Exploring transdisciplinary integration within a large research program: empirical lessons from four thematic synthesis processes

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ABSTRACT

What challenges do researchers face when leading transdisciplinary integration? We address this question by analyzing transdisciplinary integration within four thematic synthesis processes of the Swiss National Research Programme (NRP 61) on Sustainable Water Management. We adapt an existing analytical framework to compare transdisciplinary integration across the four synthesis processes regarding different types of generated knowledge (systems, target and transformation knowledge), different types of involved actors (core team, steering committee, advisory board, scientific experts and practice experts) and different levels of actor involvement (information, consultation and collaboration) at different stages of the processes. Based on a structured ex-post self-evaluation of the four synthesis processes, we present core challenges of transdisciplinary integration as perceived by core team members of the four synthesis processes and formulate empirically derived recommendations for designing and implementing future processes. We suggest that future synthesis processes should be conceptualized and initiated concurrently with all other individual research projects, involving a phasing-in stage where leaders conceptualize transdisciplinary integration, an intermediate stage of intense knowledge integration involving all relevant actor groups in a functional and dynamic way, and a final phasing out stage, where synthesis results are consolidated within the research program, validated by different actor groups and diffused to the target audiences. We argue that transdisciplinary integration requires professional competences, management skills and enough time. Finally, we suggest fostering Communities of Practice (COP) to link committed leaders and enable mutual learning processes beyond the boundaries of individual synthesis projects or research programs.

Key Words: *knowledge integration, actor involvement, transdisciplinary research, synthesis, sustainability, research management*

1. Introduction

Research activities are increasingly organized as large programs that involve a variety of individual projects and a diversity of actor groups (Adler et al., 2009). In the field of sustainability research, these programs are often expected to contribute to solving today's key sustainability problems (Hirsch Hadorn et al., 2006). Due to the complexity, ambiguity, and uncertainty of these problems, such programs often apply a transdisciplinary research approach (Jahn et al., 2012; König et al., 2013). This approach, which transcends disciplinary boundaries and bridges between science and practice, is intended to create a more comprehensive understanding of sustainability-related problems and develop practice-oriented solutions to deal with them (de Jong et al., 2016; Jahn et al., 2012; König et al., 2013; Pohl and Hirsch Hadorn, 2008; Polk, 2014).

An increasing number of such large research programs produce a synthesis, mainly toward the end of the program. The synthesis takes stock of individual project results and generates new knowledge by integrating results to establish novel (i.e., previously unrecognized) connections between them (Jahn et al., 2012; Specht et al., 2015). To contribute to societal problem solving, program synthesis often includes targeted products tailored to the specific knowledge needs of intended audiences (Campbell et al., 2015; Defila et al., 2006; Lang et al., 2012; Pohl and Hirsch Hadorn, 2007). Although "synthesis is increasingly recognized as an essential component of the scientific endeavor" (Carpenter et al., 2009; Hampton and Parker, 2011, p. 900), very few empirical studies examine how synthesis processes are structured (Bechtel, 1986; Bruce et al., 2004; Defila and Di Giulio, 2015; Enengel et al., 2012; Loibl, 2006), specifically to identify the knowledge types generated, the actor groups involved at different synthesis stages as well the extent of their involvement. There are even fewer studies (Lang et al., 2012) analyzing challenges that different synthesis stages pose in terms of knowledge integration and actor involvement.

We suggest that a detailed understanding of synthesis processes would support leaders in successfully designing and implementing transdisciplinary integration within large research programs. Exploring the challenges posed by synthesis processes should reveal critical aspects to consider when leading such processes. This could, in turn, minimize time-consuming 'learning by doing' processes, "which may unfortunately lead to a 're-inventing the wheel' phenomenon, frequently experienced by researchers involved in inter- and transdisciplinary research projects" (König et al., 2013, p. 262; Tress et al., 2007).

Hence, this empirical study addressed three research questions:

- 1) How are synthesis processes structured, who is involved and to what extent?
- 2) What challenges do synthesis processes pose in terms of knowledge integration and actor involvement?
- 3) What recommendations can be derived for future synthesis processes?

We addressed these questions by analyzing four thematic synthesis processes, which were capstone projects within the Swiss National Research Programme (NRP 61) on Sustainable Water Management. This paper first presents the conceptual framework underlying our empirical study and then describes the materials and methods used. The four synthesis processes are compared and similarities and differences with regard to knowledge types and actor groups as well as levels of actor involvement at different stages of the process are identified. Based on a structured ex-post self-evaluation of the four synthesis processes, core challenges of transdisciplinary integration as perceived by leaders (e.g. core team members) of transdisciplinary integration at different stages of the processes are presented. Finally, empirically-derived recommendations for designing future synthesis processes are formulated.

2. Conceptual framework

Previous research has mainly focused on transdisciplinary integration within research projects (Bechtel, 1986; Bruce et al., 2004; Enengel et al., 2012; Klein, 2012; Loibl, 2006) or on methods and procedures to support transdisciplinary integration (Bammer, 2008; Bergmann et al., 2012; Defila and Di Giulio, 2015; Karl et al., 2007; McDonald et al., 2009; Repko et al., 2012; Vogel et al., 2013). Less attention has been directed, however, toward transdisciplinary integration within large research programs that aim at generating synthesis products tailored to the specific needs of particular target audiences. In this section, we argue that a detailed understanding of synthesis processes and the particular challenges they pose is crucial to support leaders in successfully managing this scientific endeavor. An analytical framework for describing and analyzing transdisciplinary research projects (Enengel et al., 2012) was therefore adapted for two purposes: to compare four thematic synthesis processes across different synthesis stages and to structure the ex-post self-evaluation (Bergmann et al., 2005; Defila and Di Giulio, 1999) of the four processes in order to identify challenges arising at different stages.

