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► To cite this version:

Clémence Moreau, Marylise Cottet, Anne Rivière-Honegger, Adeline François, André Evette. Nature-based solutions (NbS): A management paradigm shift in practitioners' perspectives on riverbank soil bioengineering. *Journal of Environmental Management*, 2022, 308, pp.1-28. 10.1016/j.jenvman.2022.114638 . hal-03563134

HAL Id: hal-03563134

<https://hal.science/hal-03563134>

Submitted on 25 Aug 2022

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Nature-based Solutions (NbS): a management paradigm shift in practitioners' perspectives on riverbank soil bioengineering

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Version révisée de l'article avant acceptation par la revue « Journal of environmental management »

Référence de l'article publié : Moreau, C., Cottet, M., Rivière-Honegger, A., François, A., & Evette, A. (2022). Nature-based solutions (NbS): A management paradigm shift in practitioners' perspectives on riverbank soil bioengineering. *Journal of Environmental Management*, 308, 114638.

<https://doi.org/10.1016/j.jenvman.2022.114638>

Abstract: Nature-based Solutions (NbS) are promoted as practical and theoretical solutions that simultaneously provide human well-being and biodiversity benefits. One example is soil bioengineering using construction techniques based on living vegetation, and is frequently used for riverbank stabilization, flood protection, and erosion control. Compared with civil engineering, NbS offer many advantages such as cost reduction, limited impact on the environment, and production of ecosystem services. However, their use is still marginal for riverbank control, especially in urban areas. In this paper, we focus on soil bioengineering techniques for riverbank protection in an urban context from the practitioners' perspective. We question to what extent NbS require a shift in management paradigm. We used qualitative methods to interview 17 practitioners working in the Rhone Alps basin (France). Our results reveal that switching from civil engineering to soil bioengineering is not only a technical change, but also requires a shift from a “predict and control” paradigm to an “adaptive management” paradigm because of three major reasons. First, soil bioengineering techniques require redefinition of the performance of engineering structures with the inclusion of ecological and social dimensions. Second, the adoption of soil bioengineering

techniques requires that practitioners, elected people and inhabitants reconsider risk sharing and acceptance. Third, the techniques require practitioners to adopt a new posture, with new soft skills (humility and daring) and a new collective organization (collective feedback). Finally, we identify three levers for a broader use of such techniques: (i) systematic assessment of the ecological, economical, and social benefits of such techniques; (ii) improving risk acceptance and sharing; (iii) fostering of social learning among practitioners through collective or technical feedback.

Keywords: Soil bioengineering techniques; nature-based solutions; riverbank erosion control; river management; paradigm shift; practitioners' perceptions

1. Introduction

1.1. An emerging technique with many advantages

Ecological engineering is defined as “the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both” (Mitsch & Jørgensen, 2003). Among ecological engineering solutions, soil bioengineering utilizes living plant parts to provide soil reinforcement and prevent surface erosion (Tuttle et al., 1992) and can be used as an alternative to civil engineering for riverbank stabilization, flood protection, and erosion control (Bonin et al., 2013; Rey, 2018). Whereas “hard techniques” use inert materials (concrete, metal, rock, wire mesh), the effectiveness of “soft techniques” is based on the mechanical, physiological, and biological properties of living plants and the observation and imitation of natural models (Rey, 2018). The first traces of the use of living plants for riverbank stabilization date back to the first century BC, but soil bioengineering was gradually abandoned in the middle of the twentieth century because of mechanization and the development of civil engineering techniques after the Second World War (Lachat, 1998 ; Evette et al., 2009;). Since the 1970's, the ancient soft techniques have re-emerged in both engineering and scientific fields in response to the limitations of some civil engineering

structures (e.g., negative impacts on riparian ecosystem functions, transfer of erosion problems downstream) (Li & Eddleman, 2002).

Compared with hydraulic infrastructures based on civil engineering, soil bioengineering offers many advantages such as cost reduction, limited impact on the environment, and production of a diversity of ecosystem services (ES) (Evette & Frossard, 2009). Soil bioengineering is designed to mimic the natural functions of rivers and to maintain or restore biodiversity (Adam & Lachat, 2008; Cavaille et al., 2013; Schmitt et al., 2018, Janssen et al. 2021). Vegetated riverbanks provide numerous ES to human beings, such as regulation ES (erosion control, protection against flooding, maintenance of physicochemical water quality, carbon storage, heat island limitation, and climate change mitigation), cultural ES (aesthetic values of landscapes, and recreational activities), and provisioning ES (plant material production, e.g. for basketry) (Adam & Lachat, 2008; Nicolas et al., 2014; Symmank et al., 2020).

1.2. Nature-based solutions may be challenging in urban areas

By virtue of the various services they provide from nature, soil bioengineering techniques belong within the definition of 'Nature Based Solutions (NbS)', which are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems while simultaneously providing human well-being and biodiversity benefits (Cohen-Schacham et al., 2016; Fernandes & Guiomar, 2018). The NbS concept has quickly found acceptance in the academic field and in political agenda (Cousins, 2021). Indeed, this concept offers an integrative and systemic approach that goes beyond the vision of short-term economic gains and effectiveness, by considering simultaneously the social, environmental and economic dimensions; which implies finding win-win options or trade-offs alternatives by assessing the associated costs, benefits, impacts and risks of each solution (Nesshöver et al., 2017). The development of this concept within the scientific community will require specification of the added value of this concept in comparison with other existing concepts, and the integration of the experience of all relevant stakeholders (Nesshöver et al., 2017). Previous studies have focused on the implementation of NbS in cities (Kabisch et al., 2016). Regarding urban

ivers, there is a contrast between the opportunities offered by NbS to respond to an increasing demand for greening of cities, and the omnipresence of issues and constraints due to the urban context (Bonin et al., 2013; Warot et al., 2020). As a result, soil bioengineering techniques seem particularly necessary in urban river management, but are notably complex to implement.

