was applied in this work. Our research design was characterised by the use of qualitative and semi-quantitative methods (see Methodology section). First, we have used qualitative methods (semi-structured interviews, ethnographic study, and observations) to gain an in-depth understanding of a small number of projects. In particular, the attribution of actors' roles requires an in-depth understanding of the research processes. This can't be achieved by desk analysis alone. However, the rich material collected through the ethnographic study was not fully exploited due to time constraints. In fact, we have collected the empirical material through semi-structured interviews with the research actors as well as with farmers, elected officials, nature resource managers, journalists, etc. This material would have allowed us to deepen our understanding of the factors influencing the patterns of role distribution in our sample of projects and can be considered as a possible avenue for future research. Second, we applied semi-quantitative methods to analyse a sample of research projects. Applying such methods allowed us to test our hypotheses and provided some robustness to our findings. It has also given visibility to our results and made it easier to interpret them. Moreover, this work has offered some methodological tools to empirically explore the practical issues of TRSS. For example, in Chapter III we have proposed an analytical grid to explore project pluralism based on methodological and actor pluralism.

2.4. Exploring the drivers of change in TD research

One aspect that has not been explored in this thesis, but which I increasingly feel is essential to consider, concerns the drivers of change. Arguably, our values are the drivers of

change. Values can be defined as “trans-situational goals, varying in importance, that serve as guiding principles in people’s lives” (Schwartz 1994, p. 21). But how can we change them when the problems are becoming increasingly complex and time is playing against us? This question has been little investigated so far and deserves close attention. Some scholars have attempted to contribute to an understanding of the drivers of change. For example, Van der Leeuw (2020) highlights the role of narratives as drivers of change because they shape our values and institutions and influence our decisions and actions. The role of narratives is ‘to integrate particular events or trends in the worldview of the societies experiencing them’ (van der Leeuw 2020, p. 509). According to this author, we all need to transform the narratives that are driving our socio-environmental dynamics in unsustainable directions by emphasising ‘the role of nature, rather than that of the society’ (p. 518). From a systems thinking perspective, some authors use the concept of leverage points as a boundary object for sustainability transformation (Abson et al. 2017). They suggest focusing on three realms of leverage: reconnecting people to nature, restructuring institutions and rethinking how knowledge is created and used in pursuit of sustainability.

When it comes to science, there is a major transformation in the way knowledge is gained, which the concept of ‘regime of knowledge production’ or, in short, ‘knowledge regime’, developed by historian of science Dominique Pestre (2003) helps to understand. Pestre (2003) argues that we cannot study and understand changes in the production of scientific knowledge in isolation from changes taking place in society at large. He proposes the concept of a ‘knowledge regime’ to account for the relationship between the production of knowledge and the production of an economic, social and political order. He defines a knowledge regime as the heterogeneous and more or less coherent set of practices, specific values and norms, material equipment, places, social and institutional arrangements in relation to the economic and political spheres, and epistemic culture that dominates in a certain period. We argue that exploring these drivers of change, which are leading not only to the transformation of science, but also of the society, is crucial to further understanding the potentials and limitations of TRSS and therefore deserves close attention.

3. Limitations and way forward for future research

Several limitations of this work should be considered. These limitations concern our choices of research design and methods. First, we have shed light on some practical issues during the phases of research design and process, but not during the phase of research outcomes. Second, the limitations relate to the use of projects as units of study. Thirdly, they concern the multi-level approach we have taken in this work (focusing on the community and project levels, but not on the individual level). Finally, we discuss the methodological limitations of this work.

3.1. Exploring practical issues related to research outcomes

The practical issues related to research outcomes lie in the dual expectations of research actors to produce knowledge in accordance with academic standards and to contribute to problem solving by implementing concrete solutions (Bulten et al. 2021; Jahn et al. 2021). Indeed, TRSS lacks concrete evidence of its effectiveness in mitigating wicked problems. The challenges related to research evaluation have been addressed by a number of scholars (Lang et al. 2012; Lawrence et al. 2022). These authors highlighted the need for appropriate indicators and methods to evaluate TRSS. Indeed, tracking societal effects is not an easy task, and it has been widely discussed in literature (Walter et al. 2007; Lang et al. 2012; Hansson and Polk 2018; Williams and Robinson 2020; Jahn et al. 2021; Lawrence et al. 2022). First, there is a lack of methodology for assessing the societal effects of TRSS (Holzer et al. 2018; Lux et al. 2019). While it is relatively easy to evaluate scientific impacts (bibliometric and citation metrics), it is much more difficult to track societal effects of TRSS, such as mutual learning, or empowerment of local inhabitants (Schäfer et al. 2021). Second, it takes time to capture the societal effects. Since research projects tend to be designed for short periods of time, it becomes challenging to assess these effects.

Another practical issue relates to the legitimacy of research findings. TRSS is expected to produce actionable knowledge to mitigate wicked sustainability problems. However, what is the role of TRSS results and how can they be implemented in the policy process? According to Lang et al. (2012), the legitimacy of TRSS results is still lacking and represents a major challenge. Moreover, TRSS results "may not always lead to outcomes that satisfy both parties" (Lang et al., p. 39). In order to be accepted by societal actors, TRSS results are characterised by vagueness and ambiguity, which may lead to a lack of legitimacy in the scientific world (Lang et al. 2012). Overall, we believe that the problem of evaluating societal and research outcomes, as well as the problem of double expectations of research results, deserves close attention and is therefore a promising area for future research.

3.2. Limitations of using projects as units of study

Following others (Schneider and Buser 2018; Newig et al. 2019; Jahn et al. 2021), we have considered research projects to be an appropriate study unit for our analysis (Chapters II and III). Indeed, research projects are relatively easy to identify and constitute meaningful entities for research actors and their partners. However, the analysis of research projects as study units present some limitations. Pregering (2006) explored the challenges and potential of transdisciplinary research in contributing to the science-policy interface. He also discussed the use of the project as a unit of analysis, arguing that investigating 'the project' itself is not enough and that a broader conceptual and empirical framework is needed. Indeed, focusing on individual projects gives a partial vision of what happens in Zones Ateliers and does not take into account all the contextual factors that might influence the success or failure of a given project (e.g. history of collaborations with societal actors, existing conflicts between

actors, etc.). Moreover, projects are limited in time. Therefore, it may be difficult to capture the impacts of projects in the long term, especially when it comes to societal impacts (Schäfer et al. 2021).

3.3. Factors affecting the researchers' choices

In addition, we believe that it is necessary to address the individual level when discussing the practical challenges of TRSS. Some individual factors, such as education, professional background, experience of collaborating with the societal actors, shape the researchers' taste for TRSS and determine their choice of research strategies, methods and approaches. To our knowledge, few studies have been dedicated to exploring the individual factors of TRSS practitioners (Augsburg 2014; Scholz and Steiner 2015; Guimarães et al. 2019; Caniglia et al. 2020). According to Guimarães et al. (2019), the key characteristics, attitudes, and skills of TRSS researchers include personal fulfilment, the calling to respond to the social responsibility of science, a problem-solving urge (including going beyond disciplines), capacity to work together and use knowledge in an operationalized manner, and being reflexive (p. 13). These authors acknowledge the role of individual factors, such as values, beliefs, and personal attitudes and behaviors in shaping the design, processes and outcomes of TRSS. They stress the need to foster individual skills, such as communication skills, and emphasise the role of reflexivity in transdisciplinary research (Popa et al. 2015).

Through this work, we have collected a wealth of material that could allow us to explore these individual factors. As an exploratory study of the COLLAB² project, we have conducted 17 semi-structured interviews with the team members. The interviewees consisted of the research actors and the societal actors who are interested in TRSS to varying degrees. In addition, a series of semi-structured interviews were conducted with the ZA leaders (see Methodology section). The data collected through these surveys suggest the influence of educational and professional background, as well as personal attitudes and values, on interest in transdisciplinarity. However, due to lack of time, this material has not been exploited. This is a promising avenue for future research.

3.4. Methodological limitations

Following others (Pohl et al. 2010; Lang et al. 2012; Jahn et al. 2012; Schneider and Buser 2018), we have applied semi-quantitative methods by relying on a sample of TRSS projects. This method has a number of advantages: first, it allowed to test our initial hypotheses by analysing the correlations between different variables; second, it increased the generalisability of our findings and therefore allowed us to draw more robust conclusions; third, it allowed us to identify several patterns by comparing a sample of projects, which would not be possible by studying single cases. Although there are a number of advantages of relying on a sample of projects, this method has some limitations. In our work, we have relied on a relatively small sample of research projects. A small sample size leads to a lack of

representativeness and generalisability of our findings, as well as limited statistical robustness.

In the second chapter of the results, we have relied on a sample of 14 research projects to explore the roles of different actors in TRSS projects. We suggest that a larger sample of projects would deepen our understanding of the actors' roles and increase the robustness of the results obtained. However, focusing on a larger sample of projects is time-consuming, as identifying the roles performed by actors requires an in-depth knowledge of each project. In Chapter III, we have examined a slightly larger sample of 17 projects to test the correlations between problem wickedness and project pluralism. Here again, a larger and more diverse sample of projects may have increased the representativeness and robustness of our results. In addition, in this thesis, we have focused on a single national network. Studying other national and international research infrastructures addressing wicked sustainability problems would enrich our work. For example, Schneider and Buser (2018) focus on the research projects provided by the transdisciplinary research programme (NRP 61) on sustainable water management in Switzerland. Comparing the Swiss programme with the Zones Ateliers would shed light on the role of contextual factors (such as political organisation, research funding schemes, organisation of higher education) in the establishment of TRSS. In their recent book "Institutionalizing interdisciplinarity and transdisciplinarity. Collaborations across cultures and communities" (2022), the authors Bianca Vienni-Baptista and Julie Thompson Klein reflect on such contextual factors and provide an extensive number of cases of TRSS institutional context around the world.

4. Concluding remarks

In this thesis, we have focused on TRSS, an increasingly popular scientific field, which is considered a promising avenue to tackle the wicked sustainability problems facing contemporary societies. We have not specifically analysed whether or not TRSS allows reaching the targeted aims, nor provided recommendations on how to conduct TRSS research. Rather, we have explored how TRSS actually works in practice, by focusing on several issues that research actors face when embarking on this type of research. We have shown that the practical issues of TRSS matter and deserve close attention. We believe that acknowledging these challenges is an important step in promoting TRSS.

Focusing on the French network of Zones Ateliers has allowed us to identify several factors that influence TRSS processes, such as the organisational arrangements of research infrastructures, the wickedness of problems, and the pluralism of actors and methods in research projects. We have also provided possible methodological tools to describe and analyse these factors. We have shown that organisational arrangements matter for the functioning and dynamics of research infrastructures. As research-based meta-organisations, Zones Ateliers make significant distinctions between research actors and societal actors, which limits the range of organisational arrangements with which they can experiment.

However, they succeed in fostering transdisciplinary research projects, and we have shown that several categories of societal actors have become important players in these projects, with the exception of some types of societal actors, especially citizens. Finally, we have shown that the choice of strategies to address wicked problems in our sample of projects depends more on factors other than the degree of wickedness of the problem at hand.

To conclude, we call for pragmatic reflexivity in the context of TRSS. Research actors need to adjust their strategies, methods and approaches to a constantly changing social, political, ecological context. TRSS involves 1) addressing wicked problems; 2) collaborating with other disciplines and societal actors. This creates issues of organisational and methodological order, and potential power imbalances between actors. To overcome these practical issues, research actors need to be critical of the choices they make and recognise the limitations of their stances and ways of knowing.

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Annexes

Annex 1: Interview guide with the leaders of Zones Ateliers

Professional background

- Can you briefly introduce yourself? What is your professional background?
- What are your main responsibilities? In which instances are you involved?

Zone Atelier

- How did you get involved in the ZA? When did you get involved? What were your motivations?
- What objectives did you pursue and do you continue to pursue today through this involvement? How has it evolved over time?
- What are your duties and responsibilities as director of the Zone Atelier?
- What difficulties have you encountered in this context? How did you try to overcome them?
- In your opinion, what are the main contributions of the French network of Zones Ateliers in general and of the ZA in particular?

Synergy with other research infrastructures

- On the territory of the ZA, which structures pursue similar or complementary objectives to those of the ZA?
- What are the differences and similarities between these structures? Different approaches, especially with regard to inter- and transdisciplinarity?
- What interactions between these structures and the ZA? Existence of joint operations (calls for projects, seminars, etc.)?

Collaborations in the ZA

- What are the main types of collaboration in the ZA? How can you characterise them?
- Who do these collaborations bring together: What types of actors? Which societal actors are represented in the Zone Atelier? Which disciplines?
- What are the common research questions and research objectives?
- What do these collaborations produce: in terms of knowledge? in terms of transforming the territory?
- What difficulties and limitations of these collaborations?
- How important are these collaborations for the ZA? What contributions have these collaborations made? How it evolved over time?
- What are the ZA's ambitions in terms of collaborations? How does it go about encouraging them? With what results?