2.1. Transdisciplinary research

Many authors (cf. de Jong et al. (2016); Jahn (2008); Klein (2004); Pohl (2008)) trace the origin of the notion of transdisciplinarity back to Erich Jantsch who envisioned “the coordination of activities at *all* levels” of the science, education and innovation systems to “exert a dominant influence on the development of society and its environment” (Jantsch, 1972, pp. 406, 421, emphasis in original). Twenty years later, Mittelstraß (1992) reintroduced the notion in the context of environmental research (Pohl, 2008). In line with Brewer (1999, p. 328), who stated that “the world has problems, but universities have departments”, Mittelstraß (1992) called on the scientific community to transcend disciplinary boundaries and re-connect research with real-world problems. According to Mittelstraß (1992, p. 250) “transdisciplinarity refers to knowledge or research that frees itself of its specialized or

disciplinary boundaries, that defines and solves its problems independently of disciplines, relating these problems to extra-scientific developments”. Transdisciplinarity in this context does not intend to discount specialized and disciplinary knowledge, but to ensure that problems are not perceived one-dimensionally, i.e. from a specialized or disciplinary perspective alone (Mittelstraß, 1992). Two years later, Gibbons et al. (1994) “sparked a lively controversy” (Jahn, 2008) by contrasting a “new mode of knowledge production” (mode 2) with the older, traditional academic mode (mode 1). According to Gibbons (1994, pp. 167-168, emphasis in original), transdisciplinarity refers to “knowledge that emerges from a particular *context of application*” in which the interests of societal actors from different fields and sectors are constitutive for the research process. In this context, transdisciplinary research is a collaborative process that involves different scientific disciplines and societal actors in order to ensure that “scientific knowledge is ‘socially robust’ and that its production is seen by society to be both transparent and participative” (Gibbons, 1999, p. C81). Based on a literature review of 40 years of transdisciplinarity discourse, Jahn et al. (2012, p. 8) define transdisciplinarity as “a critical and self-reflexive research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress; integration is the cognitive operation of establishing a novel, hitherto non-existent connection between the distinct epistemic, social–organizational, and communicative entities that make up the given problem context“. The definition emphasizes the importance of integration at epistemic, social-organizational, and communicative levels in order to reach both societal and scientific progress (cf. Klein (2012); Truffer (2007)).

Thus, we apply the term transdisciplinarity to refer to research that (i) addresses societally relevant problems as drivers for posing scientific research questions, (ii) grasps the complexity of the problem by involving a variety of scientific and societal actors and accounting for the diversity of perspectives on the problem, and (iii) generates knowledge that is solution-oriented, socially robust, and transferable to both scientific and societal practice (Lang et al., 2012; Pohl and Hirsch Hadorn, 2007). Based on this understanding, transdisciplinary research can be regarded as a comprehensive, multi-perspective, problem- and solution-oriented approach that transgresses the boundaries both between scientific disciplines and between science and practice (Pohl, 2011). Through transdisciplinary research, “the people who pose the problems, those who are implicated in the problems and those who help deal with them” have the opportunity to engage in a process of mutual learning (Beck, 1986; Pohl and Hirsch Hadorn, 2008, p. 117).

2.2. *Transdisciplinary integration within large research programs*

Integration is generally acknowledged to be the core feature and challenge of transdisciplinary research (Bergmann et al., 2005; Defila and Di Giulio, 2015; Huutoniemi et al., 2010; Jahn et al.,

2012; Jahn and Keil, 2015; Klein, 2008; Pohl et al., 2008). This applies particularly to large research programs that involve several coordinated inter- and transdisciplinary research projects sharing a common goal. Such programs often produce a synthesis in order to link and relate scientific results of individual projects, integrating them into an overarching context and thus creating added value that goes above and beyond individual project results (SNSF, 2012a). For the synthesis, project results need to be screened for their contribution to answering the common questions (Defila and Di Giulio, 2015), and further processed, analyzed, integrated, prioritized, and synthesized to achieve the common goal. To contribute to problem solving for sustainability, targeted products (e.g. reports, videos, etc.) are often developed from the synthesis. These are designed to summarize the integrated results so that intended audiences can make effective use of them (Defila et al., 2006; Lang et al., 2012; Pohl and Hirsch Hadorn, 2007). Hence, transdisciplinary integration is purposeful; it is not an end in itself but a means to achieve the program's specific purpose (i.e., to advance fundamental understanding of complex societal problems, to generate practice-oriented solutions, to produce targeted synthesis products).

Following Jahn and Keil (2015, p. 7), we distinguish three levels of transdisciplinary integration within large research programs. On the epistemic level, different bodies of knowledge from science and practice need to be linked and related to each other. On the social-organizational level, different interests, perspectives and expectations of involved scientific and societal actors need to be recognized and connected, and, where possible, harmonized. On the communicative level, different means of linguistic expression need to be interlinked. Though we consider all three integration levels important, our comparative analysis focuses on knowledge integration (epistemic integration) and actor involvement (social-organizational integration) within and across four thematic synthesis processes. For details regarding the communicative level of transdisciplinary integration within the four synthesis processes see Authors et al. (subm.).

2.3. Analytical frameworks for the comparative analysis of transdisciplinary research

In recent years, various frameworks have been developed to structure evaluations of transdisciplinary research, which can be ex-ante or ex-post and formative or summative (for an overview see Jahn and Keil (2015)). Defila and Di Giulio (1999) proposed questions to evaluate transdisciplinary research proposals (ex-ante) or projects (ex-post), while Bergmann et al. (2005) formulated questions for formative evaluation of ongoing transdisciplinary research projects. Blackstock et al. (2007) proposed a framework for the summative evaluation of sustainability research that, although not explicitly referring to transdisciplinary research, was intended to guide the design of participatory research evaluation in the context of regional sustainability. Jahn and Keil (2015) developed an actor-specific quality guideline for “transdisciplinary research that aims at bringing specific knowledge to bear on

policy issues relating to sustainable development” (Jahn and Keil, 2015, p. 197). The guideline includes specific questions for researchers, program managers or donors and policy makers that are meant to empower each actor group to communicate and reflect upon effective measures to assure the quality of the research process (Jahn and Keil, 2015). Though all of these frameworks or guidelines address issues of knowledge integration and actor involvement, only the one of Jahn and Keil (2015) explicitly distinguishes different research phases and actor groups. None of them, however, differentiates different types of actor involvement at different stages of a research or synthesis project, allowing for a detailed understanding of the particular challenges they pose in terms of knowledge integration and actor involvement.

In contrast, Enengel et al. (2012) developed an analytical framework for the comparative analysis of transdisciplinary research projects that explicitly addresses different types of actor involvement at different stages of a research project. This framework includes four main elements (Table 1):

- Actor roles. Who are the relevant actor groups and what are their specific roles in the transdisciplinary research process?
- Research phases. At what stages of the research process are different actor groups involved?
- Actor integration. To what extent are different actor groups involved?
- Knowledge types. What actor groups contribute and generate which types of knowledge?