There is an agreement regarding the role of NBS in addressing environmental challenges in urban areas (Castellar et al 2021). Recent analyses have shown that soil bioengineering techniques as Nature Based Solutions can provide innovative solutions which should resist the effects of climate change in terms of provisions of biodiversity on land and in water (Mickovski, 2021) and make more efficient and more circular management of water streams (Langergraber et al., 2021). But soil bioengineering still plays a marginal role in river management (Symmank et al., 2020). References to soil bioengineering works for riverbank protection in urban areas remain rare. To our knowledge, there is no quantitative study comparing the relative proportions of bioengineering or civil engineering on the banks of urban watercourses. Scientific and technical reports mostly concern case studies describing the technical aspects, their advantages, and costs. Beyond technical recommendations, they also reveal key challenges such as the short-term vulnerability of installations, limited site access, short in-water work window, and the need for community participation (Morris & Moses, 1999; Simon & Steinemann, 2000; Sotir, 2001).

1.3. More than a technical change, a paradigm shift?

Several practical challenges for the broader adoption of the use of NbS still exist: adaptation of economic subsidy schemes, consideration of larger temporal and spatial scales, integration of diverse values by both investors, practitioners and community stakeholders, and development of ecological innovations (Maes & Jacobs, 2017). Another challenge relates to the management paradigm. Indeed, everyday management practices — making use of soil bioengineering or civil engineering — are directly determined by management paradigms, i.e., “a set of basic assumptions about the nature of the system to be managed,

the goals of managing the system, and the ways in which these goals can be achieved” (Pahl-Wostl et al., 2011). Management paradigms enable epistemological aspects to be articulated and case-specific solution strategies to be developed: they help define a problem (by distinguishing constants outside the control of practitioners, and design variables that they are able to change), make a diagnosis, and propose an action (Pahl-Wostl et al., 2011; El-Zein & Hedemann, 2016).

Shifting from hard to soft engineering may not be a simple technical change but an in-depth change in professional practices, both at individual and collective levels, corresponding to what has been theorized — in the field of science innovation — as a paradigm shift (Kuhn, 1962). This theory argues that science does not progress via a linear accumulation of knowledge, but also via periodic revolutions, in which the basic concepts and experimental practices of a scientific discipline can change abruptly. Several studies have already used this concept of a paradigm shift to discuss recent changes in urban river management. For example, Rode (2010) analyzed the evolution of public policies on urban flood hazard, and showed a shift from a technical paradigm to an environmental paradigm. Bark et al. (2021) conducted a survey on stakeholders’ perceptions of natural flood management and concluded that the acceptability of such techniques requires a paradigm shift to “work with nature”. Pahl-Wostl et al. (2011) focused on the water management sector as a whole, including science, policy, and management, and showed that the need for better inclusion of complexity and human dimensions in water management is now largely recognized, but that there is a lacuna in the translation of political rhetoric into operational changes. In the continuity of such thinking, the shift from civil engineering to soil bioengineering for the management of riverbank erosion could be anchored in a paradigm shift.

1.4. Objective

The objective of this paper was to determine if civil engineering and soil bioengineering for the riverbank management of urban streams refer to the same paradigm, or if adopting soil bioengineering practices requires a paradigm shift, which could explain why the use of soil

bioengineering still remains marginal today. Therefore, we wished to understand how management professionals approach bank erosion (problem definition, diagnosis, and proposition of action), and with this aim, we conducted a survey focused on soil bioengineering as a professional sector using semi-directive interviews with all the categories of practitioners who intervene at different steps of the riverbank protection process (innovation, design and planning, implementation, and maintenance). We focused on practitioners working in urban areas located in the Rhone Alps basin (France).

2. Materials and methods

Our approach was hypothetico-deductive. We first posited that five potential drivers could influence adoption of soil bioengineering techniques: perceived technical performance of such technique; measured and perceived ES; drivers linked to urban context; drivers linked to professional sector, practices and skills of river managers; rules, regulations and financial contexts. These hypotheses were refined from a literature review. We then designed the survey protocol.

2.1. Design of a qualitative survey. We designed a qualitative survey protocol based on online individual semi-structured interviews (Janghorban et al., 2014). We first established a panel of persons whom we wanted to interview to provide an overview of people who intervene at the various steps of the lifecycle of a riverbank structure intended for protection against erosion (Figure 1).