Interdisciplinary and transdisciplinary projects

(Explain the objectives of my research project to study collaborative projects)

- Do you have any project proposals? Why?
- Which disciplines are represented?
- Which non-academic actors (types of actors involved)?
- Number of members involved?
- What are the objectives?
- What are the types of results: scientific publications, management documents, etc?
- Project leader?
- Who funds the project? What is its budget?

Governance of the ZA

- What governance bodies exist? Who is involved in these bodies?
- If there is a document that stipulates the main rules and regulations for the members of the ZAs?
- Does the ZA in particular has a charter? What does it cover? Is it accessible?
- If so, when was it established? by whom? with what objectives? What are its main points? Is the charter available for consultation and, if so, where? How often and in what circumstances is it used?
- If not, is the elaboration of a charter envisaged?

Governance bodies:

- How many governance bodies does the ZA has? Which ones?

(if no spontaneous answer, propose as an example a management committee, a steering committee, a scientific council, etc.)

- For each of these bodie : Date of creation? Functions? Frequency of meetings?
- Who participates: number of members, disciplinary and institutional affiliation? What are the procedures for appointing members and designating a chair?
- Does the ZA have spaces for informal exchange and dialogue? Which ones? How do they work (how often)? Who has access to them? What do they produce?
- ZA members: is there a list of ZA members? Is it accessible? How was it established (according to what criteria)?
- Does it correspond to the mailing list?
- Animation of the Zone Atelier: How is the ZA facilitated? Is there a person dedicated to it?

Budget:

- What is the annual budget of the ZA to support the projects?
- Where does this budget come from?

Do you see any points to add?

I. Your professional career, the main stages of your career

- How and in what context did you start working with non-academic actors?

II. Your research and the problems linked to the ecological crisis

The place of these problems in your research

- Are you interested in these problems in your research? If so, since when?
- What types of problems in particular? Have these problems evolved?
- How would you describe these problems?
- What is the current position of these problems in your research and how has it evolved over time?
- What are your objectives in relation to these problems? Have these objectives evolved?
- How do you go about tackling these problems?
- What concepts or notions do you find useful in addressing these problems?
- What interactions and collaborations do you find useful in addressing these problems?

Methods and techniques

- What methods and techniques do you use to address these problems?
- Are these methods or techniques that you use in your research?
- Do you adapt these methods to a particular context, to a particular problem?
- How did you choose them? How do you learn to apply them?
- What kind of results do you get from applying these methods?
- What do you think are the limitations of these methods and approaches and how can they be overcome?
- What difficulties do you encounter? How do you try to overcome them?
- What do your activities in this area produce? (in terms of knowledge; in terms of action on the territory: have you observed any concrete effects of your work on the problems considered?; in terms of relations with your colleagues? your institution? the non-academic actors with whom you work?)

III. The Aliment'Action project

- Can you go back over the origins and objectives of the Aliment'Actions project?
- How would you present the project to other researchers?

Involvement in the project

- How did you become involved in the project?
- How do you see your role in the project?

The problems considered in the Aliment'Actions project

- What problems are involved?

- How and by whom will or have the problem(s) been chosen and formulated? Are non-academic actors involved in the design of these problems?

Methods used in the Aliment'Actions project

- What methods and techniques does the project rely on?
- How and by whom were they chosen?
- In concrete terms, how does it work or will it work?
- Have these methods evolved over time?
- What types of actors are involved in the project and how do they interact with them?

The effects of the Aliment'Actions project

- What effects do you expect from the project in terms of knowledge production and transformation on the territory in the short, medium and long term? Its capacity to create changes, to find solutions?
- Do you think that the project itself can cause problems on the territory?
- What are your expectations of Aliment'Action? Your doubts? Your concerns?

IV. Points to add?

I. Introducing yourself

- Can you introduce yourself (age, place of residence, etc.)?
- Your professional and associative activities, in broad terms?

II. The territory and you

- What links do you have with this territory?
- What are its main problems for you?
- Are you trying to reduce these problems and, if so, in what way? How does this effort fit into your work and life?

III. Your links with researchers

- How and when did you come to meet and work with researchers?
- What did you expect from them?
- What is your role in working with researchers?
- What place and importance do you attach to this work in your own work or life?
- What satisfactions and/or disappointments?
- How would you like to develop this work with researchers?
- Is there an experience that has marked you in the collaboration with researchers?

IV. The Aliment'Action project

- How and by whom did you hear about it? How was the project presented to you? How would you present it yourself?
- Do you feel involved in this project? If so, how did you become involved?
- What is or could be your contribution to this project?
- What activities have you participated in or do you plan to participate in as part of the project? If you have already been involved, can you describe this with specific examples?
- How has the project affected your daily life?

V. Effects

- What do you expect in the short, medium and long term? For the territory? For yourself?
- In your opinion, can Aliment'Action contribute to solving the problems you identify in the area?
- What difficulties do you identify or fear for this project?

VI. Points to add?

Annex 4: List of interviews with the directors of Zones Ateliers
 (All the interviews took place online due to the Covid-19 sanitary crisis)

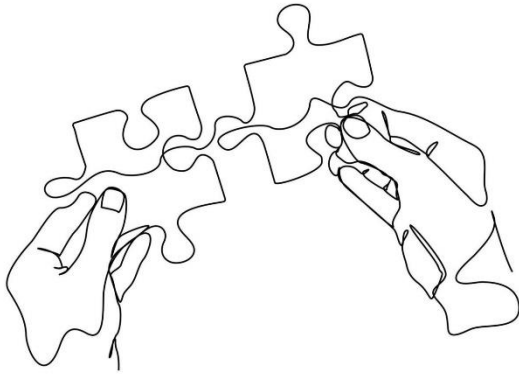
Date of the interview	Zone Atelier	Number of participants	Profile of the interviewee	Duration
19/03/2020	Alpes	2	Geologist; ZA coordinator	120 minutes
20/03/2020	Pyrénées Garonne	1	Biogeochemis	115 minutes
24/03/2020	Antarctique et sub-Antarctique	2	Ecologists (2)	102 minutes
26/03/2020	Loire	1	Ecologist	80 minutes
26/03/2020	Arc Jurassien	1	Researcher in transition (from ecology to economy)	108 minutes
27/03/2020	Pyrénées Garonne	1	Biogeochemis	62 minutes
30/03/2020	Bassin du Rhône	1	ZA coordinator	108 minutes
31/03/2020	Brest Iroise	1	Biogeochemist	145 minutes
03/04/2020	Armorique	1	Geographer	89 minutes
09/04/2020	Environnement Urbain	1	Geographer	103 minutes
15/05/2020	Plaine & Val de Sèvre	2	Ecologists (2)	87 minutes
24/04/2020	Terres Uranifères	3	Ecologist; physicist (2)	139 minutes
30/04/2020	Hwange	2	Sustainability scientist; ecologist	107 minutes
14/05/2020	Hwange	2	Sustainability scientist; ecologist	129 minutes
29/04/2020	Seine	2	Historian; scientific and technical coordinator	99 minutes
21/04/2020	Moselle	4	Geologists (2); ecologist (1); scientific advisor	79 minutes
15/06/2020	Projet ZA Argonne	1	Political scientist	90 minutes
01/09/2020	Alpes	1	Ecologist	116 minutes

Annex 5: List of interviews with the project members (project Aliment'Actions)

Date of the interview	Profile of the interviewee	Place	Duration
12/03/21	Ecologist	Centre for Biological Studies of Chizé	60 minutes
15/03/21	Technical coordinator	Centre for Biological Studies of Chizé	92 minutes
17/03/21	Territorial coordinator	Online	110 minutes
19/03/21	Mayor of the local municipality	Municipal council of the commune La Foye-Monjault	34 minutes
22/03/21	Management scientist	Centre for Biological Studies of Chizé	70 minutes
23/03/21	Intern	Centre for Biological Studies of Chizé	50 minutes
23/03/21	Farmer	Local farm	90 minutes
24/03/21	Political scientist	Centre for Biological Studies of Chizé	
24/03/21	Farmer	Local meat farm	
24/03/21	Farmer, member of the municipal council	Local farm	83 minutes
24/03/21	Members of the municipal council of the commune La Foye-Monjault (6 members)	Municipal council of the commune La Foye-Monjault	55 minutes
25/03/21	Mayor of the local municipality	Municipal council of the commune Fors	69 minutes
25/03/21	Mayor of the local municipality	Municipal council of the commune Marigny	67 minutes
25/03/21	Intern	Centre for Biological Studies of Chizé	25 minutes
26/03/21	Research engineer	Centre for Biological Studies of Chizé	47 minutes
31/03/21	Sociologist	online	92 minutes
01/04/21	Science journalist	online	72 minutes
15/04/21	Ecologist	online	97 minutes
21/04/21	Ecologist	online	107 minutes

(with the list of questions to the project partners)

SEMINAR "CHOOSING AND IMPLEMENTING RESEARCH METHODS IN SUSTAINABILITY SCIENCE"



30 November 2021 at 2pm, Autrans

The problems we face nowadays are complex, urgent, uncertain, interconnected and systemic. Sustainability science emerged in the 2000s as a new approach to dealing with complex environmental problems (Kates et al. 2001). In addition to addressing real-world problems, sustainability science encourages collaborations across disciplines and with non-academic actors (Lang et al. 2012). The methods that researchers conventionally employ, such as observation, experimentation and modelling, often show limitations in this context. Tackling this type of problem requires researchers to 'tinker with' their usual methods. This seminar will aim to reflect on these questions with the leaders of five research projects in sustainability sciences: which methods should be used? How to choose them? How to adapt them to the problem at hand? What difficulties can these problems present and how can they be overcome?

Programme

14: 00 – 14: 30 Introduction to the seminar (by Kristina Likhacheva)

14:30 -15:15 Presentation of the tool-box of td-net - Network for Transdisciplinarity Research (by Dr. Sibylle Studer)

15:15-15:45 Pause

15:45 – 17:45 Workshop "Feedback from five research projects"

WORKSHOP "FEEDBACK FROM FIVE RESEARCH PROJECTS"

PARTICIPANTS

- Emilie Couzat (for the project Alpages Sentinelles)
- Philippe Bourdeau (for the project Refuges Sentinelles)
- Marie - Elodie Perga (for the MOUNTAINCRAFT project)
- Jean - Michel Olivier (for the RhônEco project)
- Vincent Bretagnolle (for the Aliment'Actions project)

INTRODUCTION OF THE PROJECT (5 MIN PER PROJECT)

First, we ask each project leader to present yourself and to present the project to the other participants, describing the following topics:

- Problem;
- Research focus and questions;
- Duration of the project;
- Territory of study;
- Academic and non-academic actors involved in the project;
- Expected results/outcomes (scientific, operational).

DISCUSSION OF THE RESEARCH ISSUES AND METHODS

Next, we would like to continue the discussion on the research methods used in the projects. We invite the project partners to reflect on the following questions:

PROBLEM ADDRESSED IN THE PROJECT:

Nature of the problem and its solution:

- What sustainability problem does the project address? How can you characterise it?
- What kind of solution is envisaged to improve the problem?

Stakeholders concerned by this problem:

- What diversity of actors?
- Who has knowledge about the problem and the solutions envisaged?
- What are the relationships between these actors? Are there pronounced conflicts of interest between these actors?
- What is the history of collaboration between scientists and territorial actors? Were there any tensions? Have they been resolved over time?

RESEARCH METHOD MOBILISED TO MITIGATE THE PROBLEM:

Research methods in the project :

- What research method(s) are mobilised in the project?
- Have any methods been added during the project? If so, how did this happen?
- Choice of methods : How were these methods chosen, by whom?

Adapting traditional methods :

- Do these methods used in the project differ from other methods used before? If so, how?
- Did you have to adapt the classical methods to the concrete problem considered? To the fact of working with researchers from other disciplines and/or with other non-academic actors?
- In what way and to what extent did you change the methods?
- Difficulties in relation to the research methods : What difficulties have you encountered in this context (ethical, operational, financial, organisational, scientific etc.)? How were they overcome?

Annex 7: Article “Interdisciplinary and applied environmental research in France. A scientific and intellectual movement between dissent and standardisation” (published in *Revue d’anthropologie des connaissances*)

La recherche interdisciplinaire et finalisée en environnement en France.