In prior use of this framework, societal actors were found to contribute differently to different stages of the research process; involvement of societal actors appeared to be more prominent in the initial and final phases of the research process and less prominent in the middle phases of data analysis, which were mostly performed by researchers (Enengel et al., 2012). It was further reported that “there is no single optimum approach” for transdisciplinary integration, which is consistent with the findings of Raymond et al. (2010) and Klein (2012). Transdisciplinary integration was found to be influenced by the research topic to be addressed, the research goals to be achieved as well as by the preferences and constraints of the different actors involved in the process (Enengel et al., 2012).

Although Enengel et al. (2012)’s framework was developed for describing and analyzing transdisciplinary research projects, we use it as a reference frame for the comparative analysis of transdisciplinary synthesis projects and their ex-post self-evaluation. Both research and synthesis projects involve different types of scientific and societal actors at different stages of the process and also different levels of actor involvement. While transdisciplinary synthesis projects are often embedded in joint research programs and build on scientific results of individual research projects, process designs also need to be tailored to the specific goals to be achieved, the overarching questions to be answered, and the target audiences to be reached by the synthesis project (Authors et al., subm.). In both cases, there is a need to reflect on the process in order to track progress and realign knowledge integration and actor involvement during the process as well as to improve the design and

implementation of future synthesis processes (Bergmann et al., 2005; Blackstock et al., 2007; Defila et al., 2006; Lang et al., 2012).

2.4. Analytical framework for the comparative analysis of transdisciplinary synthesis

We adapted Enengel et al. (2012)'s analytical framework as shown in Table 1. The typology of actor roles was modified from the original to differentiate among five actor groups generally involved in synthesis projects within large research programs: (1) the core team, which comprises a group of researchers and/or consultants that are responsible for designing and implementing transdisciplinary integration; (2) the steering committee, which consists of internationally acknowledged scientific experts representing different disciplines and countries and is responsible for drawing up the implementation plan for the research program, approving or rejecting pre- and full proposals of individual projects, organizing and monitoring scientific coordination, and defining and ensuring program synthesis (SNSF, 2010a) (3) the advisory board, which involves key national actors from different sectors and decision levels, advises the steering committee, presents the concerns expressed by politicians, authorities, industry and civil society and embeds the research program in its wider socio-economic and political context (SNSF, 2010b, p. 13); (4) scientific experts from within and/or outside the research program, who support the core team and bring in their results and/or their expertise in the synthesis project, and (5) practice experts from different sectors and decision levels (local, cantonal, and/or national), who provide the core team with specific practical, political and/or contextual insights.

To enable a detailed analysis of actor involvement within and across the four synthesis projects, our analytical framework distinguishes between nine synthesis stages as shown in Table 1, which were derived empirically on the basis of interviews with core team members (cf. section 3.1). This contrasts with the seven research phases identified by Enengel et al. (2012) (Table 1).

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Table 1

Comparison of analytical frameworks for describing and analyzing transdisciplinary research projects (upper row) and synthesis projects (low row)

	WHO?	WHEN?	WHY?	WHAT?
Original framework for research projects (Enengel et al., 2012)	<i>Typology of actors</i> <ul style="list-style-type: none"> • Core scientists • Scientific consultants • Professional practice experts • Strategic case actors • Local case actors 	<i>Differentiation of research phases</i> <ul style="list-style-type: none"> • Problem history • Problem identification and structuring • Research design and selection of methods • Data collection • Data analysis and triangulation • Reflection, interpretation and synthesis • Dissemination of results 	<i>Objectives and forms of actor integration</i> <ul style="list-style-type: none"> • Information • Consultation • Knowledge co-production and empowerment 	<i>Typology of knowledge</i> <ul style="list-style-type: none"> • Scale dimension (context-specific knowledge; generalized knowledge) • Functional dimension (phenomenological knowledge; strategic knowledge) • Epistemic cognitive dimension (experiential knowledge; scientific knowledge)
Adapted framework for synthesis projects (changes from Enengel et al. (2012) marked in bold font)	<i>Typology of actors</i> <ul style="list-style-type: none"> • Core team • Scientific experts • Practice experts • Steering committee • Advisory board 	<i>Differentiation of synthesis stages</i> <ul style="list-style-type: none"> • Identify synthesis topics, key messages and target audiences • Define objectives, questions and responsibilities • Determine methods and procedures • Submit and approve synthesis proposal • Collect, screen data and results • Process, analyze and integrate data and results • Prioritize and synthesize data and results • Validate synthesis results • Diffuse synthesis results 	<i>Typology of actor involvement</i> <ul style="list-style-type: none"> • Information • Consultation • Collaboration 	<i>Typology of knowledge</i> <ul style="list-style-type: none"> • Systems knowledge • Target knowledge • Transformation knowledge

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In the typology of actor involvement, collaboration was substituted for knowledge co-production and empowerment to distinguish three distinct forms of actor involvement usually encountered in synthesis projects (Table 1). The term *information* (i.e. in the sense of informing) is used to refer to one-way forms of communication between different actor groups; actors are informed about the synthesis project through articles, books, policy briefs, presentations, and/or documentaries (videos), but are afforded only limited power to influence the process and/or the outcome (Brandt et al., 2013; Krütli et al., 2010). Consultation comprises two-way forms of communication; actors are asked to comment on the synthesis proposal/project, and to bring in their knowledge (e.g. through questionnaires and/or interviews) individually, in small groups, in larger meetings, or via digital platforms. The actor group initiating the consultation (e.g. the core team) decides whether to include these contributions in the synthesis project or not. Collaboration encompasses multi-way forms of communication (e.g. debates, workshops) that are often moderated by one actor group (e.g. the core team); experts from science and practice are empowered to develop the synthesis project in collaboration with the core team, and thus to “codetermine both process and the outcome on an equal footing” (Krütli et al., 2010). *Information* and consultation do not require commitment and allow for a broad involvement of different actors, whereas collaboration does require commitment but is limited to only a small number of actors (Krütli et al., 2010).

The typology of knowledge was altered to differentiate among three types of knowledge generally generated by synthesis projects and intended to contribute to sustainability (Table 1): (1) systems knowledge about the origin of the societal problem, its current state and future trends, (2) target knowledge about the desired goals of future developments, and (3) transformation knowledge about the transition from the current to the target state (CASS and ProClim, 1997; Pohl and Hirsch Hadorn, 2007).

3. Materials and methods

3.1. The NRP 61 case study

NRPs funded by the Swiss National Science Foundation (SNSF) represent coordinated research efforts, in which individual research projects with a common goal apply inter- and transdisciplinary approaches to contribute to the solution of contemporary problems of national importance (SNSF, 2010a). Information on NRP 61 on Sustainable Water Management is available on the SNSF website (<http://www.nrp61.ch/en>) and elsewhere (Authors et al., *subm.*).

