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Abstract

Sustainability science is an emerging scientific field that aims to address the environmental problems facing contemporary societies. This article explores the relationship between the wickedness level of these problems and the research stances and methods scientists use to address them. It reviews a sample of 17 research projects addressing diversely wicked environmental problems, all of which originate in the same distributed network of research infrastructures in France. We distinguished between the political complexity and the cognitive complexity of the problems addressed and between the collaborative pluralism and the methodological pluralism of the projects. While we expected overall positive relationships between these paired aspects, we found positive but, at best, weakly significant correlations between cognitive complexity and political complexity, between methodological pluralism and collaborative pluralism, and between problem wickedness and project pluralism. We identified three research stances: a correspondence between project pluralism and problem complexity; reductionism, when methodological or collaborative pluralism was lower than expected; and integrationism, in the opposite case. We found that project pluralism tended to increase and the latitude of choice between research stances tended to decrease according to problem wickedness. Addressing highly wicked problems thus seems to significantly constrain research stances and methods. Our empirical data also suggested the possible influences of project duration and leadership on project pluralism. This article thus clarifies the factors that influence how sustainability science is concretely carried out and the constraints that addressing highly wicked problems places on scientists.

Keywords: wicked problems, methodological pluralism, collaborative pluralism, transdisciplinary research, research stances and methods, LTSER

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: 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.

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: 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: 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 methods[1], 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. 2022). 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. 2022: 52). Over the last decade, various lists and typologies of methods targeted at newcomers to the field (e.g. Biggs et al. 2022[2]) 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., 2022).

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 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

[1] 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.

[2] 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

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.

Methods

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 practices[3]. 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.

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: 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

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

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 1).

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.

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 2). 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.

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. Biggs et al. (2022) 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.

Results

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 Fig. 1). 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 (Fig. 1). 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).

Project pluralism

Again as expected, we found an overall positive – and weakly significant (r=0.49, p=0.04, n=17; Fig. 2) – 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).

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 (Figs. 1, 2), 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 (Fig. 3a) We found an overall tendency toward positive correlation, which was marginally significant (r=0.41; p=0.08, n=17; see Fig. 3a), 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 (Fig. 3a). 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 Fig. 3) 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 (Fig. 3b).

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 4). We found no project with methodological integrationism and collaborative reductionism or vice versa.

Discussion

Sustainability science has been presented as ‘a different kind of science’ (Kates 2011: 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.

Problem wickedness

The dispersion of the level of correspondence between problem wickedness and project pluralism (Fig. 3a) 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 Fig 3a), which may have several explanations. Although strongly advocated in sustainability science (Poteete et al. 2010; Biggs et al. 2022), 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 4). 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).

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. 2022), 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.

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 Wehrden[4] rather than that proposed by Biggs et al. (2022). However, there is significant 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).

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

[4] See https://sustainabilitymethods.org/index.php/Methods

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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Declaration of Competing Interest

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

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