Un mouvement scientifique et intellectuel entre dissidence et normalisation

Interdisciplinary and applied environmental research in France. A scientific and intellectual movement between dissent and standardisation

La investigación medioambiental interdisciplinar y aplicada en Francia. Un movimiento científico e intelectual entre la disidencia y la normalización

Isabelle Arpin, Théo Jacob, Anne-Gaëlle Beurier, Christine Hervé et Kristina Likhacheva



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Éditeur

Société d'Anthropologie des Connaissances

Résumé en français : Cet article étudie la recherche interdisciplinaire et finalisée en environnement (RIFE) en France, de son émergence dans les années 1960 à aujourd'hui. Il mobilise la littérature sur l'émergence des champs scientifiques et s'appuie sur des entretiens et une analyse documentaire. Il montre que la RIFE présente tous les traits des mouvements scientifiques et intellectuels (MSI). En revanche, elle se distingue par sa grande hétérogénéité et elle se situe toujours entre dissidence et normalisation. Le caractère inabouti de son

institutionnalisation tient à son fondement épistémologique, marqué par le rejet du réductionnisme et du techno-centrisme. La RIFE se retrouve partiellement en décalage avec le régime de production de connaissance qui prévaut depuis les années 1990, et les tentatives de standardiser ses méthodes et ses données suscitent des tensions et de nouvelles formes de dissidence. En même temps qu'il améliore la connaissance de la dynamique de la RIFE en France, l'article contribue à enrichir la théorie des MSI.

Mots clefs, mots clefs : émergence des champs scientifiques, mouvement scientifique et intellectuel, technologie, standardisation, recherche interdisciplinaire, recherche finalisée, environnement, France

Title (en anglais): Interdisciplinary and applied environmental research in France: a scientific and intellectual movement between dissent and standardisation

Abstract: This article examines interdisciplinary environmental research (RIFE) in France, from its emergence in the 1960s to the present day. It mobilises the literature on the emergence of scientific fields and is based on interviews and documentary analysis. It shows that the RIFE has all the features of the scientific and intellectual movements (SIMs). However, it is characterized by its great heterogeneity and is still situated between dissent and normalization. Its incomplete institutionalisation is due to its epistemological foundation, marked by the rejection of reductionism and techno-centrism. RIFE is partly out of step with the knowledge production regime that has prevailed since the 1990s, and attempts to standardise its methods and data are generating tensions and new forms of dissent. The article simultaneously improves our knowledge of the dynamics of EIFR in France and contributes to the theory of MSI.

Keyword,keyword: emergence of scientific fields, scientific and intellectual movement, technology, standardisation, interdisciplinary research, applied research, environment, France

Titulo (en espagnol): La investigación medioambiental interdisciplinar y aplicada en Francia: un movimiento científico e intelectual entre la disidencia y la normalización

Resumen: Este artículo examina la investigación medioambiental interdisciplinar (RIFE) en Francia, desde su aparición en los años 60 hasta la actualidad. Moviliza la literatura sobre la aparición de campos científicos y se basa en entrevistas y en el análisis documental. Muestra que la RIFE tiene todas las características de los movimientos científicos e intelectuales (MCI). Sin embargo, se caracteriza por su gran heterogeneidad y se sitúa siempre entre la disidencia y la normalización. El carácter inacabado de su institucionalización se debe a su fundamento epistemológico, marcado por el rechazo al reduccionismo y al tecnocentrismo. La RIFE está en parte desfasada con el régimen de producción de conocimiento que ha prevalecido desde la década de 1990, y los intentos de estandarizar sus métodos y datos dan lugar a tensiones y nuevas formas de disenso. Al mismo tiempo que mejora el conocimiento de la dinámica de la EIFR en Francia, el artículo contribuye a la teoría de los MCI.

Palabras claves, palabras claves : aparición de campos científicos, movimiento científico e intelectual, tecnología, normalización, investigación interdisciplinar, investigación aplicada, medio ambiente, Francia Introduction

Introduction

Une partie de la recherche en environnement est interdisciplinaire et finalisée. Elle se caractérise par sa volonté de contribuer à la résolution de problèmes concrets d'environnement à l'échelle de territoires, comme l'artificialisation des grands fleuves ou l'érosion de la biodiversité dans les zones d'agriculture intensive. Elle implique des

chercheurs d'un grand nombre de disciplines des sciences de la vie et de la Terre, des sciences de l'homme et de la société (SHS) et des sciences appliquées. Elle inclut un ensemble évolutif d'approches présentant, sous des vocables différents (recherche action participative, recherche transdisciplinaire en environnement, science de la durabilité, etc.)³¹, suffisamment de caractéristiques communes pour pouvoir être rapprochées. Nous désignons ce champ hétérogène par une périphrase englobante, — recherche interdisciplinaire et finalisée en environnement (RIFE) —, que nous avons élaborée pour les besoins de cet article. Par-delà leurs différences, celles et ceux qui pratiquent ce type de recherche ont des conceptions voisines des causes, de la gravité et de l'urgence de la crise environnementale et de la façon dont la recherche scientifique peut contribuer à comprendre cette crise et à lui faire face ; ils et elles se retrouvent dans des programmes, des dispositifs et des terrains de recherche communs et publient dans des revues créées pour ce type de recherche.

La RIFE repose sur l'idée que les sociétés contemporaines font face à des problèmes caractérisés par une grande complexité, un degré d'incertitude élevé, un ancrage dans des contextes territoriaux spécifiques, une diversité de définitions et de cadrages et une absence de consensus sur les solutions à mettre en œuvre. La prise en charge de tels problèmes nécessite, selon ses partisans, d'« intégrer » les perspectives et les connaissances d'une diversité de disciplines et d'acteurs sociétaux. Après avoir été longtemps contestée et marginale, la RIFE apparaît de plus en plus comme indispensable à l'élaboration de moyens innovants, efficaces et socialement acceptables de faire face à la crise environnementale actuelle - ce qui se reflète dans les politiques scientifiques nationales et internationales (Barry et Born, 2013). Toutefois, la RIFE ne constitue pas, à ce jour, un champ scientifique clairement identifié, du moins en France.

Comment expliquer qu'un courant scientifique en phase avec la mise à l'agenda politique et scientifique des problèmes d'environnement n'ait pas réussi à pleinement s'institutionnaliser en plus de cinquante ans d'existence ? Nous entendons éclairer cette question sur la base d'une généalogie socio-historique de la RIFE inspirée de la notion de mouvement social et intellectuel (MSI) (Frickel et Gross, 2005). Les MSI ont été définis comme un type spécifique de mouvement social, orienté vers la conception et la réalisation d'un « projet collectif de changement intellectuel » dans un domaine ou un ensemble de domaines (Frickel et Gross, 2005). Cette notion nous a semblé particulièrement pertinente pour retracer et analyser l'histoire d'un type de recherche qui entend impliquer des acteurs académiques et non académiques autour de problèmes d'intérêt commun.

La notion de communauté épistémique telle que formalisée par Haas (1989) pouvait également sembler adaptée à notre étude. Nous lui avons cependant préféré celle de MSI pour plusieurs raisons. Premièrement, Haas a développé la notion de communauté épistémique à propos de collectifs relativement faciles à délimiter, comme celui qui s'est impliqué dans la conception du plan d'action pour la Méditerranée (Haas, 1989). La RIFE, elle, est plutôt une nébuleuse qui évolue dans la longue durée et que la notion de mouvement reflète plus adéquatement que celle de communauté. Deuxièmement, les membres des communautés épistémiques de Haas ne sont pas en premier lieu des chercheurs

³¹ Présenter ces champs dépasse la portée de cet article. Pour une revue internationale, voir (Knapp et al., 2019).

académiques mais des employés d'organisations comme le PNUE dotés d'un haut niveau de formation scientifique. Troisièmement, la notion de communauté épistémique renvoie classiquement à un échelon international tandis que la RIFE concerne des problèmes d'environnement à une échelle relativement restreinte, celle des « territoires ».

Si la RIFE se prête bien à une analyse en termes de MSI, nous verrons qu'elle présente aussi des anomalies par rapport à la théorie élaborée par Frickel et Gross (2005). Ces anomalies nous amènent à proposer d'enrichir cette théorie en prêtant davantage attention aux implications de l'épistémologie sous-jacente des MSI sur leur potentiel de diffusion. Nous montrerons en particulier que l'anti-positivisme, l'anti-réductionnisme et l'anti-technocentrisme historiques de la RIFE rendent difficile son unification autour d'un couple standardisé théorie-méthode, qui joue un rôle central dans l'affirmation de nouveaux champs scientifiques (Fujimura, 1988). L'article poursuit ainsi un double objectif : mieux comprendre l'histoire de la RIFE en France depuis son émergence dans les années 1960 jusqu'à aujourd'hui, et contribuer à la littérature sur l'émergence des champs scientifiques.

Nous avons étudié la dynamique de la RIFE en France en nous appuyant sur des entretiens semi-directifs et une analyse documentaire. Cette enquête s'inscrit dans une recherche plus large auprès des promoteurs de ce type de recherche (n = 43)³², et des responsables de trois structures qui lui sont communément associées : les réserves de biosphère françaises (RB) (n = 23), les Zones Ateliers (ZA) (n = 15) et les Observatoires Hommes-Milieus (OHM) (n = 14). La quasi-totalité de ces entretiens ont été réalisés entre mars 2020 et mars 2021, à distance en raison des mesures sanitaires liées à la pandémie de COVID-19. Nous avons utilisé trois entretiens réalisés dans le cadre de recherches antérieures auprès de chercheurs qui ont fortement contribué au développement de la RIFE en France et aujourd'hui décédés. D'une durée moyenne de deux heures (minimum : 1 heure ; maximum : 3h30), les entretiens ont porté sur l'émergence et l'évolution de la RIFE en France, ainsi que sur le parcours des enquêtés et les circonstances et les raisons qui les ont amenés à s'engager durablement dans ce type de recherche. Les entretiens ont tous été enregistrés et transcrits. Menée à l'aide d'un logiciel d'analyse qualitative, leur analyse a visé à mettre au jour la diversité des facteurs susceptibles d'expliquer la dynamique de la RIFE en France. La documentation que nous avons par ailleurs réunie s'est avérée extrêmement riche : plusieurs ouvrages et articles (Jollivet, 1992 ; Brun et al., 2017 ; Mougnot, 2011 ; Cornu, 2021) ont été consacrés à la RIFE en France, et la revue *Natures Sciences Sociétés* constitue une source d'informations précieuse sur son évolution depuis la parution de son premier numéro en 1993.

Nous commencerons par présenter les éléments de la littérature sur l'émergence des champs scientifiques que nous avons mobilisés pour analyser l'histoire de la RIFE. Nous retracerons ensuite cette histoire au prisme de la notion de MSI, en distinguant trois étapes. Premièrement, nous montrerons que la RIFE en France présente tous les traits des MSI. Deuxièmement, nous verrons qu'elle constitue un MSI particulièrement hétérogène, du fait de son extension à plusieurs grands domaines scientifiques et secteurs de la société.

³² À trois exceptions près, ces entretiens ont été réalisés auprès de chercheurs séniors ou retraités, impliqués dans la RIFE depuis longtemps et membres de diverses institutions de recherche (par ordre décroissant du nombre d'informateurs : CNRS, INRAE, IRD, MNHN, CIRAD) et d'universités. Un entretien a été effectué avec un ancien agent de l'Unesco.

Troisièmement, nous dégagerons une tendance récente à l'élaboration de méthodes et de techniques de production de données standardisées, qui génère des tensions au sein du mouvement. La discussion qui suit éclairera le maintien de la RIFE dans une position intermédiaire entre dissidence et normalisation, et soulignera les apports de notre étude à la littérature sur l'émergence des champs scientifiques.

Éléments de littérature sur l'émergence des champs scientifiques

Kuhn (1962) a fortement contribué à faire reconnaître l'importance de la dynamique de la connaissance scientifique. Selon lui, le progrès scientifique ne résulte pas seulement d'une accumulation progressive des connaissances : à certains moments, l'ensemble formé par les hypothèses, les théories, les méthodes et le langage, qui dominait dans une communauté scientifique — un paradigme dans les termes de Kuhn —, vient à être contesté en raison de son incapacité à rendre compte de certains phénomènes. Il peut finir par être balayé par un nouveau paradigme, incommensurable avec le précédent. De longues phases de « science normale », ancrée dans le paradigme dominant, sont ainsi séparées par des « révolutions scientifiques » où se produisent les changements de paradigme. Maints travaux inspirés de ceux de Kuhn ont considéré l'expression de perspectives dissidentes comme un des moteurs de la dynamique scientifique.