Program synthesis was conceived from the outset as a joint endeavor of all research projects (16 in total). The steering committee, with support from the NRP 61 program coordinator and implementation officer, developed a draft synthesis concept and presented it to the project leaders (and other invited researchers) at the first Progress Report Meeting held approximately 14 months after the

start of the projects in January 2010. Project leaders and researchers advised the steering committee to organize a workshop to define synthesis topics, key messages, and target audiences of potential syntheses jointly. Based on the workshop results, the steering committee decided to produce four thematic syntheses (TS) mainly for a technical audience (i.e. relevant local, cantonal, and federal authorities, trade associations, NGOs, and private companies) and one overall synthesis (OS) for the general public. Table 2 provides an overview of the different topics, objectives, and products of all synthesis projects.

The steering committee invited four core teams (drawn from the NRP 61 research community) to develop the four TS proposals by outlining content and structure of the respective synthesis, identifying the individual projects to be included, outlining the knowledge from within and/or outside NRP 61 to be integrated, defining roles and responsibilities of involved actors, and determining milestones and deliverables (SNSF, 2012b). The OS proposal was developed by the steering committee in collaboration with external consultants. Following approval by the SNSF National Research Council, all synthesis projects started in October 2012 and ended in June 2014 (excluding the subsequent four month period of layouting and translating final synthesis products). The proposal of TS 3 originally included a plan for concurrent analysis of and reflection on the synthesis process (Authors et al., subm.). The SNSF requested the TS 3 core team to separate this component from the initial proposal and submit a separate proposal, which extended the analysis to include all four TS projects. The proposal was submitted in November 2012 and approved in January 2013 by the SNSF National Research Council (Authors et al., subm.). The project was conducted by the authors of this paper.

Each TS project was led by a core team and involved – to different degrees – the steering committee, the advisory board, as well as experts from science and practice. Each TS involved 7-16 individual research projects (16 projects in TS 1, 11 projects in TS 2 and 7 projects in TS 3 and TS 4). Due to overlapping synthesis topics, all projects (with the exception of one individual project) were included in more than one TS.

The NRP 61 offers a valuable case study for our comparative analysis of four synthesis projects for the following reasons:

- Synthesis was given a high priority within the program from its outset.
- Synthesis comprised four different TS projects, enabling comparison of knowledge integration and actor involvement across the four projects.
- The four TS projects involved different types of scientific and societal actors with varying levels of involvement at different stages.
- Two authors of this paper participated as a researcher and a coordinator in the program, allowing them to follow all research and synthesis projects from their very beginning.

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Table 2

Overview of topics, objectives, and products of the four thematic syntheses (TS) and one overall synthesis (OS) of the NRP 61 on Sustainable Water Management

TS/OS	Topics	Objectives	Products
TS 1	Water resources in Switzerland: Availability and management – today and tomorrow	<ul style="list-style-type: none"> • Present the foundations of the current state of water resources and water uses in Switzerland and outline the anticipated future situation. (<i>Systems knowledge</i>) • Analyze the potential impact of climate and socio-economic changes on both water resources and water uses in Switzerland. (<i>Systems knowledge</i>) 	Report (Björnsen Gurung and Stähli, 2014) Practice oriented article (Jörg-Hess et al., 2014)
TS 2	Management of water resources under growing user demands	<ul style="list-style-type: none"> • Analyze present and potential future demands on water resources and aquatic ecosystems; identify their potential impact on water resources, aquatic ecosystems, and other uses; identify present and potential future conflicts and synergies resulting from overlapping demands. (<i>Systems knowledge</i>) • Determine the need for action in order to prevent, mitigate or resolve potential conflicts and/or leverage potential synergies; identify potential courses of action to overcome conflicts and/or foster synergies; suggest potential tools for conflict management. (<i>Transformation knowledge</i>) 	Report (Lanz, Rahn, et al., 2014) Practice oriented article (Lanz, Fuhrer, et al., 2014)
TS 3	Sustainable water and wastewater management in Switzerland: Challenges and options for action	<ul style="list-style-type: none"> • Analyze current and future challenges to urban water and wastewater management in Switzerland and their causal relationships. (<i>Systems knowledge</i>) • Formulate targets of sustainable water and wastewater management in Switzerland. (<i>Target knowledge</i>) • Identify potential courses of actions and assess their consequences against the normative concept of sustainability. (<i>Transformation knowledge</i>) 	Report (Hoffmann et al., 2014) Practice oriented article (Jordi, 2014)
TS 4	Sustainable water governance: challenges and approaches	<ul style="list-style-type: none"> • Analyze today's water governance in Switzerland; clarify concepts such as water governance and water management; illustrate case studies on water governance and water management. (<i>Systems knowledge</i>) • Define criteria for sustainable water governance in Switzerland. (<i>Target knowledge</i>) • Formulate recommendations for sustainable water governance in Switzerland. (<i>Transformation knowledge</i>) 	Report (Schmid et al., 2014a) Practice oriented article (Schmid et al., 2014b)
OS	Sustainable water management in Switzerland: NRP 61 shows the way ahead	<ul style="list-style-type: none"> • Synthesize key messages of the NRP 61 	Book (120 pages) (Leitungsgruppe NFP 61, 2015) Practice oriented article (Leitungsgruppe NFP 61, 2014)

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Note. Target audiences of the four TS projects included local, cantonal, and federal authorities, trade associations, NGOs and private companies and of the OS project the general public.

- The lead author of this paper was a core team member of TS 3, enabling her to design and implement this synthesis process, as well as to experience some challenges of transdisciplinary integration throughout the process.

3.2. Methods

We used qualitative methods of empirical social research to study transdisciplinary integration within four thematic synthesis processes (Denzin and Lincoln, 2005). In a first series of qualitative interviews with the core team members of TS 1, TS 2, and TS 4 in the course of the synthesis processes we characterized different knowledge types, identified different synthesis stages, determined different types of scientific and societal actors involved in the process and specified their level of involvement. For each TS, we mapped the different actors and their involvement at different stages of the synthesis process. Based on the mapped synthesis processes, we conducted a second series of qualitative interviews with the core team members of all TS projects at the end of the four processes. The interviews served to validate the mapped synthesis processes, and to identify key challenges experienced in the four processes. All interviews, including the interview with core team members of TS 3, were conducted by the lead author of this paper. The lead author herself was not interviewed. All core team members were provided with interview questions (first and second series of interviews) and mapped synthesis processes (second series of interviews) one week before the interviews. Interviews were complemented by participant observations carried out by all authors during various NRP 61 program meetings and workshops (Authors et al., *subm.*).