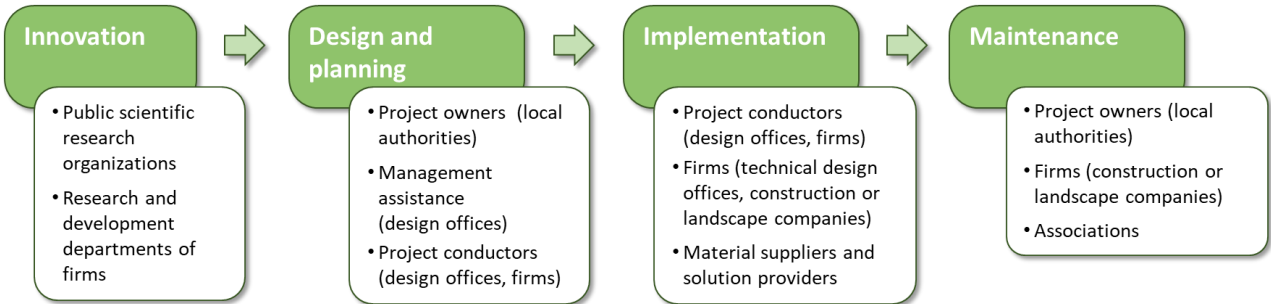


Figure 1: Practitioners involved in the life cycle of riverbank erosion control structures

The next step was to design an interview grid. The questions were open-ended, and their order could be changed from one interview to another, to allow the flow of the interviewee's thoughts and comments to be followed in a manner as close as possible to a natural conversation (Olivier de Sardan, 2004). Four main topics were discussed during the interviews:

1. General presentation: professional background, main missions, employer
2. Riverbank protection techniques: techniques used, persons involved in technical choices, criteria used to define the performance of structures, perceived ecosystem services provided by riverbank structures
3. Drivers influencing technical choices (following the five previously mentioned hypotheses)
4. Conclusion and feedback on the online protocol

2.2. Sample recruitment

Conducting of the interviews. First, we contacted people (by phone or email) from the core group of the project (project team, partners), then gradually enlarged our professional list of contacts using the snowball sampling technique (i.e., asking interviewees to suggest other people we could contact). In total, we contacted 25 people, 17 of whom agreed to participate, while one person refused because of lack of time and 7 did not answer.

Our final panel represents the variety of the targeted practitioners, with six people classified as project owners, six people as project conductors, two people from associations, one from a company, one from a scientific organization, and one from a funder. The panel contained far more men than women (14/17), but we do not know if this is representative of the gender distribution within the sector.

2.3. Conducting of the interviews

Interviews were conducted from May to November 2020, and lasted for 1 hour 20 minutes on average (from 1 to 2 hours). Because of the sanitary context caused by the Covid-19

pandemic, we conducted the interviews online using videoconferencing software and following online qualitative interview principles (Janghorban et al., 2014). At the end of each interview, we assessed the impact of the online techniques on our survey. Respondents answered that this protocol had no impact (n=10) or limited impact (i.e. conviviality, possibility to give more details, to share document or to show study site; n=7). We thus considered that the online methods were not an important bias affecting our study. On the basis of a document sent before the interview, the interviewees gave their oral consent for the recording of the interview and communication of the anonymized analysis.

We conducted the interviews in tandem, following the principles of semi-structured interviews, particularly empathetic listening, triangulation, iteration, and saturation (Olivier de Sardan, 2004).

2.3. Analysis

The interviews were fully transcribed. We conducted our analysis following three principles.

First, according to the hypothetico-deductive approach we adopted, our analysis grid was built on the five previously mentioned hypotheses.

Secondly, we followed the principles of the thematic analysis, defined as “a method for identifying, analyzing and reporting patterns (themes) within data” (Braun & Clarke, 2006). According to the methodological standards, we classified portions of discourse held in the interviews within different themes, following the hypotheses. This enables to identify how themes are repeated from an interview to another, how they overlap, join, contradict or complement (Paillé & Mucchielli, 2012). The analysis grid contained three columns: the ‘key idea’, which sums up a relevant idea regarding our hypotheses; ‘verbatim’ related to this idea; and ‘scientific literature’ discussing this idea.

Third, we followed an iterative process. The constant dialog between theoretical and ground truth aspects enriched the analysis, as well as allowing the questions to be refined for the next interview, with more depth for the most interesting points. Some results which are

presented in this article derived from our hypotheses (e.g., the professional posture), others emerged during the interviews and analysis (e.g., risks acceptance and sharing).

We discuss later the strengths and limitations of these methodological choices (see 4.4.).

3. Results

Analysis of the interviews revealed three specific features of soil bioengineering techniques in comparison with civil engineering: a redefinition of performance, a new risk acceptance, and a specific posture for practitioners. These features constitute the essence of the soil bioengineering approach, but can also explain why the use of the techniques remains marginal in urban river management.

3.1. Redefining the performance of riverbank structures

The performance of a technique is defined as its ability to reach a predefined objective with no or low negative outputs. The main objective of soil bioengineering and civil engineering structures remains the same: controlling bank erosion, and thus protecting goods and persons. However, according to practitioners, it is not possible to compare the two techniques with strictly equivalent criterion. This is why a new characterization of mechanical, ecological, and social performance of riverbank structures is advocated.