Ces travaux se sont notamment intéressés à l'émergence de nombreuses disciplines, spécialités et communautés scientifiques, dont la biologie moléculaire (Mullins, 1972) et son utilisation dans la recherche sur le cancer (Fujimura, 1988), la pharmacogénomique (Hedgecoe, 2003), la physique (Gingras, 1991) et la biologie de synthèse (Molyneux-Hodgson et Meyer, 2009 ; Bensaude Vincent, 2013). Ils ont mis en évidence une série de facteurs qui influencent ces dynamiques d'émergence. Fujimura (1988) a expliqué l'essor rapide d'une discipline par la constitution d'un ensemble (« *package* ») standardisé à l'interface de plusieurs mondes sociaux. Dans le cas de la biologie moléculaire dans la recherche sur le cancer, cet ensemble est composé d'une théorie unificatrice (la théorie de l'oncogène) et d'un ensemble évolutif de technologies standardisées (les enzymes de restriction, les séquenceurs d'ADN, etc.) : un nombre croissant de chercheurs en cancérologie se sont convertis à la biologie moléculaire à mesure que le perfectionnement de l'ensemble théorie-méthodes augmentait les bénéfiques potentiels et réduisait les risques de cette conversion. Mullins (1972) a souligné le rôle d'un leader charismatique dans le développement d'un des groupes à l'origine de l'émergence de la biologie moléculaire, le groupe phage. Hedgecoe (2003) a souligné l'importance du choix des termes et de leur puissance rhétorique pour désigner les disciplines scientifiques émergentes³³.

Frickel et Gross (2005) ont, pour leur part, proposé une « théorie générale des mouvements scientifiques et intellectuels » (MSI) pour rendre compte de l'ensemble des processus d'émergence dans le champ scientifique, qu'ils aient trait à des disciplines, des spécialités, des communautés, des réseaux, etc. En s'appuyant sur la théorie des mouvements sociaux, ils prédisent qu'un MSI a plus de chance d'émerger et de se développer si : 1) il est promu par des scientifiques seniors doté d'un statut intellectuel élevé, ou par de jeunes chercheurs

³³ Voir aussi, à propos de la biologie de synthèse, Molyneux-Hodgson et Meyer (2009) et Bensaude Vincent (2013).

protégés par des scientifiques renommés ; 2) ses membres ont accès à un ensemble de ressources matérielles, structurelles et organisationnelles ; 3) ses promoteurs disposent d'espaces de micromobilisation où ils peuvent recruter de nouveaux membres ; 4) il permet à ses membres de mener un travail en accord avec le type d'intellectuels qu'ils souhaitent ou pensent être. La théorie des MSI offre ainsi des clefs pour analyser la dynamique d'émergence d'un champ scientifique, depuis l'expression d'une position dissidente jusqu'à sa constitution en un mouvement plus ou moins institutionnalisé.

Un mouvement scientifique et intellectuel

Nous verrons dans cette section que la RIFE a émergé en se construisant contre l'épistémologie positiviste et réductionniste dominante, en se dotant d'un appareil conceptuel, et en organisant l'accès à un ensemble de ressources.

Se construire contre

La RIFE a attiré des personnes qui voulaient s'attaquer à ce qu'elles tenaient pour des défaillances majeures de l'organisation et du fonctionnement des sociétés industrielles, relatives à l'activité scientifique d'une part, et aux effets négatifs du développement capitaliste sur la société et l'environnement de l'autre. Ses partisans ont en commun de promouvoir une approche systémique, à rebours de l'idée d'une science isolée de la société et régie par les cloisonnements disciplinaires. Néanmoins, le poids respectif et la nature politique de leurs engagements ont varié dans le temps, si bien que l'on peut distinguer, à gros traits, deux générations, au sens d'acteurs formés par les mêmes événements marquants (Dodier, 2003) : la première venue à la RIFE dès le début des années 1970, et la seconde à partir des années 1990-2000.

Contre une science séparée de la société et gouvernée selon la seule logique disciplinaire

La RIFE s'est construite contre une présentation de la recherche scientifique comme une activité à part. Elle a fortement bénéficié de l'action d'un organe gouvernemental : la Délégation générale à la recherche scientifique et technique (DGRST). De sa création officielle en 1961 à son absorption dans le ministère de la recherche en 1981, la DGRST a en effet mis sur pied, dans de nombreux domaines³⁴ dont la RIFE, des comités réunissant des hauts fonctionnaires et des scientifiques de renom, qui ont financé des programmes de recherche sur une base contractuelle. En favorisant les rencontres et les échanges entre des scientifiques et des hauts fonctionnaires, elle a constitué un des espaces de coproduction de la science et du politique, un de ses « vivants traits d'union » (Crespy et Jouvenet, 2020, p. 33).

La RIFE s'est également construite contre l'organisation essentiellement disciplinaire de la recherche et de la formation universitaires. À la charnière des années 1960 et 1970, les critiques visant les universités, perçues comme repliées sur des disciplines établies et coupées du reste de la société, se sont multipliées. Le biométricien Jean-Marie Legay (1925-2012),

³⁴ Pour un exemple dans le domaine du risque environnemental global, voir Crespy et Jouvenet (2020).

membre du groupe « Méthodologie pour l'écologie » de la DGRST à partir de 1969, associe ici la pensée disciplinaire à une idéologie conservatrice :

« Héritage lointain de Descartes et d'un esprit analytique qui divisait les difficultés en autant de parties qu'il était nécessaire pour les résoudre séparément, [la pensée monodisciplinaire] a refusé la complexité des situations réelles et les interactions entre les parties ; elle a ignoré la notion de système aussi longtemps que possible ; elle en repousse maintenant les conséquences. L'administration universitaire, les grands corps de l'État s'accrochent désespérément à la classification d'A. Comte » (Legay, 1981, p. 61).

L'aspiration à un fonctionnement de la recherche et de la formation universitaires plus ouvert à l'interdisciplinarité et aux échanges avec la société s'est en particulier exprimée lors de la conférence de l'Organisation pour la coopération et le développement économique (OCDE, 1972), à laquelle ont participé plusieurs scientifiques français ou francophones (voir Piaget, 1972).

La RIFE est ainsi née d'une opposition au réductionnisme, au cartésianisme, au positivisme et au techno-centrisme scientifique. La théorie générale des systèmes, diffusée en France par des ouvrages (Morin, 1977 ; Le Moigne, 1977 ; Legay, 1996) inspirés du développement de la modélisation mathématique, de la cybernétique et des sciences pour l'ingénieur, a été un point d'accord central de ses partisans. Tous ont en effet mis en avant « la pensée complexe » et les nouvelles épistémologies constructivistes fondées sur des principes d'incertitude et de réflexivité. L'approche systémique a constitué une façon de faire dialoguer plusieurs formes de savoirs dans l'exploration conjointe des différentes facettes d'un objet :

« L'artifice de la méthode des systèmes permet de mettre en présence des réalités qui ne sont pas a priori du même ordre [exemple : système écologique et système économique]. C'est en cela que réside sa force pour organiser la coopération interdisciplinaire » (Godard et Legay, 1992, p. 200).

De la contestation du capitalisme à la contestation des atteintes à l'environnement

Le développement par la DGRST d'une offre de recherche visant à infléchir l'action publique a répondu aux aspirations de chercheurs très engagés politiquement et soucieux d'inscrire le travail scientifique dans une perspective de progrès social (Billaud, 1992). L'approche marxiste, en particulier, a fortement influencé une partie des pionniers de la RIFE. Par exemple, des sociologues ruralistes impliqués dans les travaux financés par la DGRST se sont mobilisés aux côtés d'agronomes et d'écologues pour renouveler la critique de la rationalité à l'œuvre dans la société capitaliste, en étudiant de nouveaux objets à la frontière des activités techniques et économiques telles que le pastoralisme, la chasse ou la cueillette (Billaud, 1992). Président du comité « Diversification des modèles de développement rural » de la DGRST (1982-1986), le sociologue Marcel Jollivet souligne avoir ressenti le besoin de mettre en œuvre une recherche interdisciplinaire pour analyser les effets du capitalisme sur les sociétés agricoles et rurales :

« Je me suis dit que j'avais absolument besoin de rapprocher une sociologie des exploitations et des familles paysannes d'une grande fresque sur le capitalisme. C'était, en fait, comment le capitalisme transformait l'agriculture pour l'amener à répondre à ces exigences de profit. Donc ma sociologie critique, elle est marxienne. Et donc, partant de là, j'observais bien sûr que ces transformations bouleversaient la famille, bouleversaient les villages, bouleversaient les techniques. Et je travaillais déjà beaucoup avec des gens du milieu de l'agronomie » (entretien 23, 30/03/2021)³⁵.

C'est par le biais de l'évolution des techniques d'exploitation agricole et des bouleversements des sociétés rurales que ces sociologues se sont, progressivement et à travers les problématiques sociales, intéressés aux problèmes environnementaux. Pointée depuis fort longtemps (Bonneuil et Fressoz, 2013 ; Audier, 2017), la gravité de ces derniers a pris une visibilité nouvelle dès les années 1960, grâce notamment à la parution d'ouvrages comme *Silent spring* (Carson, 1962), *The limits to growth* (Meadows et al., 1972) et, en France, *Avant que nature meure* (Dorst, 1965). La conférence internationale sur « l'utilisation rationnelle et la conservation des ressources de la biosphère », dite conférence de la biosphère, organisée à Paris en 1968 par l'*International Council for Science* (ICSU) et l'Unesco, témoigne du désenclavement de ces questions et de leur retentissement dans la communauté scientifique française. Dès cette époque, la montée des préoccupations environnementales (voir notamment Lascoumes, 1994, 1999 ; Charvolin, 2003 ; Ollitrault, 2008) a contribué à souligner l'étroitesse du lien entre aide à la décision et interdisciplinarité dans un contexte de pression sociale croissante.

Toutefois, c'est véritablement à partir des années 1990-2000 que la lutte contre les atteintes à l'environnement s'est affirmée comme un enjeu prioritaire de la RIFE en France. Les chercheurs venus à la RIFE durant cette période se sont en particulier pleinement emparés des enjeux de conservation de la biodiversité, s'éloignant du registre critique de la première génération et reléguant les questions sociales au second rang de leurs préoccupations :

« Les sociologues de l'environnement étaient pour la plupart des sociologues du travail, des ruralistes, qui avaient basculé vers l'environnement après, mais qui étaient clairement dans la défense de l'opprimé. [...] Moi, c'était souvent la difficulté que j'avais, y compris avec les pères de l'interdisciplinarité [...]. Évidemment, ça a fondé mes lectures, ma vision, mais il y avait quand même toujours ce petit truc où l'environnement était une espèce de norme qui allait structurer le paysage, les gens. [...] Ça ne correspondait pas à la perte de biodiversité qu'on observait, qu'on documentait » (directeur de recherche au CNRS en géographie, entretien 16, 05/10/2020).

³⁵ Une version de l'entretien dont est issu cet extrait est à paraître dans *Natures Sciences Sociétés*, d'où l'absence exceptionnelle d'anonymat.

Un travail d'opérationnalisation théorique a permis d'équiper ces contestations d'un ensemble de prises conceptuelles qui, malgré leur diversité, s'inscrivent toutes dans une approche systémique des fonctionnements naturels et sociaux.

Constituer un appareil conceptuel

Ce travail a visé à inscrire la RIFE dans un mode de recherche particulier, à caractériser ses objets d'étude et leurs propriétés, et à identifier des concepts mobilisables dans un contexte d'action publique.

De la science pluri-inter-transdisciplinaire des années 1970 à la science post-normale des années 1990

Généralement considérée comme le début de la réflexion sur l'interdisciplinarité (Klein, 2013), la conférence de l'OCDE (1972) a fourni à la RIFE un premier cadrage conceptuel. On peut notamment citer la contribution d'Erich Jantsch (1929-1980), convaincu, déjà, que le modèle de développement occidental connaissait une crise systémique. Jantsch (1972) voyait dans l'université le seul agent d'innovation suffisamment puissant pour renouveler en profondeur le fonctionnement et les institutions de la société. Cependant, cela nécessitait de réformer complètement l'université, et de fonder son organisation sur l'interdisciplinarité et la transdisciplinarité, considérées comme des degrés hiérarchisés de coordination et d'intégration des connaissances.