After completion of the synthesis processes, we used the method of ex-post self-evaluation to reflect jointly on the aspects that went well (or less well), and the things to do differently in future synthesis processes (Bergmann et al., 2005; Defila and Di Giulio, 1999). We therefore organized a synthesis workshop in close collaboration with core team members of the four completed TS projects. The workshop involved core team members, scientific experts, as well as the NRP 61 program coordinator and implementation officer and was facilitated by the second author of this paper (who was involved in this study, but not in any other NRP 61 research or synthesis project). The lead author acted as both researcher on transdisciplinary integration (Step 1 and 3) and core team member of TS 3 (Step 2, 4, and 5) (see also section 5.3.):

Step 1. As a starting point, the lead author presented a poster visualizing the different types of actors involved in the four TS projects. The workshop participants were divided into five groups; four groups consisting of the core team members of each TS and the associated scientific experts and one group consisting of the NRP 61 program coordinator and implementation officer.

Step 2. Each group discussed the various roles of different actors (e.g. core team, advisory board, steering committee, scientific experts, practice experts) involved in their TS. Based on this discussion, a list of basic requirements for successful performance of the various roles was compiled.

Step 3. The lead author presented a poster mapping the four different synthesis processes. The poster illustrated the different actor groups involved in the process and specified their level of involvement at different stages of the process.

Step 4. Each group discussed their synthesis process, identified the challenges they experienced at different stages of the process in terms of knowledge integration and actor involvement, and assigned the perceived challenges to the corresponding synthesis stages on the poster.

Step 5. On the basis of Steps 1-4, the participants collectively formulated recommendations for designing and implementing future synthesis processes.

Actors and their involvement at different stages of the synthesis process were analyzed using the analytical framework described in section 2.4. By consistently mapping the various actors and their involvement at different stages of the synthesis process for each TS in the same way, we were able to compare knowledge integration and actor involvement across the four TS. We could identify similarities and differences with regard to the generated knowledge, the involved actors and the levels of actor involvement at the different stages of the process. By prior agreement with participating core team members of the four projects, we excluded any explicit assessment relating knowledge integration and actor involvement in the TS projects to their overall performance.

The qualitative methodology of grounded theory was applied to derive key challenges from our empirical data (Glaser and Strauss, 1967), in contrast to using an existing theoretical framework for this purpose. We encoded the second series of interviews and the results of the synthesis workshop according to the language used by the different actor groups involved in the four TS projects. For encoding, we clustered similar challenges according to groups, described them in a more general way, and assigned them to the corresponding stage of the synthesis process. Finally, we compared the four TS projects, and refined and reformulated the encoded challenges.

After completion of our empirical study, the SNSF organized a workshop on transdisciplinary integration within large research programs. The lead author presented the results of our empirical study and discussed them with steering committee presidents, program coordinators, and implementation officers of past and current NRPs, including NRP 61, and representatives of the SNSF (e.g. the head and deputy head of the Programmes division, the head of the communication division, and the head of the finance unit in the Programmes division) involving altogether 33 participants (see also section 6.).

4. Structure of synthesis processes

In this section, we follow Enengel et al. (2012) by first characterizing the different types of knowledge generated in the four synthesis processes and the different types of actors involved at different stages of the processes. We then identify the different levels of actor involvement throughout the processes.

4.1. Generated knowledge and involved actors

Table 2 highlights the three types of knowledge generated in the four synthesis projects: One project (TS 1) produced exclusively systems knowledge and one project (TS 2) generated systems and transformation knowledge. Two projects (TS 3, TS 4) produced all three types of systems, target and transformation knowledge. The knowledge types correspond to the different objectives that underlie the four synthesis projects (see Table 2).

Table 3 summarizes the various types of actors involved in the four TS projects. Each synthesis project included a core team, scientific experts, practice experts, the NRP 61 steering committee and advisory board. One project (TS 2) additionally involved a project team composed of five scientists who jointly developed the TS 2 proposal. After approval, the TS 2 project team established a core team, which was responsible for implementing the synthesis process and synthesizing data and results. The core team for each TS comprised a group of 3-4 scientists and/or consultants with complementary disciplinary backgrounds. In addition, the synthesis processes involved 6-18 scientific experts and 2-15 practice experts (Table 3).

Fig. 1 illustrates the stages of the synthesis process at which the different types of actor groups were involved. As shown in Fig. 1, the steering committee and advisory board were mainly involved in the initial stage of the projects (when synthesis topics, key messages, and target audiences of the four TS were defined) and in the final stages (when synthesis results were validated and diffused). In contrast to the other three synthesis projects, TS 3 also included the steering committee and advisory group in the analysis of data and results (middle stage). The core teams were involved in all synthesis stages and were responsible for transdisciplinary integration. With the exception of TS 3, experts from science and practice were not involved in the initial stages of the synthesis process but were rather involved primarily in collecting, screening, processing, analyzing, and integrating data and results, as well as in validating and diffusing final synthesis results. TS 4 included practice experts only in the final stages of its synthesis process.

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Table 3

Description of TS specific actor groups involved in four thematic synthesis projects of the NRP 61 on Sustainable Water Management