First, assessment of the performance of soil bioengineering structures requires temporal and spatial scale shifts. Regarding the temporal dimension, respondents affirmed that while the performance of civil engineering is optimal immediately after installation, the performance of soil bioengineering structures is low at the beginning but increases over time. Indeed, plants need to develop their roots and branches to perform their structural function. Regarding the spatial dimension, civil engineering structures tend to limit erosion in close proximity to the site of concern, without taking into account the whole dynamics of a river. To the contrary, soil bioengineering is more relevant at a larger scale, with consideration of the functioning of the fluvial hydrosystem (e.g., it can dissipate river energy; Table 1 A1). This is why its performance should be assessed not at the scale of the issues to be protected (e.g., the

urban area), but for the river as a whole. To conclude, regarding the objective of erosion control, soil bioengineering might appear to show less performance locally and over short-time scales, but offers many advantages if the scales being considered are expanded.

In addition to these mechanical aspects, soil bioengineering offers ecological and social benefits. From an ecological point of view, soil bioengineering is much less traumatic for ecosystems. During the work phase, soil bioengineering requires more manual labor and less heavy machinery than civil engineering, and thus generates less disturbance on ecosystems (Table 1 A2). The plants used for soil bioengineering are collected locally as much as possible, or raised in a nursery by the project owners themselves (Table 1 A3). Moreover, soil bioengineering structures provide many ES such as biodiversity, carbon storage, aesthetic and landscape value, quality of life and recreational uses, urban heat island mitigation, and invasive species control. A further benefit of soil bioengineering structures is their integration (also called transparency) within the landscape, both from a visual and ecological point of view (Table 1 A4). There appears to be a consensus on this among practitioners (Table 1 A5), but it is also perceived by public representatives and inhabitants. Regarding the social performance of vegetated riverbanks, practitioners converge on the idea that soil bioengineering works redefine social uses. Riverbanks may well have been previously considered as marginal spaces with undesirable or illegal uses (e.g., drug or alcohol abuse, waste dumping), and may then become more socially valuable after bioengineering works (e.g., for family walks, outdoor sports; Table 1 A6). Opinions on the aesthetic value of soil bioengineering banks diverge: some managers think that soil bioengineering techniques are perceived positively as they are associated with the greening of cities (Table 1 A7), others argue that inhabitants consider such banks to be poorly maintained or just do not notice soil bioengineering structures (Table 1 A8), and yet other managers mention that they do not know how these banks are perceived and used by inhabitants (Table 1 A9).

The ecological and social dimensions of performance remain poorly measured, and several reasons are given for this. First, there is no standardized protocol for assessing the ES provided by vegetated banks (Table 1 A10). Second, assessment is rarely included in the funding of projects, and it is not considered a priority by funders, local authorities, or design offices (Table 1 A11). The result is a paradoxical situation, with there being a consensus on the ecological and social value of vegetated banks, but few field assessments to support this consensus.

To sum up, according to the interviewees, riverbank structures have not only an erosion control function, but also play roles in the restoration of ecosystems and human well-being, which is why stakeholders advocate for a redefinition of performance to be assessed at larger spatial and temporal scales, and according to three dimensions: mechanical, ecological, and social dimensions. Currently, the absence of such approaches minimizes the realized advantages of soil bioengineering techniques.

| A. Quotes about performance of soil bioengineering structures¹ | | Interviewee² |
|--|--|--|
| A1 | The Gier is a very powerful river, with strong variations in flow. As a result, it tends to make its own channel, and needs sediments to dissipate its energy. Therefore, if we prevent it from moving in one place with the use of hard techniques, it will scrape the opposite bank. Vegetation is naturally very present, and as a result, mixed or soil bioengineering techniques come a little bit by themselves. | Interviewee 13 Project owner, Local |
| A2 | Soil bioengineering companies work with a light touch, they hardly use mechanical excavators. | Interviewee 17 Scientist, International |
| A3 | When we create riprap, very often the quarries used are not adjacent, and costs and impacts of transport are therefore involved. In soil bioengineering, what we try to do is to take local samples. We also have a client who is going to create their own nursery; the aim is not to get plantings from the other end of France, which are not from the area. | Interviewee 7 Project conductor Regional |
| A4 | I speak of ecological transparency. This means that the structure is integrated and no longer visible, and we find similar species | Interviewee 5 Project |

¹ Repetitions, interjections, and grammatical mistakes have been removed to improve readability. Translations are from the original French statements.

² Statements are anonymised, but we indicate the number of the interviewee, his/her position, and the scale of the action.

| | | |
|------------|---|---|
| | assemblages present in similar environments upstream and downstream. | conductor, National |
| A5 | We don't need to convince the project managers of the usefulness of soil bioengineering, that's a debate we never have! | Interviewee 6 Project conductor Regional |
| A6 | It used to be a hangout for dope smokers and beer drinkers. Now, it has become everyone's favorite stroll. Yes, there really has been a big reappropriation of this site. | Interviewee 15 Project owner, Local |
| A7 | I've always had positive feedback from residents: it's beautiful, it's welcoming, it's more accessible, with a pathway, benches, frogs, birds. We saw this during the lockdown. | Interviewee 6 Project conductor, Regional |
| A8 | You never hear "It's good what you're doing" very much. Maybe because the work very quickly becomes unnoticeable because it looks very natural; therefore, people think it's part of the scenery. Furthermore, people almost prefer a mineral bank to a natural bank, which seems less maintained and a bit messier. It's also true that in France we have a French garden culture: things have to be very clean, very smooth, very straight. | Interviewee 14 Project owner, Local |
| A9 | I'm not sure if people are passing through there more since the soil bioengineering work, I just don't know. In any case, I don't have the data to confirm it. | Interviewee 16 Project owner, Local |
| A10 | On performance indicators — That is a very good question, there is very little on them in the literature, almost nothing. | Interviewee 17 Scientific, International |
| A11 | In the management of aquatic environments, monitoring is somewhat the poor relation. Currently, there is not always a need for a systematic follow-up, and there may be new technologies set up, which are sometimes much too time consuming and are not always adapted to the project objective. | Interviewee 2 Association, Regional |