Après la crise économique des années 1970 et l'essoufflement des mouvements contestataires, un nouveau régime de production de connaissance³⁶ s'est constitué au début des années 1990 (Pestre, 2003). Efficacité, *accountability*, connectivité, autonomie, créativité, mobilité, adaptabilité et participation sont devenus les maîtres mots d'un nouveau « contrat » entre la science et la société (Lubchenco, 1998). Un ensemble de travaux ont alors appelé à de profonds changements de l'activité scientifique. Deux d'entre eux se sont avérés particulièrement influents, et continuent d'être une référence centrale des partisans de la RIFE. Le premier (Gibbons et al., 1994) a opposé deux modes de production de la connaissance. Dans le mode 1, la production de connaissances aurait été essentiellement confiée à une science théorique et disciplinaire menée au sein d'institutions largement autonomes. Dans le mode 2, elle serait devenue une activité productive comme une autre, beaucoup plus socialement distribuée, orientée vers les applications, transdisciplinaire et évaluable par une batterie de critères, dont l'utilité sociale. Le second (Funtowicz et Ravetz, 1993) a réclamé la mise en œuvre d'une « science post-normale », considérant que les risques et problèmes environnementaux ne peuvent pas être traités par des approches réductionnistes et rationalistes, du fait de leur degré d'incertitude élevé, de l'absence de consensus sur les valeurs, de l'ampleur des enjeux et de l'urgence des décisions à prendre. Cette littérature a fourni aux pionniers de la RIFE un deuxième cadrage conceptuel, qu'ils ont

³⁶ La notion de « régime de connaissance » repose sur l'idée que la production de connaissances ne peut être isolée de la production d'un ordre économique, social et politique. Un régime de connaissance consiste en un assemblage hétérogène et plus ou moins cohérent de pratiques, de valeurs et de normes spécifiques, d'équipements matériels, de lieux, d'arrangements sociaux et institutionnels, en relation avec les sphères économique et politique, et d'une culture épistémologique dominante.

largement mobilisé, dans un double objectif de légitimation et de compréhension des changements qu'ils opéraient :

« On a tous lu ça (l'ouvrage de Gibbons et al. et l'article de Funtowicz et Ravetz) à l'époque avec avidité, parce que ça ouvrait des espaces, ça nous légitimait, ça nous aidait à avancer » (directeur de recherche en écologie à l'INRA, retraité, entretien 4, 27/03/2020).

Insérer les problèmes dans des systèmes complexes adaptatifs

Les tenants de la RIFE considèrent que les problèmes à prendre en compte s'insèrent dans des ensembles dont ils ont fait leur objet d'étude. Les dénominations successives de ces ensembles – *human use systems*³⁷, anthroposystèmes³⁸ et socio-écosystèmes³⁹ (Lagadeuc et Chenorkian, 2009) – reflètent deux constantes : leur positionnement à l'interface entre nature et société, et leur approche en termes de systèmes.

Le travail de conceptualisation a également porté sur la caractérisation des propriétés de ces systèmes et sur leur capacité d'adaptation. Deux auteurs anglo-saxons ont été particulièrement influents : l'écologue Crawford S. Holling (1930-2019) et l'économiste hétérodoxe Elinor Ostrom (1933-2012). Le premier a, dès les années 1970, proposé une théorie écologique de la résilience, qu'il a alors définie comme la capacité d'un système à persister en absorbant des fluctuations imprévisibles (Holling, 1973). À partir des années 1990, la seconde a étudié les systèmes de gouvernance favorisant la cogestion des ressources naturelles (Ostrom, 2009), et introduit les institutions dans l'analyse des processus qui affectent les socio-écosystèmes. Ces deux cadres d'analyse ont été agrégés au début des années 2000 au sein du réseau scientifique international *Resilience Alliance*, qui a mis l'accent sur la gestion adaptative et participative des socio-écosystèmes (Jacob et Hervé, 2022).

Des concepts inscrits à l'agenda politique

Les tenants de la RIFE entendent intervenir sur les problèmes identifiés à l'échelle de territoires. Il leur fallait donc aussi des prises conceptuelles pour penser la possibilité et la nécessité d'agir dans un contexte de crise environnementale. Plusieurs concepts inscrits à l'agenda politique et scientifique mondial à la charnière des années 1980 et 1990⁴⁰ ont contribué à transformer les interactions entre la nature et la société en problèmes traitables par une recherche finalisée. La constitution progressive d'une boîte à outils conceptuels a permis de revendiquer une capacité d'action sur une diversité de problèmes d'environnement. Elle a poussé des chercheurs en sciences de la nature à opérer un

³⁷ Défini comme un système à travers et par lequel les ressources sont gérées (di Castri, 1976, p. 245).

³⁸ Défini comme un « système interactif entre deux ensembles constitués par un (ou des) sociosystème(s) et un (ou des) écosystème(s) naturel(s) ou artificialisé(s) s'inscrivant dans un espace géographique donné et évoluant avec le temps » (Vivien et Muxart, 2011, p. 42).

³⁹ Initialement proposé par Berkes et Folke (1998).

⁴⁰ Avec, notamment, la publication du rapport Brundtland en 1987, la création du GIEC en 1988 et l'adoption de la Convention sur la diversité biologique lors du sommet mondial de Rio en 1992, qui ont donné une légitimité politique aux concepts de développement durable, de changement climatique et de biodiversité, respectivement.

mouvement vers la société et les sciences sociales, comme l'expliquait en 2008 l'écologue Robert Barbault (1943-2013) à propos de la biodiversité :

« La biodiversité, ce n'est pas simplement la diversité du vivant (ça, ce n'est nouveau pour personne). La biodiversité, ça nous parle de nous, ça nous parle de l'homme : et plus précisément de notre rôle (destructeur ou protecteur) au sein d'une diversité dont nous faisons partie. La biodiversité a été une façon extraordinairement efficace de revisiter l'écologie⁴¹. »

La fabrique d'un appareil conceptuel s'est poursuivie, avec, notamment, l'émergence de notions structurantes pour les institutions internationales, comme celui de services écosystémiques, popularisé en 2005 par le *Millennium Ecosystem Assessment*, ou les objectifs du développement durable, adoptés par les Nations Unies en 2015. Parallèlement, le débat académique et politique s'est enrichi de nouvelles notions, dont celle d'Anthropocène (Bonneuil et Fressoz, 2013).

L'émergence de la RIFE a simultanément reposé sur la mise en place d'une organisation collective permettant à un nombre significatif de chercheurs d'accéder aux ressources indispensables à l'accomplissement de leurs travaux.

Organiser l'accès à des ressources

Comités, programmes, départements et infrastructures de recherche

Il existe entre les ministères et les laboratoires de recherche des structures intermédiaires (Crespy et Jouvenet, 2020) qui définissent des orientations, distribuent les financements, encadrent et évaluent les projets et les activités. Une succession de comités, de programmes et de départements ont ainsi fortement contribué à façonner la RIFE.

Un programme international a été déterminant dans son émergence, dans de nombreux pays (Reed, 2016) et notamment en France : le programme *Man and the Biosphere* (MAB) de l'Unesco, lancé en 1971, dont la création figurait en tête des recommandations de la conférence de la biosphère. La volonté d'orienter la science en fonction de problèmes à résoudre dans la société, le choix d'unités d'étude qui puissent être considérées comme des *human use systems*, l'interdisciplinarité et l'implication d'acteurs locaux dans la conception et la mise en œuvre des projets ont, d'emblée, fait partie des idées maîtresses du MAB (di Castri, 1976).

En France, dans le sillage de la conférence de la biosphère, la DGRST a mis sur pied plusieurs comités sur les questions environnementales. Leurs intitulés⁴² traduisent la volonté de mettre la recherche scientifique au service de la résolution des problèmes environnementaux, tels qu'ils étaient alors envisagés (Jollivet, 1992). Plusieurs dizaines de scientifiques, issus de nombreuses disciplines des sciences de la nature (biologie, écologie,

⁴¹ Source : entretien réalisé par Wildproject en 2008, <http://www.wildproject.fr/rb.html>, page consultée le 14/12/2009.

⁴² Créé en 1968, le comité « Lutte biologique » a pris le nom de « Équilibres et luttes biologiques » en 1972. Il a été remplacé en 1976 par le comité « Gestion des ressources naturelles renouvelables », auquel a succédé le comité « Écologie et aménagement rural » de 1979 à 1982 (Deffontaines, 1992a).

hydrologie, parasitologie, etc.), des SHS (sociologie, géographie, etc.) et des sciences appliquées (agronomie, sciences forestières), y ont participé. Créé en 1971, le ministère de l'environnement a constitué d'autres comités avec des objectifs et des méthodes similaires, et financé un ensemble de programmes sur des problèmes très variés de 1990 à 2016⁴³. Ces comités et ces programmes ont eux aussi favorisé l'émergence du mouvement en France (Mougenot, 2011, p. 80).

Loin d'avoir été purement endogène, l'organisation de la RIFE a donc, comme celle de la recherche sur le risque environnemental global (Crespy et Jouvenet, 2020), été aussi et d'abord impulsée par des structures internationales (l'Unesco) et gouvernementales (la DGRST, le ministère de l'environnement) qui ont enrôlé des scientifiques. Ce n'est que dans un deuxième temps et sous l'influence de ces premières initiatives, venues à la fois de leurs bases et du pouvoir central, que les organismes de recherche se sont engagés dans ce mode de recherche, presque simultanément pour le CNRS et l'INRA, mais par des voies différentes⁴⁴.

Au CNRS, les comités mis en place par la DGRST ont permis la création, dès 1967, d'instituts permanents et puissants (Institut national d'astronomie et de géophysique et Institut national de physique nucléaire et de physique des particules) dans plusieurs domaines scientifiques (Chatriot et Duclert, 2006). La RIFE, en revanche, s'est longtemps développée dans un cadre plus précaire. Plusieurs programmes ont succédé au programme interdisciplinaire de recherche en environnement, connu sous le nom de PIREN, lancé en 1978 (Muxart, 2004 ; Vivien et Muxart, 2011 ; Brun et al., 2017). Comme ceux de la DGRST, ces programmes ont développé des actions incitatives, fondées sur la diffusion d'appels à projets de recherche, sélectionnés et évalués par une série de comités. De nombreux jeunes chercheurs ont fréquenté des promoteurs et des pionniers de la RIFE dans ces comités, qui ont constitué autant d'espaces de micromobilisation et de socialisation à la RIFE. Les moyens des programmes de recherche en environnement sont toutefois restés limités. Le directeur de l'un d'eux a souligné, en entretien, que c'était « *une petite chose* » à côté des instituts du CNRS. En 2006, ce dernier a finalement décidé de créer un département transversal pour s'occuper des questions d'environnement : le département environnement et développement durable (EDD), devenu l'institut écologie et environnement (Inee) en 2009, lorsque les départements du CNRS ont été transformés en instituts.

L'INRA, lui, a créé en 1979 le département Systèmes Agraires et Développement (SAD), dédié aux recherches interdisciplinaires et visant le développement agricole (Deffontaines et Hubert, 2004 ; Cornu, 2021). La précarité du SAD, mal doté en moyens humains et financiers (Cornu, 2021), en a longtemps fait un choix d'affiliation risqué, notamment pour les jeunes chercheurs. Qualifié à sa naissance de département « ambulance », il matérialise la rencontre entre des chercheurs souvent hétérodoxes, et l'intérêt stratégique d'un institut public à s'ouvrir, à la marge, à des recherches plus attentives à la complexité des réalités locales.

⁴³ Voir le numéro spécial de NSS « *Pour une recherche en appui à l'action publique : leçons de l'expérience du ministère de l'environnement (1990-2016)* », paru en 2017 (volume 25, supplément 2017).

⁴⁴ Nous ne pouvons pas examiner ici le rôle significatif dans le développement de la RIFE d'organismes de recherche nationaux plus petits, comme le Cemagref, l'Orstom ou le Cirad. Pour le Cemagref, voir (Griset, 2001).

Des dispositifs territorialisés

Par construction, la RIFE est une recherche de terrain et de long terme. Son développement a nécessité l'identification de sites qui puissent correspondre à des « systèmes » mêlant des composantes naturelles et des composantes humaines, et accueillir, dans la durée, des chercheurs intéressés par ce type de recherche. Les premiers sites choisis dans le cadre des recherches financées par la DGRST n'avaient pas de label particulier. Pour l'essentiel, ils concernaient des régions économiquement marginales, en particulier les moyennes montagnes frappées de plein fouet par l'exode rural ou encore les Antilles françaises⁴⁵ (Legay et Deffontaines, 1992, p. 384 ; Cornu, 2021).

La RIFE s'est notamment développée au sein des trois dispositifs territorialisés que nous avons étudiés, qui ont été progressivement institués des années 1970 à aujourd'hui pour favoriser le développement de ce type de recherche. Ils sont animés par des organisations très ouvertes, sans procédure formalisée d'entrée et de sortie de leurs membres, et dotés de moyens financiers et humains très variables mais, dans l'ensemble, limités.