Actor groups	TS1	TS2	TS3	TS4
Core team (involved disciplines)	Scientists (3) <i>Environmental sciences, environmental physics, hydrology, economics, and social sciences</i> n=3	Consultant (1), Scientists (3) <i>Environmental sciences, geoinformatics, and geography</i> n=4	Scientists (3) <i>Environmental sciences, environmental engineering, and hydrogeology</i> n=3	Consultants (2), Scientists (2) <i>Geography and economy</i> n=4
Project team (involved disciplines)	n=0	Scientific experts (5) <i>Agroecology, environmental sciences, glaciology, and hydrology</i> n=5	n=0	n=0
Scientific experts (involved disciplines)	<i>Economics, law, political science, hydrology, snow hydrology, landscape dynamics, hydrogeology, forest dynamics, biology, aquatic ecology, and water chemistry</i> n=18	<i>Hydrology, aquatic ecology, aquatic chemistry, political science, and environmental sciences</i> n=6	<i>Environmental sciences, decision analysis, hydrogeology, hydrology, water chemistry, and limnology</i> n=7	<i>Geography, biology, agroecology, decision analysis, law, and political science</i> n=8
Practice experts	Representatives from the federal office for the environment (1), cantonal authorities (2), NGOs (2), and trade associations, including the Swiss Water Association (1), the Swiss Gas & Water Industry Association (1), and the Swiss Water Management Association (1) n=8	Representatives from the federal office for the environment (3), cantonal authorities (1), consulting companies (1), NGOs (1), and trade associations, including the Swiss Water Association (1), the Swiss Gas & Water Industry Association (2), and the Swiss Water Management Association (1) n=10	Representatives from the federal office for the environment (3), cantonal authorities (4), municipal authorities (1), consulting companies (2), water supply companies (2), stakeholder network of Swiss water management (1), and trade associations, including the Swiss Water Association (1), the Swiss Gas & Water Industry Association (1), and Communal Infrastructure (1) n=15	Representatives from the federal office for the environment (1), and consulting companies (1) n=2
Steering committee (involved disciplines)	Internationally recognized scientific experts (the same for TS1, TS 2, TS3, and TS 4) <i>Environmental engineering, aquatic ecology, environmental economics, hydrology, meteorology, and geophysics</i> n=6			
Advisory board	Key stakeholders from the Swiss water sector (the same for TS1, TS 2, TS3, and TS 4), representing the national council (2), the federal office for the environment (1), cantonal authorities (3), NGOs (1), and trade associations, including the Swiss Water Association (1), the Swiss Gas & Water Industry Association (1), and the Swiss Water Management Association (1) n=10

Fig. 1. Involved actors and level of actor involvement at different stages of four thematic synthesis processes of the NRP 61 on Sustainable Water Management (adapted from Enengel et al. (2012))

4.2. Types of actor involvement

The type of involvement of different actor groups varied at different stages in the four synthesis projects (Fig. 1). In all synthesis projects, *information* took place at the stage of collecting and screening data and research results, as well as at the stage of diffusing final synthesis results. Scientific experts from the NRP 61 research community and practice experts from the Swiss water sector informed the core teams regarding specific research results (TS 1, TS 2, and TS 3) and delivered practical, political, and/or contextual insights (TS 1 and TS 2). All four core teams published the results of the synthesis process in thematic reports, presented their findings to a wide public on different occasions (e.g. press conference, scientific conference, practice workshop), and summarized their findings in practice-oriented articles that appeared in a Swiss trade journal (see Table 2, Products). The steering committee further diffused the final synthesis results to relevant local, cantonal, and federal authorities, trade associations, NGOs, and private companies.

Moreover, all synthesis projects involved consultation. In the initial stages, the steering committee consulted the four core teams to solicit their comments on the results of the synthesis workshop held in September 2011 and to commission the synthesis proposals. One synthesis project, TS 3, developed the proposal in consultation with scientific experts. The steering committee commented on all proposals. In the middle stages, all synthesis projects consulted scientific experts; some projects (TS 1, TS 2, and TS 3) consulted practice experts and one project (TS 3) consulted the steering committee and advisory board. Again, only one project (TS 3) prioritized data and results in consultation with scientific and practice experts (Fig.1). In the final stages, all core teams with the exception of TS 1 consulted all actor groups (e.g. steering committee, advisory board, experts from science and practice) to validate their synthesis results. As shown in Fig. 1, synthesis results were validated several times in an iterative process, involving seven meetings between the core teams of all TS and the steering committee, one meeting between the core teams and the advisory board, as well as several meetings (not shown in Fig. 1) between the core teams of the different synthesis projects.

Two synthesis projects (TS 3 and TS 4) had a higher level of actor involvement. These synthesis projects developed integrative assessment procedures with the aim of integrating a variety of sustainability criteria (derived from the individual research projects) into a single methodological framework (Authors et al., subm.) thus enabling the generation of target knowledge for sustainable water and wastewater management (TS 3) and sustainable water governance (TS 4). The development of such frameworks required close collaboration between the core teams and the scientific experts involved in the individual research projects. One synthesis project (TS 3) defined methods and procedures of knowledge integration in collaboration with scientific experts (Authors et al., subm.). And one synthesis project (TS 4) prioritized data and results (e.g. on water management and water governance) in collaboration with scientific experts.

As shown in Fig. 1, TS 1 and TS 2 involved the same type of actors with the same type of involvement at all stages of the synthesis process. In both projects, actor involvement was limited to *information* and consultation. Collaboration occurred only in TS 3 and TS 4 and involved exclusively the core teams and the scientific experts. Proposal development was restricted to the core team (TS 1 and TS 4) or the project team (TS 2). Only TS 3 developed its proposal in consultation and collaboration with scientific experts. Collection, integration, and prioritization of data and results included only experts from science (for all TS) and practice (TS 1, TS 2, TS 3) with the exception of TS 3 involving both the steering committee and the advisory board in analysis. With the exception of TS 1, validation and diffusion of final synthesis results involved all different actor groups.

Consistent with prior work (Enengel et al., 2012; Klein, 2012; Raymond et al., 2010), the results illustrate that similar approaches were adopted to develop the initial synthesis proposals and to validate and diffuse final synthesis results, but diverse approaches were used to collect, integrate, prioritize and synthesize data and results. This diversity in the middle stages of the four synthesis processes is consistent with the “Principle of Variance,” which holds that integration is influenced by the objectives to be achieved (i.e. the knowledge to be generated), the questions to be answered, and the result to be integrated (Authors et al., subm.; Klein, 2012). Integration is also influenced by the actors involved, their disciplinary and professional background, as well as by the roles core team members assume in the synthesis process (Authors et al., subm.; Klein, 2012). Authors et al. (subm.) show that core team members of TS 1 and TS 2 acted at most stages as collaborators, engaging in two-way forms of communication with other actors, and at some stages as scholars (TS 1) or advocates (TS 2). In contrast, core team members of TS 3 and TS 4 assumed the role of facilitators, supporting multi-way forms of communication among experts, at most stages but shifted their role and acted as collaborators (TS 3) or scholars (TS 4) at some stages (Authors et al., subm.).

5. Challenges of transdisciplinary integration

In this section, we will present empirical observations from the four TS processes and their overall framework conditions as derived from the interviews and the ex-post self-evaluation (see section 3.2.). First, we will illustrate challenges in terms of knowledge integration and actor involvement as perceived by core team members of the four TS. The challenges are assigned to the particular stage at which core team members experienced them (Fig. 1). Second, we will present challenges related to the overall framework conditions of the four TS as observed by the core team members, the NRP 61 implementation officer and program coordinator. Wherever possible all observations are supported by quotes from the interviews. Though the lead author of this paper was not interviewed, two quotes from her are derived from her interviews with other core team members (see section 3.2.). These quotes are used to describe the challenges she experienced as one of the core team members of TS 3; they are

marked with (*lead author*). Finally, we will discuss the dual role of the lead author as both core team member and principal investigator of the concurrent research on transdisciplinary integration.