Table 1: Eleven quotes about the performance of soil bioengineering structures attained from the interviews

3.2. Accepting and sharing risks

Compared with civil engineering, soil bioengineering techniques are perceived as being more risky. In particular, the practitioners reported in their interviews concerns expressed by elected representatives and inhabitants. Thus, the adoption of such techniques requires both reducing the perception of risk and accepting a higher level of risk, especially in the first years of riverbank structures.

Practitioners consider that soil bioengineering techniques are reliable once the plants reach a certain stage of development. They admit that predicting the performance of soil bioengineering techniques with a theoretical approach is almost impossible because of the complexity of interactions between plants, soil, and water (Table 2 B1). However, they stated that there are sufficient technical manuals, hindsight, and feedback to be able to size structures and predict their performance with an empirical approach (Table 2 B2). According to the interviewees, public representatives and inhabitants tend to perceive soil bioengineering techniques as being more risky, because they find the concrete used in civil engineering is reassuring. One of the missions of soil bioengineering practitioners is thus to convince project owners and users of the viability and reliability of such techniques (Table 2 B3).

Practitioners may adopt several strategies to improve the public's trust in soil bioengineering. Sometimes, soil bioengineering structures are implemented in an area with no potential loss, or on short lengths, to test their efficiency (Table 2 B4). This is made possible because the techniques are flexible and low cost. With such a trial-and-error approach, practitioners accumulate knowledge and expertise, and they can refine the techniques and thus reduce the risk (Table 2 B5). Moreover, such trials can be used as show-cases to convince local authority and public representatives (Table 2 B6). However, even with the use of these strategies, the risk of partial failure is real during the first years after installation. Adopting soil bioengineering techniques thus requires increasing the level of risk acceptance (Table 2 B7).

An important question then arises over who takes responsibility; if we have to accept taking risks, who should take them? Legally, the principal contractor or construction company must offer a guarantee for plant development for the first years after installation (generally three years). However, this guarantee applies only for small events and some interviewees note legal uncertainties in relation to the guarantee (Table 2 B8). Negotiations between the project owner and project conductor around the issue of responsibility can lead to oversizing of structures, because project contractors want to limit their financial and legal risk taking (Table

2 B9). This is why practitioners ask for better risk sharing between professionals (Table 2 B10).

All in all, low risk acceptance is a major brake on the wider use of soil bioengineering, especially in urban areas where potential losses are numerous. According to practitioners, inhabitants and public representatives trust less in soil bioengineering techniques than in civil engineering. Practitioners judge these techniques as reliable, but they admit that the risk is higher during the first years, which raises the issue of legal and financial responsibility. The absence of a clear legal framework on these issues can be discouraging for both project owners and project conductors.

| B. Quotes about risk acceptance | | |
|--|--|---|
| B1 | We are working with living things, so we are working on something that is in fact multi-scalar in the sense of hierarchical theory. We work with living models that are not quantifiable, or at least they cannot be modeled in a productive way. | Interviewee 17 Scientific, International |
| B2 | There are a lot of books, research on the techniques, case studies, feedback. What we perhaps lack is feedback from ten or fifteen years of experience with fairly ambitious soil bioengineering techniques. But today, we have what we need in terms of size calculations. | Interviewee 9 Project conductor, Regional |
| B3 | At the beginning, public officials were rather reluctant to use soil bioengineering techniques. There was a strong culture of rockfill in our watershed. Then, gradually, thanks to post-flood works, we were able to use soil bioengineering techniques; and as we had a succession of floods afterwards, the public officials were able to see that it finally held up well. | Interviewee 14 Project owner Local |
| B4 | There is a brushwood barrier of 4–5 m length that has gone. We'll let it go, we'll see how it evolves, we don't have any issues in the immediate vicinity, we're not at the foot of the dike, so we can let the river work as it wishes. | Interviewee 16 Project owner, Local |
| B5 | One technician wanted to try the row of stakes trick. It's a bit experimental. I said "yes, it won't cost us much". We provided the stakes, it didn't cost us anything except for a bit of manpower from the Green Brigade ³ . In this way, little by little, we learned about solid transport, reserve capacity, the implantation of brushwood barriers... | Interviewee 10 Project owner, Local |
| B6 | The great difficulty for technicians working with local and regional authorities is to convince local residents, partners, agricultural bodies or local farmers, and public officials, that banks can be protected without necessarily using excessive materials. But... it's spreading, there are | Interviewee 2 Association, Regional |