Créées dans la foulée du programme MAB, les réserves de biosphère (RB) ont été les premiers dispositifs explicitement conçus pour accueillir ce type de recherche et, plus précisément, expérimenter avec les acteurs locaux des modes de développement durable. Leur reconnaissance juridique est laissée à l'appréciation de chaque État. Néanmoins, la désignation en tant que RB appartient à l'Unesco après examen d'un dossier de candidature, réévalué tous les dix ans. À plusieurs reprises, le constat a été fait, en France (Cibien, 2006) comme à l'étranger (Reed, 2016), que leurs maigres ressources humaines et financières et leur faible visibilité ne leur permettaient pas d'enclencher une dynamique d'expérimentation collective de grande ampleur. Pour autant, les RB sont restées un modèle de référence international pour explorer les possibilités d'associer les acteurs de terrain à la conception et la mise en œuvre des politiques publiques environnementales. Certains promoteurs de la RIFE comme Robert Barbault (Barbault et al., 2006), président du conseil d'administration du MAB-France de 2000 à 2013, ont particulièrement défendu leur capacité à accueillir ce mode de recherche.

Les zones ateliers (ZA) sont les héritières à la fois des programmes de recherche interdisciplinaires en environnement du CNRS, du programme MAB et du programme international sur la recherche écologique de long terme (LTER, pour *long-term ecological research*). Le terme de « zones ateliers » (ZA) est apparu au sein du Groupement d'Intérêt Public pour la recherche sur les hydrosystèmes (GIP Hydrosystèmes), créé en 1993 dans le sillage des programmes de recherche interdisciplinaires du CNRS sur les grands fleuves (Lévêque, 2011). Il s'agissait de disposer de sites expérimentaux dotés de grands équipements pour mener des recherches à long terme réunissant des compétences et des disciplines diverses, y compris en sciences sociales, pour aborder la complexité des systèmes en présence. Après le démantèlement du GIP à la fin des années 1990, les ZA sont réapparues en 2000, dans un appel d'un programme de recherche en environnement du CNRS (Lévêque

⁴⁵ Citons, par exemple, les programmes Briançonnais, Pyrénées, Causse Méjean et bilharziose, du nom d'une maladie transmise par les escargots d'eau douce, qui a longtemps constitué un problème de santé publique dans les Antilles françaises.

et al., 2000). Leur création et leur renouvellement tous les cinq ans dépendent de l'Inee, qui leur alloue une dotation annuelle d'un montant limité. Elles se sont élargies à d'autres types de socio-écosystèmes et sont fédérées au sein d'un réseau national des ZA (RZA). Elles constituent la version française des plateformes pour la recherche socio-écologique de long terme (*long-term socio-ecological platforms*).

À partir de 2007, la RIFE a disposé d'un troisième type de dispositifs territorialisés, propres à la France cette fois-ci : les Observatoires Hommes-Milieus (OHM). Autres outils de promotion de l'interdisciplinarité de l'Inee, les OHM sont axés sur des territoires fortement anthropisés, et caractérisés par l'existence d'un « événement fondateur » (comme l'arrêt d'une activité industrielle majeure) qui vient bouleverser les socio-écosystèmes existants (Chenorkian, 2020). Leurs promoteurs entendent constituer des lieux où toutes les disciplines étudient le même objet et se nourrissent de ces échanges pour proposer une « compréhension globale du système complexe étudié » (Chenorkian, 2020). La labellisation en 2012 du dispositif OHM comme laboratoire d'excellence (LabEx DRIIHM) lui a permis de bénéficier de crédits relativement conséquents.

Ces dispositifs ont entre eux de fortes proximités : ils poursuivent des objectifs similaires, attirent le même type de chercheurs et se recouvrent parfois spatialement⁴⁶. L'Inee envisage actuellement de rapprocher les ZA et les OHM selon des modalités qui restent à définir. À l'échelle internationale, les RB et les plateformes LTSER sont régulièrement présentées comme des dispositifs apparentés (voir, par exemple, Holzer et al., 2018). Les ZA, les OHM et les RB gérées par la France couvrent à eux trois une quarantaine de sites (16 RB, 14 ZA, 13 OHM) qui concernent une diversité de problématiques environnementales, en France métropolitaine, dans les territoires ultramarins (3 RB, 1 ZA, 2 OHM) et à l'international (1 ZA et 5 OHM). Trouver des terrains propices à la RIFE est dans ces conditions devenu plus facile. L'accès à des revues où publier les travaux est une autre ressource indispensable au développement d'une recherche, fût-elle finalisée.

La création d'une revue française et l'insertion dans une communauté internationale

Les pionniers de la RIFE en France ont créé une revue pour remédier à la rareté des publications issues du PIREN (Jollivet, 1992), et créer une communauté scientifique française « partageant une méthode interdisciplinaire rigoureuse sur le plan scientifique »⁴⁷. Fondée en 1993, *Natures Sciences Sociétés (NSS)* a été la revue de référence de la RIFE en France⁴⁸. Le choix de rédacteurs en chef reconnus et respectés dans leur domaine scientifique (le sociologue Marcel Jollivet, le biométricien Jean-Marie Legay et le climatologue Gérard Mégie (1946-2004), président du CNRS de 2000 à 2004) a visé à conférer de la légitimité à un mode de recherche encore très contesté (Jollivet, 1992, p. 19). Plusieurs membres du comité de rédaction avaient été très impliqués dans les programmes de la DGRST ou les programmes

⁴⁶ C'est par exemple le cas en Camargue (RB de Camargue, OHM Vallée du Rhône, ZA Bassin du Rhône).

⁴⁷ Marcel Jollivet (com. personnelle).

⁴⁸ L'ambition, le contenu et la longévité de la revue nécessiteraient une analyse approfondie, qui dépasse le cadre de cet article.

de recherche interdisciplinaire du CNRS. NSS s'est fortement appuyée sur leur expérience pour porter une exigence de réflexivité sur la recherche interdisciplinaire.

Sans se détourner complètement de NSS, la deuxième génération de chercheurs de la RIFE en France s'est employée à s'insérer dans ce mode de recherche à l'échelle internationale. Certains réseaux ont été particulièrement ciblés, comme la *Resilience Alliance*, initiée par Holling, qui promeut une recherche intégrée sur les socio-écosystèmes et publie la revue *Ecology and Society* depuis 1997 :

« On a fait beaucoup d'efforts pour entrer dans Resilience Alliance. On a fait beaucoup d'efforts, pas forcément couronnés de succès, pour entrer dans Society and Natural Resources. Et chaque fois, on a mis quelqu'un d'entre nous. On a chargé quelqu'un du collectif de faire, pas du lobbying mais de l'entrance. Parce que c'est compliqué de rentrer dans ces machins. Et X est membre du bureau de Resilience Alliance. Ça a mis dix ans, mais il y est arrivé » (directeur de recherche en écologie à INRAE, retraité, entretien 7, 05/06/2020).

En même temps qu'elle a multiplié et diversifié leurs débouchés académiques, l'insertion dans une communauté internationale a facilité l'accès de ces chercheurs à des financements privés :

« Eux (les membres de la Resilience Alliance) montent des projets à l'international avec des financements à l'américaine, ce sont des financements par des entreprises. On ne sait absolument pas faire en France. Eux ont des millions de dollars, qu'ils ont par des fondations privées. Et dès que tu es reconnu comme membre du club, tu as tous les avantages du club » (directeur de recherche en écologie à INRAE, retraité, entretien 7, 05/06/2020).

Ce qui précède montre que la RIFE s'est construite en opposition aux idées dominantes et présente toutes les caractéristiques des MSI : l'implication de chercheurs établis et influents (Holling et Ostrom à l'international ; Jean-Marie Legay et Marcel Jollivet, par exemple, pour la France), la fabrication d'un appareil conceptuel, la mise en place d'une organisation collective garantissant un accès aux ressources nécessaires à l'accomplissement du travail de recherche, la promotion d'idées (la critique contre la modernisation capitaliste et ses effets sur les sociétés rurales, puis la défense de l'environnement) en phase avec les préoccupations de ses membres. En revanche, la RIFE se distingue de la plupart des MSI par une position et une composition très particulières.

Un mouvement particulièrement hétérogène

Les MSI peuvent être intradisciplinaires, comme dans le cas de la géographie théorique et quantitative européenne francophone (Cuyala, 2014), ou interdisciplinaires, comme dans le cas des neurosciences (Chamak, 2011) ou de la biologie de synthèse (Vermeulen, 2018). En revanche, ils concernent rarement à la fois les sciences de la vie, les sciences de la Terre, les sciences humaines et sociales (SHS) et les sciences appliquées. Par ailleurs, ceux qui les

initient et s'y engagent sont le plus souvent des acteurs de la recherche scientifique : les MSI sont, pour l'essentiel, internes à la science. La RIFE, elle, est un mouvement particulièrement hétérogène. Elle concerne d'une part plusieurs grands domaines scientifiques, même si c'est à des degrés divers, et la priorité de ses partisans est de s'attaquer à des problèmes concrets d'environnement en lien avec les acteurs des territoires.

Un mouvement à l'interface de plusieurs domaines scientifiques

Si l'appartenance à un champ disciplinaire ne détermine pas l'adhésion à la RIFE (Brun et al., 2017), les membres de certaines disciplines ont été d'emblée particulièrement à l'aise avec son programme et ont fortement participé à son émergence et son développement initial. Cela a notamment été le cas d'une partie des écologues, spécialisés dans l'étude des écosystèmes, familiarisés avec les notions de complexité, d'interdépendance, voire de résilience, et habitués à raisonner en termes de flux de matière et d'énergie. Une partie des agronomes étaient, eux aussi, en quelque sorte prédisposés à contribuer à un mouvement qui entendait répondre à des problèmes concrets, en accordant une place centrale à la pensée systémique et en s'ancrant dans des territoires (Deffontaines, 1992b). Les chercheurs en SHS ont eu, dans l'ensemble, plus de mal à s'inscrire dans la RIFE, bien qu'un petit nombre d'entre eux aient contribué à son émergence. Ils ont longtemps eu le sentiment d'être invités dans les projets tardivement, pour obtenir des financements ou faire de l'ingénierie sociale, plutôt que pour étudier les processus sociaux et politiques et stimuler les débats académiques et sociétaux. En bref, ils ont craint que leur implication dans la RIFE ne les cantonne dans un rôle ancillaire ou de service (Barry et Born, 2013 : 12 ; Boudes, 2008).

Si les grands domaines scientifiques ont contribué très inégalement à la RIFE, tous lui ont apporté des leaders, bien établis dans leur discipline respective. Peuvent être cités, notamment, Jean-Claude Lefeuvre, Jacques Baudry, Bernard Hubert, Robert Barbault et Bernard Delay en écologie, Jean-Marie Legay et Alain Pavé en biométrie, Jean-Pierre Deffontaines en agronomie, Gérard Mégie en climatologie, Christian Lévêque en hydrobiologie et, du côté des sciences humaines et sociales, Marcel Jollivet, Bernard Picon et Jean-Paul Billaud en sociologie, Georges Bertrand et Nicole Mathieu en géographie et Jacques Weber en économie. Les chercheurs, ingénieurs et techniciens qui se sont ralliés au mouvement sont venus d'une large gamme de disciplines, même si les sciences de la nature et notamment l'écologie ont été nettement plus représentées que les autres domaines scientifiques. Alors que les chercheurs qui s'engagent dans les MSI disciplinaires se comptent habituellement en dizaines (Frickel et Gross, 2005), l'interdisciplinarité élargie de la RIFE lui a permis de se prévaloir d'une base particulièrement large. Par exemple, Pavé (2001) évaluait à un millier le nombre de chercheurs impliqués dans le programme « environnement, vie et société » du CNRS.

La position de la RIFE à l'interface de plusieurs domaines scientifiques a aussi permis à ses promoteurs de revendiquer une capacité à prendre en charge un éventail de problèmes d'environnement, liés aussi bien à l'évolution de l'agriculture qu'à la conservation de la nature, aux pollutions d'origine industrielle, ou encore aux questions de santé environnementale. Ses partisans ont pu s'implanter dans un ensemble de territoires très diversifiés en termes de milieux naturels et d'activités humaines. Sa position lui a ainsi donné

du crédit, en lui apportant une masse critique et une grande extension spatiale. Mais elle a simultanément suscité d'importantes rivalités entre les départements des instituts de recherche.

Au CNRS, des tensions très vives sont immédiatement apparues, comme l'illustre la terminologie guerrière régulièrement employée dans les entretiens, ici par le directeur d'un programme interdisciplinaire en environnement du CNRS : « *dès le début, ça a été la guerre, je dis bien la guerre* » (directeur de recherche en écologie, retraité, entretien 31, 26/02/2021). La RIFE n'a cessé d'être divisée et ballotée entre des programmes et des départements, et ses leaders se souviennent s'être très régulièrement confrontés aux directions de départements puis d'instituts du CNRS. Se situant au début des années 1980, le même informateur évoque « *la grosse forteresse Terre Océan Atmosphère Espace, TOAE, qui a été extrêmement combative ; ils voulaient récupérer toutes les recherches sur l'environnement* ».