5.1. Perceptions on the four thematic synthesis processes

5.1.1. Defining methods and procedures

Knowledge integration requires a common vision shared by all team members on how to link scientific results of individual research projects to each other as described by Pohl et al. (2015) for the successful publication of interdisciplinary research. This implies a joint effort of the core team (ideally together with experts from science and practice) to deliberate and agree on an adequate combination of integration methods and procedures to be applied throughout the synthesis project (Authors et al., subm.; Lang et al., 2012). If the core team fails to arrive at such a joint vision (e.g. for lack of time to meet as a group), integration of scientific results becomes a major challenge as highlighted by one core team member:

The beginning was very difficult and tedious: to build a [core] team and to agree as a team on a concept, how we want structure the synthesis. In fact, we have agreed much too late on that concept. It would have been better to take some more time at the beginning to discuss the whole forth and back. Because, once we have agreed on it, it was comparatively easy to work on the synthesis.

The statement emphasizes that the development of a joint vision of the integrated outcome often triggers further work on the synthesis (Pohl et al., 2015). Developed at the outset, it provides a basis for structuring and systematizing the results and relating them to each other. It also serves as a basis for defining the contributions of each actor group, the purpose of each contribution and the methods by which the contributions are made throughout the synthesis process. It thus enables a structured involvement of all actor groups (Lang et al., 2012) and enhances their commitment to bring in their results and/or expertise actively in the different synthesis stages, as pointed out by one core team member:

I think one of most important steps that we have taken at the beginning was to define [in collaboration with scientific experts] methods for integrating the results from very different projects. It allowed us to structure the synthesis, to communicate with each other [...] and to define the roles and responsibilities of different actors involved in our project. It also enabled us to assign specific tasks [...] and to include all relevant actors in our project without overburdening them. In our case, this was very well received by the experts.

Both statements underline the importance of a common vision in order to structure the subsequent stages of the synthesis process and to ensure the right level of actor involvement throughout the

process (see also section 6.1.). To our knowledge, such a finding has not previously been documented in the literature on transdisciplinary integration within large research programs.

5.1.2. Collecting and screening data and results

Knowledge integration requires an intensive process of collecting and screening data and results provided by individual research projects and other sources. As TS 1 and TS 2 aimed at presenting an overview of water resources and water uses in Switzerland (TS 1) and of conflicts and synergies resulting from overlapping user demands (TS 2), core team members of both synthesis processes worked intensively to embed data and results from individual projects in a broader scientific and societal context. Core team members considered the non-involvement of experts at this stage of the process (Fig. 1) as a strength since it allowed them to bring the different parts of the puzzle together first and then discuss the overall view on water resources and water uses (TS 1) or conflicts and synergies (TS 2) with a wide range of experts from science and practice (see Table 3).

TS 4 aimed at analyzing sustainable water governance in Switzerland based on several case studies provided by 7 individual research projects. In contrast to TS 1 and TS 2, core team members opted for bilateral exchange with scientific experts in order to define which parts of their case studies should be incorporated into the final synthesis report and which parts should not (Fig. 1). Core team members perceived consultation of scientific experts as a strength as it allowed them to make effective use of their results and ensure consistency of the synthesis report with the individual projects.

The different approaches chosen by TS 1 and TS 2 (e.g. non-involvement of experts; inclusion of knowledge from diverse sources beyond individual projects) as compared with TS 4 (e.g. expert consultation, integration of knowledge from individual projects) illustrate the need to clarify the object and purpose of each synthesis project. In particular, it is important to clarify whether the synthesis draws mainly on individual project results (TS 4) or on additional sources (TS 1 and TS 2) (see section 6.1.)

5.1.3. Processing, analyzing, and integrating data and results

In line with general design principles for inter- and transdisciplinary research (Bergmann et al., 2005; Defila et al., 2006; Lang et al., 2012; Pohl and Hirsch Hadorn, 2007), knowledge integration requires the involvement of experts from science and practice. Core team members of TS 1 and TS 2 perceived expert consultation as appropriate in order to process, analyze, and integrate data and results (Fig. 1). One core team member described this involvement as follows:

I preferred working bilaterally with the people. I think this is much more open and much more fruitful when talking directly and alone with them. They take more time. It is more productive than conducting workshops.

Consultation enabled the core teams to include a wide range of experts from science and practice (see Table 3) in an efficient way without having to engage in a demanding process of negotiation among experts and core team members. The weakness of this type of involvement lies in the interpretation and integration of data and results from one single perspective (e.g. the perspective of the core team) – and not from different perspectives. Collaboration with experts (Fig. 1, TS 3, TS 4) can compensate this weakness as highlighted by one core team member (*lead author*):

Our process was very collaborative. We spent a lot of time in organizing meetings and workshops to bring people together. The advantage is that at least the experts involved in our project broadly support the final report. But this has been a time-consuming process with some frictional losses - because everyone had a different perspective that needed to be accounted for. But, at the end, the acceptance of the report is high.

Collaboration requires a commitment among experts to jointly process, analyze and integrate data and results from different perspectives. As highlighted in the quote, it is a time-consuming process that is limited to a relatively small number of experts from science and/or practice (Krütli et al., 2010). Its strength lies in its ability to shift responsibility for knowledge integration gradually from the core team to the entire group of experts and core team members (Authors et al., *subm.*) thus creating ownership and increasing legitimacy for the final integrated outcome.

5.1.4. Prioritizing and synthesizing data and results

Knowledge integration necessarily involves the prioritization of research results to be included in the final synthesis report. This implies a joint effort of the core team to screen, analyze and prioritize data and results. If experts from science and practice are not involved in this process (Fig. 1: TS 1, TS 2), they might challenge prioritization as being biased. In this regard, one core team member noted:

We derived our prioritization directly from the research projects. We looked which projects provided which answers to which questions. We considered it our task to weight the results. [...] In the end, we came under criticism for having treated some topics rather superficially.