| | | |
|------------|--|--|
| | quite a few showcase sites and pilot projects that have been completed. | |
| B7 | With soil bioengineering, in the first years the stabilization and maintenance effects on the banks are very limited, and this is why it is also a major decision for the project owner to say: "We are going for soil bioengineering". Even if we know that at the beginning we are taking a risk, it can look like a good bet. So, this is also where the acceptance phase takes place. | Interviewee 8 Project conductor, Regional |
| B8 | Normally, there is a guarantee by the company for the first three years, but this is for very small-scale events. Therefore, it is not used very much because it is complicated; it can be huge sums if there is a flood for example. This is a major point that is still not accepted by anyone, because no one wants to take this responsibility. Therefore, from a regulatory point of view, it is something that is a bit missing. | Interviewee 8 Project conductor, Regional |
| B9 | That's really the sticking point. I will let you imagine the kind of discussion... the client asks his architect to put in place a less resistant technique, while telling him: "You will still maintain responsibility if it ever goes wrong". In the end, despite the balance of power, even if the client is the river authority, it is often the designer who has the last word. This leads to over-dimensioning of the work. | Interviewee 15 Project owner Local |
| B10 | There is a sensitive subject: the problem of risk sharing. How can we discuss these issues with the project owners? What do they expect from us? What do we expect from them, as project managers? How do we share this? Because very often, we have the impression that we are each in our own corner. | Interviewee 9 Project conductor, Regional |

Table 2: Ten quotes about risk acceptance from the interviews

3.3. Adopting a humble and audacious posture

Even if there is competition or tension between practitioners of soil bioengineering, they share a common vision on the posture inherent to the soil bioengineering approach.

The French soil bioengineering sector is new and recently structured. It is composed of associations, project owners, small firms specializing in soil bioengineering, and big firms that have recently opened a branch specializing in green techniques. Tensions can exist between local and national firms, or between big/generalist and small/specialized firms (Table 3 C1). These tensions arise particularly during the tender process (Table 3 C2). Negotiations also exist between project owners and principal contractors, around the previously mentioned issues of risk sharing and expertise. Indeed, sometimes the project owner and project contractor can disagree on technical aspects, and more generally, they may compete around their status as "the expert" (Table 3 C3). Tensions can also exist

between different firms working on the same project, especially between civil and soil bioengineering firms (Table 3 C4), or even within an institution (Table 3 C5).

Despite these tensions, practitioners share a common vision of their work, and their profiles show certain similarities. First, they have a multidisciplinary profile combining skills in ecology and botany, hydrology, hydraulics, and engineering, but also soft skills such as nature observation or the ability to engage in dialogue with numerous and various stakeholders. Second, they all highlight the importance of continuous training based mainly on empirical experience (more than on initial training) for the acquisition of knowledge and skills on soil bioengineering (Table 3 C6). They are also prone to share their experience and exchange information between peers. Collective exchanges, for example technical days set up by the association ARRAA⁴, are mentioned repeatedly in the interviews. These exchanges enable practitioners to share their experience of both successes and failures, and encourage them to be audacious and humble (Table 3 C7). These two human qualities recur in the speeches of the interviewees; They allow professionals to question themselves and to take steps backward if necessary, which is essential when starting a trial and error process and when taking risks (Table 3 C8, C9).

Another recurring point in the practitioners' discourses is the convergence between professional and personal ethics. Two kinds of professionals coexist. The majority of interviewees were specialized in soil bioengineering techniques. They were graduates in ecology, hydrology, or engineering with an environmental component. For them, the practice of soil bioengineering is a way to combine human development and conservation (Table 3 C10). For others, working in local authorities or construction firms, soil bioengineering is only a part of their activities. Their discourses highlight the satisfaction they feel from soil bioengineering projects in comparison with other projects (Table 3 C11). For all interviewees, soil bioengineering techniques contribute to the common good (Table 3 C12), and they are sometimes seen as a mission (Table 3 C13).

⁴ Rhône Alps Auvergne River Association

Without ignoring the tensions that can exist between practitioners, there is a shared vision and a community of practice, which is a real lever for the broader use of soil bioengineering techniques.

| C. Quotes about attitudes and viewpoints | | |
|---|--|--|
| C1 | There are many companies, I will criticize certain firms that also specialize in soil bioengineering but that are national in scope, so what guarantees do they bring? When the workforce comes from the other end of France, we know that once they have finished planting, they will not return to water the plants! | Interviewee 3 Construction company, Regional |
| C2 | The public procurement procedure is based on an analysis of the offers. You give a mark to the candidates on the basis of the technical value of the offer and the price. If you have a price that is more or less the same between two companies and you have a technical brief from one side that is very well polished because it is a large group, whereas the other side is a small company with a technical brief that is a little rougher... you award the contract to the large group, although once the shovels are on the ground, it is not the same at all! | Interviewee 15 Project owner, Local |
| C3 | Sometimes, I argue with clients and project leaders; I find them too interventionist. But after a while, I have no other option than to let go, I am only a project conductor. | Interviewee 6 Project conductor, Regional |
| C4 | We are working by allotment, that is to say that we have really separated the civil engineering and plant engineering sections. We require co-activity between the companies, which is not necessarily obvious to them. The installation of bioengineering techniques takes time, and moreover it is done by hand; it is not as efficient as a mechanical shovel... In terms of relations with the companies, it was complicated, they were saying: "You are delaying me". | Interviewee 11 Project owner, Local |
| C5 | We'll spend a lot of time setting up processes, issuing letters of instruction, all because we're in isolation. The bigger the structure, the more you sectorize... | Interviewee 12 Project owner, Local |
| C6 | My knowledge of soil bioengineering... I was trained as an agricultural technician, so through that and then afterwards in my studies, and by the fact that I have always been interested in the environment. I was also able to benefit from training organized by the association of environmental technicians, in partnership with an engineering office. Then, we learned by doing things, knowing that it's not a very complex technique... It's common sense. | Interviewee 14 Project owner, Local |
| C7 | It is a personality trait of our profession. ARRAA is a witness to this, the tip of the iceberg. It's this sort of network, which I don't know of in any other profession, this network around experiences, which says: "Here, | Interviewee 15 Project owner, |