En 2002, l'idée de transformer l'Institut national des sciences de l'univers (Insu) en Insue (E pour environnement) suscite l'ire d'une partie des membres du programme qui réclament « la création d'un département scientifique interdisciplinaire des Sciences de l'environnement au CNRS incluant la participation des chercheurs en Sciences de l'homme et de la société » (Muxart, 2004, p. 312). Pour eux, ce sont clairement des rapports de pouvoir et la hiérarchie entre les grands domaines scientifiques qui se jouent dans l'attribution de la recherche en environnement à tel ou tel département :

« “Les biologistes, les gens qui s'occupent des sociétés humaines, c'est pas très intéressant ; la vraie science c'est chez nous que ça se fait”. C'est comme ça que ça se disait, faut être clair : “la vraie science, c'est chez nous” » (entretien 31).

L'abandon du projet de création d'un Insue au profit de la création du département EDD puis de l'Inee n'a pas mis un terme aux rivalités. Sans pouvoir détailler ici l'histoire longue des rivalités et des alliances entre les structures au sujet de la RIFE, retenons que le positionnement de ce mouvement à l'interface de plusieurs domaines disciplinaires l'a constamment soumis à des querelles et à un tiraillement entre des structures au moins en partie concurrentes.

Un mouvement en prise avec des problèmes concrets

Si la RIFE a d'emblée été en prise avec des problèmes concrets « à l'échelle des territoires », c'est surtout les chercheurs de la deuxième génération qui ont été amenés à interagir très régulièrement avec des acteurs de la société, à la fois financeurs et partenaires de leurs travaux. Tandis que leurs aînés se définissaient avant tout comme des « passeurs de frontières » (Jollivet, 1992) disciplinaires, ils se sont davantage inscrits dans un mode de gouvernance de la recherche qui, par quête de légitimité, d'opérationnalité et de compétitivité, a encouragé l'implication d'acteurs non scientifiques dans la production de connaissances.

Cette nouvelle manière de produire du savoir s'est diffusée dans un contexte d'effacement de l'État au profit d'une grande diversité de parties prenantes, aux intérêts multiples et

potentiellement en conflit. La recherche a dû simultanément s'engager plus nettement du côté des acteurs sociaux et des communautés, et s'aligner avec les problématiques gestionnaires, qu'elles proviennent des mondes économique ou politique. Cette dynamique d'ouverture renvoie à une stratégie de désenclavement (Dodier, 2003) : par une série d'opérations qui consistent à lier sa légitimité à son extérieur, une institution tente de transformer les pressions externes en une participation interne. On peut donc aussi voir une forme d'opportunisme politique de la part des organismes de recherche dans l'institutionnalisation de la RIFE, même si elle a de fait offert aux acteurs de la recherche de nouvelles opportunités.

La focalisation sur des problèmes concrets a en effet favorisé l'accès des partisans de la RIFE à un ensemble de ressources. Des partenaires publics ou privés, comme la Compagnie nationale du Rhône ou EDF dans le cas de la ZA Bassin du Rhône, leur ont apporté des moyens financiers conséquents, et ont pu faciliter leur accès à des terrains et aux acteurs affectés par les problèmes considérés. Leur proximité avec certains acteurs de la société a par ailleurs contribué à accroître une légitimité de plus en plus fondée sur l'utilité de la recherche pour la société, ou sur sa promesse :

« Les apports des zones ateliers, c'est quand on arrive à faire ce lien acteurs-chercheurs, c'est-à-dire quand on tend vers la transdisciplinarité : la recherche devient une recherche-action et elle commence à influencer les politiques publiques par rapport à des arguments scientifiques, ce qui inclut la notion de long terme, c'est-à-dire de gain sociétal, d'utilité à long terme » (professeur d'université en écologie, membre d'une direction d'une ZA, entretien 46, 26/03/2020).

La montée en puissance des préoccupations pour l'environnement dans la société et l'affirmation d'une exigence d'utilité sociétale de la recherche scientifique ont clairement bénéficié à la RIFE en incitant un nombre croissant de chercheurs à rejoindre ses rangs. Elles ont permis à ses promoteurs de présenter l'implication dans la RIFE comme une obligation plutôt que comme une option :

« Le Sommet de la Terre (1972, Stockholm ; 1992, Rio de Janeiro) a enfin mis la recherche en face de ses responsabilités sociétales. Le chercheur ne peut plus dès lors se contenter de viser l'excellence au sein de sa discipline, mais doit s'impliquer dans des systèmes de connaissance et des pratiques plus complexes, impliquant des associations avec d'autres disciplines » (Brun et al., 2017, p. 29-30).

Dans le même temps, le positionnement particulier de la RIFE a, au contraire, pu freiner sa dynamique. D'une part, il a paradoxalement parfois réduit ses ressources, singulièrement dans le cas des RB. Pour mettre en œuvre leur programme, celles-ci n'ont en effet pu compter sur le soutien massif ni des institutions scientifiques, qui ne les ont pas considérées comme des dispositifs de recherche à part entière, ni des institutions de conservation de la nature, qui ont orienté leurs ressources en matière de recherche vers d'autres structures comme les parcs nationaux. Au-delà du cas des RB, financer l'intervention d'acteurs de la société dans des projets de recherche semble rester en pratique très difficile :

« On est en train de répondre à un appel d'offres de l'Ademe et d'autres organismes (...) sur la transition alimentaire. Et même dans un appel d'offres comme ça, avec des finalités sociétales très clairement affirmées, on ne peut pas financer, en tout cas facilement, une tierce partie qui n'est pas dans le monde académique ou dans le monde associatif » (directeur de recherche en écologie au CNRS, membre d'une direction d'une ZA, entretien 54, 15/04/2021).

D'autre part, le positionnement de la RIFE a généré des tensions internes et des critiques externes. Une partie des chercheurs engagés dans le mouvement ont en effet considérablement étendu le spectre de leurs collaborations, sous l'effet conjugué de la montée de l'affirmation, par des acteurs aux intérêts fortement divergents, d'une préoccupation pour l'environnement, et de la contraction des financements publics de la recherche scientifique. Initialement liée à des services centraux et déconcentrés de l'État et à des institutions publiques, la RIFE s'est progressivement rapprochée d'acteurs aussi divers que des associations environnementales et professionnelles et des entreprises privées, prêtant le flanc aux dénonciations d'une forme exacerbée de politisation de la recherche – qu'elle soit militante ou néolibéralisée. Son positionnement a également favorisé l'expression de questionnements et de critiques sur sa scientificité, notamment dans le cas de projets où il ne s'agit plus seulement de répondre aux demandes des acteurs sociétaux, mais aussi de les impliquer dans les activités et les productions de la recherche.

Sa grande hétérogénéité a donc constitué à la fois un facteur de consolidation et de fragilisation. Elle peut contribuer à expliquer sa longévité, qui a elle aussi eu un effet ambivalent. Si elle a ancré la RIFE dans la durée et nourri la rhétorique d'une avance française dans ce domaine, elle a aussi généré des incompréhensions, les membres de la deuxième génération de la RIFE ne se reconnaissant pas toujours, on l'a vu, dans les aspirations sociétales de leurs aînés.

Cette longévité de la RIFE constitue une sorte d'anomalie par rapport à la trajectoire des MSI prédite par la théorie de Frickel et Gross (2005). Les MSI sont, en effet, censés avoir une durée de vie assez réduite, de l'ordre d'une à deux décennies : après s'être développés à divers degrés, ils disparaissent, soit parce qu'ils n'ont pas réussi à attirer suffisamment de chercheurs, soit, à l'inverse, parce qu'ils ont réussi à s'imposer et se sont institutionnalisés, devenant alors un nouveau champ ou une nouvelle spécialité scientifiques. Plus de cinquante ans après son émergence, la RIFE en France est toujours dans un entre-deux.

Un mouvement entre dissidence et normalisation

Née d'une opposition au positivisme, au réductionnisme et au techno-centrisme scientifiques, la RIFE apparaît actuellement engagée dans des voies divergentes : une voie de normalisation, vers laquelle la pousse notamment son intégration dans des infrastructures de recherche nationale et européenne ; des voies minoritaires qui, pour certaines, rappellent l'engagement politique des pionniers et, pour d'autres, cherchent à faire émerger un mouvement dissident dans le mouvement.

Vers une standardisation par les infrastructures de recherche ?

L'intégration dans des infrastructures de recherche nationale et internationale est un puissant facteur de normalisation des pratiques et de l'organisation des communautés de recherche, et un instrument de gouvernement de la recherche (Louvel, 2021). La France a engagé dans les années 2000 une politique de désignation d'infrastructures de recherche nationales, étroitement associée à la politique européenne. Depuis la constitution du *European Strategy Forum for Research Infrastructures* (ESFRI) en 2002, l'Union européenne accorde aux infrastructures de recherche une importance grandissante, les considérant comme un moteur essentiel de la croissance d'une économie fondée sur la recherche et l'innovation (Hallonsten, 2020). Ces infrastructures sont, en conséquence, rendues de plus en plus visibles dans des documents en forme de « feuille de route » (voir ESFRI, 2018), de stratégie (voir MESRI, 2018), ou de livre blanc (voir Mahé et Marlin, 2020) (Louvel, 2021). En 2018, le RZA a été officiellement reconnu infrastructure de recherche nationale, ce qui s'accompagne d'une série d'objectifs à atteindre. Cette reconnaissance implique notamment l'établissement d'une politique tarifaire, qui fait des scientifiques des utilisateurs de services dont les infrastructures de recherche doivent pouvoir calculer le coût complet. Elle implique aussi une politique des données visant à atteindre les objectifs de l'Union européenne en matière d'accessibilité, de partage, d'interopérabilité et de réutilisation des données (données FAIR, pour *Findable, Accessible, Interoperable and Reusable*). La « FAIRisation » des données mobilise de fait aujourd'hui une part conséquente du temps et des moyens des dispositifs de la RIFE. Les ZA sont amenées à s'organiser pour se conformer progressivement aux standards nationaux et internationaux en la matière, ce qui oriente l'allocation des ressources et la hiérarchisation des priorités, au niveau de chacune des ZA et du réseau national. Le RZA a récemment contribué au projet de recherche *Terra Forma*, conçu pour implanter un vaste réseau de capteurs « intelligents à bas coût » et collecter une gamme de données physiques, géochimiques et biologiques sur les socio-écosystèmes. Selon sa lettre d'intention, ce projet

« s'inscrit pleinement et résolument dans la dynamique de construction de l'infrastructure de recherche européenne eLTER [Integrated European Long-Term Ecosystem, critical zone and socio-ecological system research infrastructure] qui, à l'échelle européenne et en lien étroit avec des initiatives similaires sur d'autres continents, porte l'ambition de développer un système d'observation et de recherche intégrée du fonctionnement de la zone critique⁴⁹ et des socio-écosystèmes, en associant géosciences, sciences de la biodiversité et sciences sociales, et en promouvant des partenariats renforcés entre communauté académique, décideurs et citoyens. »

Dans les OHM, les effets de ces stratégies se retrouvent dans l'encouragement à pratiquer la science ouverte et à la pérennisation des données. En 2019, le projet So-driihm, issu d'un groupe de travail interne aux OHM, a obtenu un financement de l'agence nationale pour la recherche (ANR) pour créer une infrastructure numérique visant à faciliter le stockage et le partage des données.

⁴⁹ C'est-à-dire la couche de la Terre qui joue un rôle critique pour le vivant.

Le RZA constitue par ailleurs une composante de la contribution française à eLTER. eLTER fait partie des projets inscrits dans la feuille de route d'ESFRI qui pourraient, d'ici quelques années, être labellisés infrastructures de recherche « d'intérêt pan-européen ». Cette labellisation implique le respect d'exigences supplémentaires, qui portent en particulier sur les variables considérées comme essentielles pour suivre un ensemble de socio-écosystèmes à travers l'Europe, selon des protocoles prédéfinis. Les gestionnaires des plateformes qui seront retenues dans eLTER devront être en mesure de fournir ces variables aux utilisateurs, en même temps que d'autres services, comme l'accueil des chercheurs dans les plateformes. Les signes d'un mouvement de standardisation des pratiques, des données et de l'organisation de la RIFE, en fonction de normes définies à l'échelle européenne, sont donc indéniables. Cependant, des signes de dissidence sont également perceptibles.

Des anciennes aux nouvelles dissidences ?

Deux types de contestation des dynamiques de normalisation en cours peuvent être distingués : celle de pionniers de la RIFE, qui ne reconnaissent pas, dans l'évolution du mouvement, certaines valeurs qui ont motivé leur implication, et celle de chercheurs qui, comme les tenants de la normalisation, se sont ralliés au mouvement plus tardivement.

Selon ses pionniers, l'inscription de la RIFE dans des politiques incitatives fondées sur des appels à projets ne l'a pas empêchée de se développer, à ses débuts, dans une grande liberté d'organisation. Ils considèrent qu'elle a été un mouvement « *bottom-up* » (Brun et al., 2017, p. 118), très éloigné des pratiques contemporaines de bureaucratisation managériale de la recherche. Le directeur d'un programme interdisciplinaire en environnement du CNRS a insisté sur l'importance qui était alors accordée à la dimension informelle et expérimentale de la RIFE :

« Je voudrais être très clair là-dessus aussi : on ne voulait pas instituer des structures formelles. On voulait dès le départ faire des expérimentations, c'est-à-dire essayer de voir comment des groupes de chercheurs étaient capables de s'organiser pour mettre en place une recherche sur des thématiques interdisciplinaires (...). On ne souhaitait pas mettre trop de... de législation j'allais dire, entre guillemets » (directeur de recherche en hydrobiologie à l'IRD, retraité, entretien 30, 02/03/2021).

Des chercheurs qui ont contribué à la création de NSS observent que la banalisation de l'interdisciplinarité lui a fait perdre sa « portée subversive » (Billaud et al., 2018 : 1) et déplorent que la RIFE soit, en quelque sorte, rentrée dans le rang. C'est aussi une forme d'engagement politique, très marquée par le marxisme ou mai 68, qui a disparu avec une partie des pionniers, comme Jean-Marie Legay, membre actif du parti communiste tout au long de sa carrière⁵⁰.

Tout en ayant parfaitement réussi à s'intégrer dans les canons de l'évaluation scientifique et les critères d'excellence internationale, des chercheurs venus à la RIFE à partir des années 1990-2000 s'opposent eux aussi aux dynamiques de normalisation en cours. Ils pointent un

⁵⁰ <https://maitron.fr/spip.php?article137051>, notice LEGAY Jean-Marie [LEGAY Jean, Marie, dit] par Jacques Girault, version mise en ligne le 16 mai 2011, dernière modification le 14 mai 2021.

risque de remplacement des principes de réflexivité, d'exploration et de co-construction avec les acteurs par une approche essentiellement prédictive, prescriptive et technologique des problèmes. Au sein du RZA, des voix dénoncent une hégémonie d'eLTER dans les orientations du réseau et un retour en force du réductionnisme et du technocentrisme. Cette nouvelle dissidence apparaît fortement liée à la conviction que l'accélération et l'aggravation de la crise environnementale rendent totalement insuffisant l'objectif de documenter et de comprendre les changements à l'œuvre dans les socio-écosystèmes. Ces chercheurs sont animés par un sentiment d'urgence absolue – « *notre horizon de tir, il est de moins de dix ans aujourd'hui, peut-être même beaucoup moins* » (directeur de recherche en écologie au CNRS, membre de la direction d'une ZA, entretien 54, 15/04/2021). Ils veulent aller à la fois plus vite et plus loin, en expérimentant des méthodes de transformation des sociétés contemporaines qui impliquent humains et non-humains, et réintègrent la question des asymétries de pouvoir.

Cette tendance présente certaines caractéristiques des MSI : elle s'inscrit contre une RIFE de plus en plus établie, et qui la rejette. Elle est impulsée par des chercheurs qui disposent d'un statut élevé. Dans les ZA, elle est notamment portée par un écologue qui a dirigé le RZA de 2014 à 2020 (voir Bretagnolle, 2021), et par l'actuel directeur du réseau, venu de la biogéochimie marine et qui se reconnaît maintenant dans la « science de la durabilité » (voir Ragueneau, 2020). Tous deux sont directeurs de recherche au CNRS. En revanche, le degré d'organisation collective de ce mouvement émergent reste limité. La dissidence s'exprime plutôt dans le cadre de projets de recherche, qui peinent à trouver des financements pérennes, mais constituent des lieux de micromobilisation particulièrement actifs :

« Nous-mêmes évoluons à vitesse très grand V, nous-mêmes c'est-à-dire le collectif des chercheurs à l'origine du projet. (...) Le projet, la maturation, les pistes de solution, les réflexions évoluent très vite parce que le contexte évolue lui-même très vite. Il y a un an, il n'y avait pas de covid ; et dans un an, on ne sait pas ce qu'on aura ; ça va très très vite » (directeur de recherche en écologie au CNRS, membre de la direction d'une ZA, entretien 54, 15/04/2021).

Discussion

Nous avons regroupé sous le terme de RIFE des recherches menées pour prendre en charge des problèmes d'environnement en associant une diversité de disciplines scientifiques et de secteurs de la société. Nous avons montré que la RIFE correspond à une nébuleuse mouvante et traversée par des tensions internes plutôt qu'à un collectif soudé et bien délimité.

Nous avons mobilisé la théorie des MSI pour retracer et analyser la dynamique de ce type de recherche en France depuis ses débuts dans les années 1960. Les facteurs mis en avant par Frickel et Gross (2005) nous ont permis de comprendre comment ce type de recherche a pu émerger. La RIFE a été promue par des scientifiques reconnus et influents. S'engager dans ce type de recherche leur a permis de mener des travaux en accord avec leurs convictions politiques (la défense de sociétés rurales disloquées par la modernisation capitaliste pour la première génération, la défense de l'environnement pour la deuxième) et scientifiques (la pensée complexe et constructiviste), et de revendiquer une posture de chercheur dissident.

Ils sont parvenus à créer des espaces de micromobilisation et à organiser l'accès à une partie des ressources nécessaires à l'accomplissement du travail de recherche, notamment des programmes, des revues et des terrains.

Pourtant, la RIFE ne s'est que partiellement institutionnalisée. Que lui est-il arrivé ? Contrairement à des disciplines comme la pharmacogénomique (Hedgecoe, 2003) ou la biologie de synthèse (Bensaude Vincent, 2013), elle n'a pas été désignée par une appellation fédératrice et porteuse d'une forte charge rhétorique. Introduit au début des années 2000 dans la littérature anglo-saxonne (Kates et al., 2001), le terme de « science de la durabilité » (*sustainability science*) pourrait aujourd'hui servir de bannière à la RIFE. Néanmoins, son utilisation est récente en France, et son destin encore très incertain. Autre absence frappante dans l'histoire de la RIFE : celle de méthodes standardisées, dont le rôle a été majeur dans l'émergence de nouveaux champs disciplinaires (Fujimura, 1988). Les variables essentielles d'eLTER et les réseaux de capteurs de *Terra Forma* visent à standardiser l'étude des socio-écosystèmes. En ce sens, ils peuvent être considérés comme l'équivalent des technologies de l'ADN pour la biologie moléculaire. Mais ils interviennent eux aussi tardivement dans l'histoire du mouvement, et une partie des tenants de la RIFE rejettent le technocentrisme et le réductionnisme dont ils sont porteurs.

L'idée de couple ou d'ensemble standardisé (*standardized package*) avancée par Fujimura (1988) est particulièrement pertinente pour comprendre les difficultés d'émergence de la RIFE. Contrairement à la biologie moléculaire, la RIFE n'a pas émergé autour d'un couple standardisé théorie-méthode mais autour d'un couple problème-théorie. Les promoteurs de la RIFE ont cherché à formuler moins des réponses ou des promesses que des questions qui renvoient au rapport entre science et société. Ils ont défendu le principe d'une exploration conjointe et sur mesure des problèmes socio-environnementaux par les chercheurs et les acteurs des territoires, selon une logique itérative propre à l'approche systémique. Le couple problème socio-environnemental- théorie des systèmes complexes qu'ils ont constitué s'est trouvé partiellement en décalage avec le régime de production de connaissance qui s'est affirmé dans les années 1990. Il répond mal, en effet, aux exigences d'efficacité et d'*accountability* de ce dernier. L'enjeu des dynamiques d'institutionnalisation en cours est un glissement vers un ensemble standardisé théorie des socio-écosystèmes-méthodes de description standardisées-données, plus en phase avec ce nouveau régime. Ainsi, l'originalité de la RIFE en France n'est pas tant sa dissidence, même si celle-ci a la particularité d'être explicitement scientifique et politique, que son ancrage épistémologique constructiviste. C'est la tension entre ce fondement épistémologique et le type de standardisation attendu dans le régime de connaissance actuel qui explique, selon nous, que la RIFE se situe toujours dans un entre-deux, après plus de cinquante ans d'existence.

Notre étude a mobilisé la littérature sur l'émergence des champs scientifiques. Elle y contribue en retour de trois manières. Premièrement, elle souligne la pertinence de la notion de MSI pour analyser la dynamique de recherches qui entendent associer des acteurs très diversifiés autour de problèmes d'intérêt commun tel que les problèmes d'environnement. Frickel et Gross (2005 : 208) ont évoqué le cas de ces mouvements sans l'approfondir, à propos, précisément, de la science de la durabilité, entrée dans la littérature anglo-saxonne (Kates et al., 2001) peu avant la publication de leur article. De tels mouvements se distinguent

nécessairement des mouvements scientifiques moins directement en prise avec la société, et *a fortiori* des mouvements disciplinaires. Ils sont en effet soumis à des facteurs à la fois de consolidation et de fragilisation, rendant leur dynamique moins linéaire et plus imprévisible que celle de MSI classiques. Cette imprévisibilité est très marquée dans le cas de la RIFE, la perspective réelle ou fantasmée d'un effondrement de la société industrielle nous plongeant dans une temporalité de l'imminence qui bouscule la trajectoire des MSI initialement proposée. Là où Frickel et Gross envisageaient essentiellement deux options – la réussite ou l'échec de l'institutionnalisation –, notre analyse suggère l'existence d'autres possibilités, comme l'émergence d'un mouvement dans le mouvement. Ce processus nous aurait complètement échappé si nous avions uniquement considéré les premières décennies du mouvement. Notre étude montre ainsi l'intérêt de suivre les MSI sur le temps long : c'est son deuxième apport. Troisièmement, elle met en évidence la nécessité de compléter la théorie proposée par Frickel et Gross (2005) par une hypothèse supplémentaire : un MSI a plus de chance de se développer si son fondement épistémologique est compatible avec un type de standardisation en phase avec le régime de connaissance dominant.

Conclusion

Nous avons caractérisé la recherche interdisciplinaire et finalisée en environnement (RIFE) en France, et analysé sa dynamique depuis les années 1960 en mobilisant la littérature sur l'émergence des champs scientifiques. Nous nous sommes particulièrement appuyés sur la théorie des mouvements scientifiques et intellectuels (MSI). L'essence d'un MSI étant de produire et diffuser des idées, cette théorie nous a conduits à nous intéresser aux circulations au sein de la RIFE. La position de ce mouvement à l'interface de plusieurs disciplines et catégories d'acteurs, sa dimension à la fois nationale et internationale et sa longévité font que ces circulations sont à la fois inter- et transdisciplinaires, globales et intergénérationnelles.

Nous avons mis en évidence l'existence de deux générations au sein du mouvement français. La première, clairsemée, a été composée de chercheurs fortement préoccupés par les enjeux sociétaux et souvent influencés par la pensée marxiste. À partir des années 1970, ils ont construit les ressources conceptuelles et organisationnelles pour penser et mettre en œuvre une recherche en rupture avec une organisation encore essentiellement disciplinaire de la recherche. Avec l'émergence d'un nouveau régime de production de connaissances dans les années 1990, une nouvelle génération, plus nombreuse, a rejoint la RIFE. Cette deuxième génération, qui a fait passer les enjeux d'environnement avant les problématiques sociales, s'est davantage insérée dans la communauté internationale et a étroitement collaboré avec une grande diversité d'acteurs.

Nous avons ainsi à la fois prolongé et relu le récit proposé par la génération des pionniers de la RIFE en France (Jollivet, 1992 ; Brun et al., 2017), principalement centré autour des expériences fondatrices de la DGRST et des programmes interdisciplinaires en environnement du CNRS. Comme tout récit, celui que nous proposons est susceptible d'exercer un effet sur son objet. En regroupant sous une même appellation des recherches diversifiées, il pourrait contribuer à unifier et faire exister le mouvement. En pointant les tensions actuelles autour d'une standardisation des approches socio-écologiques, il

pourrait, au contraire, contribuer à sa fragmentation. Quoi qu'il en soit, il ne constituera qu'une ressource parmi d'autres pour les acteurs de cette histoire, s'ils viennent à le mobiliser. Le cas échéant, nous espérons qu'il participera à favoriser leur réflexivité : l'enjeu est fondamental, à l'heure où les chercheurs sont de plus en plus encouragés à devenir des spécialistes de la résolution des problèmes. Nous espérons aussi que d'autres travaux viendront éclairer la dynamique de la RIFE dans d'autres pays et permettront d'analyser la façon dont des événements et des processus nationaux et internationaux se sont combinés pour conduire à des dynamiques d'émergence à chaque fois singulières.

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