| | | |
|------------|--|---|
| | guys, I did this at home. My river is like this. I did this, it worked.” That doesn't exist elsewhere. | Local |
| C8 | If I had to give only one piece of advice, it would be to dare; simply, to go and dare to take risks, dare to do and test. | Interviewee 2 Association, Regional |
| C9 | What's missing is the questioning and the humility. It's being able to say: “We think it will evolve like this”. And if we're wrong, keeping open the possibility of coming back to intervene afterwards. | Interviewee 15 Project owner Local |
| C10 | Certainly, the soil bioengineering aspect, and more globally restoration, are for me a big “plus” of the job. We try to do some good, even if it is human intervention. | Interviewee 8 Project conductor, Regional |
| C11 | Me, in my profession as a builder, I am one of the men of the shadows, you can't see what we are doing. For example, when we work on drinking water infrastructure, at the end of the work the street is often in a worse state than before. When I work on the river, it's magnificent... Through earthworks, rockfill, and vegetation, we have created a kind of alchemy of minerals, plants, and so on. | Interviewee 3 Construction company, Regional |
| C12 | Me, I do this job because there is soil bioengineering. I know that if I am asked to lay miles of riprap or sheet piling on a river, I will not do it, it is not my job. I'm here to work on the environment, on ecology. I don't want to put my knowledge into something that is not going in the right direction. | Interviewee 12 Project owner, Local |
| C13 | Me, I think it's great to be able to promote these bioengineering techniques. It's a sort of small fight, without great ambition, but yes, it's part of a positive image that I can have of my job. | Interviewee 11 Project owner, Local |

Table 3: Thirteen quotes about attitudes and viewpoints from the interviews

4. Discussion

The objective of this study was to determine to what extent the adoption of soil bioengineering techniques requires a paradigm shift. According to Kuhn's definition and previous works on management paradigms (Kuhn, 1962; Pahl-Wostl et al., 2011; Halbe et al., 2015;;), we identified three conditions for the existence of a management paradigm shift: (i) the paradigm should be shared within the practicing community; (ii) the paradigm should help to articulate epistemological aspects and case-specific solution strategies; (iii) the

emergence of this paradigm should conflict with the previous or dominant paradigm in the field.

4.1. The existence of a community of practice

According to Kuhn, a paradigm is shared by an epistemic community, with a consensus on what is to be observed and analyzed (Kuhn, 1962). As we focus here on the practitioners' perspective, we would rather refer to a 'community of practice', i.e. a group of people "who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Wenger, 1999).

Doré and al. (2014) questioned the existence of a common vision that can apply to the soil bioengineering sector. They identified three issues on which actors have diverging positions: the semantic field (tension between engineering and ecology), the epistemological field (debates on the relationship between science and action, with two poles, conservationists and utilitarian), and the ethical field (non-intervention or control of ecosystems). According to the authors, it is difficult to consider there being a community of values, but this does not hinder the progress of projects and collaboration between practitioners (Doré et al., 2014)

Our findings show that despite some tensions or competition, practitioners converge on a shared vision of their work: they all have a multidisciplinary profile, they agree on the importance of continuous training, they share a humble and audacious posture towards natural dynamics, and they like the convergence between personal and professional ethics. The presence of an arena for collective exchanges (e.g., regional river practitioners' professional network) corroborates the existence of a community of practice. The diverging positions cited by Doré and al. (2014) do not appear in our results. This may be because we focused on anthropic contexts (i.e., urban rivers where non-intervention is not an option), and practitioners share a pragmatic vision of their work: according to them, soil bioengineering plays a part in the control of ecosystems, but it can also contribute to maintain or restore natural riverbank dynamics for the shared benefit of ecosystems and urban residents.

The existence of a community of practice is essential because it enables social learning, defined as “a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks” (Reed et al., 2010). Indeed, the adoption of soil bioengineering techniques requires not only technical learning, but also an in-depth change in the understanding shared within a group of practitioners.

4.2. A typical example of an “adaptive paradigm”

Several management paradigms coexist in natural resource management, and Halbe et al. (2015) identified five of them. The “predict and control paradigm” aims to minimize uncertainty and increase the predictability of responses to problems. The “adaptive paradigm” is based on experimentation, iteration, and resilience; its intention is to deal with high uncertainties through the continuous monitoring and revision of measures. The “economic paradigm” aims to reach economic viability. In the “traditional paradigm”, traditional knowledge and approaches are central. Finally, “the community involvement paradigm” is grounded in the participation of stakeholder groups.

Our analysis shows that practitioners refer to the adaptive paradigm. Indeed, all practitioners mention the importance of the trial-and-error process, and their strategies to limit — or at least learn — risks by testing techniques on low-potential loss situations, or by using low-cost techniques. During the peer-to-peer exchanges, practitioners can also acquire feedback on their trials and failures and exchange information on possible solutions. The two human qualities of audacity and humility are central to adaptive management, because they enable experimentation with new techniques, but also adaptation of them if necessary, following an iterative process.

4.3. Going beyond the “predict and control paradigm”

The “predict and control” paradigm is historically dominant in engineering. However, driven by rising sustainability issues, the “adaptive” and “community involvement” paradigms are

burgeoning (Halbe et al., 2015). Indeed, in the natural resource management field, problems are usually complex, messy, with a high level of uncertainty, and diverging opinions regarding the definition of the problem and potential solution strategies (Halbe et al., 2015). In this context, the problem-solving approach inherent in the “predict and control paradigm”, shows its limits: by circumscribing the problem, this approach favors limited-time horizons and focuses on technological aspects to the detriment of social and political dimensions (El-Zein & Hedemann, 2016).

Soil bioengineering techniques clearly break with the “predict and control” management paradigm. First, our results show that predicting the performance of soil bioengineering structures with a theoretical approach is complex, if not impossible, because of the complexity of interactions. Thus, the sizing of structures is mostly based on empirical approaches (Evette et al., 2018). Moreover, if soil bioengineering techniques fall within the control of the ecosystem (to the contrary of the doctrine of river mobility), they require a higher level of risk acceptance than needed for the use of civil engineering. Finally, soil bioengineering techniques lead to redefinition of performance, with the inclusion of social and ecological dimensions and upscaling of assessments. In this manner, they propose a new way of circumscribing the problem.

However, our study also shows that soil bioengineering techniques do not belong to the “community involvement paradigm”. Indeed, erosion control is still defined as a technical problem, with a low level of involvement of citizens, even though the necessity to include stakeholders has been noted in previous studies (Morris & Moses, 1999), and conclusive experiences have already been obtained in other cities (City of Calgary, 2017). Thus, the inclusion of public representatives and inhabitants in the choice of techniques could be a lever for improving risk acceptance, and therefore, the acceptance of soil bioengineering techniques. Indeed, in an urban context, the social stakes associated with nature in the city are tremendous: mental health, places for recreation, island heat mitigation (Andersson et al., 2014). From this perspective, the authors of this paper are currently conducting a

quantitative survey with inhabitants of an urban area to compare their social perceptions of vegetated and artificial riverbanks.

4.4. Strengths, limitations and perspectives of the study

From a theoretical point of view, this study filled a gap around the question of adaptive management of NbS, which is recommended for dealing with uncertainty, complexity and dynamics (Nesshöver et al., 2017). Our study gives concrete examples of opportunities and challenges of such management.

From a practical point of view, this study enables to raise recommendations at various scales: from local (implementing soil-bioengineering techniques in an area with no potential loss, or on short lengths, to convince elected people and inhabitants, communicating about success); to regional (giving institutional support to peer-to-peer exchanges), to national (clarifying the legal framework of risk sharing between professionals).

From a methodological point of view, the thematic analysis method that we chose was adapted to our exploratory research question: it offered a flexible tool, that provided a detailed account of the data and enabled us to identify a common thread that extend across the set of interviews, taking in account latent content (Vaismoradi, 2013). However, this method presents some limitations, especially because it offers few possibility to conduct a peer checking and systematic analysis (Vaismoradi, 2013). Research perspectives include deepening our analysis with a systematic analysis through content analysis and/or quantitative analysis with a broader panel.

5. Conclusion: the adoption of soil bioengineering techniques requires a paradigm shift

This article sheds light on the specifics of riverbank soil bioengineering techniques in an urban context. They can be summed up in one sentence that came up several times in the interviews: “We work with the living”. Indeed, while plants are considered as a potential

weakness in civil engineering structures, their structural role is central in soil bioengineering (Schiechtl et al., 1997).

More than a technical change, these techniques require a change in problem definition, its diagnosis, and the proposition of action. Working with the living implies redefining the definition of the performance of erosion control structures, renegotiating risk sharing and risk acceptance, and adopting a humble and audacious posture. All in all, soil bioengineering techniques fall within the “adaptive paradigm”, being based on experimentation and an iterative refinement of strategies. This breaks with the dominant paradigm of “predict and control”, and could explain why soil bioengineering techniques remain marginal in river management, despite their advantages, which are all the more in urban areas.

Our study enabled us to identify three levers for a broader use of soil bioengineering in cities: (i) more integrative assessment of the ecological, economic, and social benefits of such techniques that currently seem under-evaluated; (ii) a broader acceptance of risks, especially by elected people and inhabitants, and a better risk sharing between professionals, which requires a clarification of the legal framework; (iii) encouraging peer-to-peer exchanges and technical feedback on field experience to foster social learning among practitioners.

Acknowledgments: The authors would like to thank all the practitioners who took part in this study for their support; the Rhone Mediterranean Corse Water Basin Agency that funded this project, through the framework agreement with the ZABR (Zone Atelier Bassin du Rhône), *i.e.* the Rhone River LTER (Long-Term Ecological Research), and the Grand Lyon Metropolis (especially Hervé Caltran and Pauline Brémond).

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