Since priority setting strongly depends on which actors are involved, it is crucial to ensure that actors included in the prioritization process adequately represent the most relevant actor groups, both in number and in characteristics (Caron-Flinterman, 2005). However, this poses a twofold challenge as described by Lang et al. (2012, p. 36) for research projects: “first, in the majority of projects, it is only possible to involve a relatively small number of actors due to limited resources and methodological

reasons; second, it is very tempting to rely on the network of ‘usual suspects’, namely, people who have been involved in previous projects or are generally interested in participatory [...] processes—but by no means represent all or even the most relevant stakeholder groups.” Though stakeholder analysis provides a systematic way of identifying stakeholders with a legitimate stake in the process and its final outcome, synthesis projects “still face the challenge of how to involve representatives of future generations. This is particularly important in infrastructure projects [such as TS 3, see Table 2] that create path dependencies for one or more generations” (Lang et al., 2012, p. 36). TS 3 did not meet this challenge, but involved experts from science and practice in their prioritization process (see Fig. 1: TS 3). Structuring the process in a transparent way enabled the core team to legitimize the inclusion of some topics, but not others, in the final report. One core team member said:

We asked the experts from science and practice to rate the challenges to be addressed in our synthesis report: The frequencies with which the experts rated the challenges determined our priorities. This was a very transparent and reproducible process. On the one hand, it allowed us to set priorities; on the other hand, it provided us with arguments, when someone asked us why we neglected some topics.

Both statements emphasize the need to prioritize research results in consultation and/or collaboration with experts from science and practice (Fig. 1: TS 3, TS 4) in order to increase the legitimacy of the final integrated outcome. So far, the need for jointly prioritizing results has received limited attention in the literature.

5.1.5. Validating synthesis results

Knowledge integration is expected to generate results relevant for societal problem solving (Polk, 2014). To ensure practical relevance, synthesis projects generally involve experts from different sectors and decision levels (e.g. advisory board, practice experts) in order to capitalize on their specific insights. If they are not involved in the validation of final synthesis results (Fig. 1, TS 1) or, conversely, if they are only involved in the validation (Fig. 1, TS 4), practice experts and/or key national stakeholders might challenge the practical relevance of final results. In this regard, one core team member noted:

We originally intended to set up a group of practice experts to accompany our project. However, we decided not to do so: On the one hand, because the schedule was pretty tight to set up the group; on the other hand, because many experts were already involved in other research or synthesis projects; in fact, we did not want to burden them unduly. Instead, we sent the draft report to two experts and invited them to submit written comments. The disadvantage of our approach was that one of the two experts considered our report as being too academic.

The quote poses the question of the right level of actor involvement throughout the synthesis process (see also section 6.1.). It also indicates the need to define the roles and responsibilities of experts and/or key national stakeholder at different stages of the synthesis process as highlighted in section 5.1.1. and to include them in the validation of final synthesis results. As for the prioritization of research results, the need for validating synthesis results has not yet been reported in the literature.

5.2. Perceptions on the overall framework conditions of the four thematic synthesis processes

5.2.1. Scientific coordination within and across synthesis projects

Knowledge integration requires substantial scientific coordination in order to generate synthesis products tailored to the specific needs of the target audience. This is particularly important for research programs that involve several synthesis projects with some thematic overlaps between them. Here, scientific coordination across all synthesis projects (and across all subsequent stages of the synthesis process) becomes a key challenge. This involves not only facilitating interaction and communication within and across all synthesis projects (and teams) but also managing interfaces between synthesis and research projects.

In the context of NRP 61, scientific coordination within and across all synthesis projects was delegated to the four core teams (SNSF, 2012b). This posed a major challenge to all core teams as pointed out by one core team member:

Dividing the synthesis into four thematic synthesis projects and one overall synthesis project led to a number of consequences. It implied a considerable effort in coordination: Only to define our synthesis proposal and to establish contact with the people involved we had countless meetings and workshops. [...] We had even more meetings and workshops to coordinate between all synthesis projects. This was a gigantic effort.

All efforts to coordinate within and across the various synthesis projects were accompanied by the members of the steering committee and brought together by the committee president (SNSF, 2012b). Since the president was unavailable over longer periods, some core team members had the impression that there was no one who effectively “held all threads together” and actually steered their coordination efforts. One core team member expressed this frustration with trying to coordinate across all synthesis projects as follows:

It is a very complex issue to coordinate four thematic syntheses and one overall synthesis. [...] There was no one, who pulled the strings together. It was entirely up to us to coordinate across the various synthesis projects. For me, this was unsatisfactory. Eventually, I decided just to focus on my synthesis project and to disregard the overlaps with the other projects.

Though delegation of scientific coordination was perceived as a major challenge and caused some frustration, giving way to resignation, it also allowed the four core teams the creative freedom to self-direct their synthesis project and to decide autonomously who should (and who should not) be involved in the synthesis project and, for those involved, when and how. Core teams were thus free to shape interaction and communication within and across synthesis projects according to their own preferences, resulting in a diversity of approaches as summarized in Fig. 1: some favored consultation with a wide range of experts from science and practice (TS 1, TS 2); others preferred close collaboration with scientific experts (TS 3, TS 4); some coordinated thematic overlaps with other synthesis projects bilaterally (TS 1, TS 2), while others discussed overlaps in workshops carried out with all synthesis projects (TS 3, TS 4).

5.2.2. Availability of research results and expert knowledge

Knowledge integration targeted on final synthesis presupposes the availability of research results to be linked, related and cited as underlined by Pohl et al. (2015) for the successful publication of interdisciplinary research. If results are not ready because individual projects are delayed or provide unexpected results, knowledge integration becomes a major challenge. Asked about this challenge, one core team member (*lead author*) said:

Some research results that we wanted to include in our synthesis were not ready yet; the respective projects were delayed. Other projects, in turn, managed to publish their results in time. The results of these projects are rather overrepresented in our synthesis report – which does not mean, however, that they are more relevant than other results.

Availability of research results turned out to be a challenge for all core teams, especially since synthesis projects and research projects were conducted in parallel. Overlap in time, however, enabled the core teams to involve researchers and practitioners from individual research projects in their synthesis project and thus to tap into their expert knowledge reaching far beyond the boundaries of their individual projects.

This raises the question concerning the best timing of synthesis projects (i.e., the best overlap in time between the research and synthesis projects). With too much overlap, results might not be ready and hence not included, or misrepresented, but expert knowledge might be easily available. With too little overlap, in contrast, it might be difficult, if not impossible, to bring in expert knowledge as experts might become involved in other research projects after their individual projects are concluded (see also section 6.1.)

5.2.3. Consolidation of final synthesis results

Another challenge experienced by some core team members concerned the consolidation of final synthesis results. Though experts from science and/or practice validated final results at the end of each synthesis project (see section 5.1.5.), some core team members felt frustrated as they finally lacked time to discuss the final synthesis results within the research program. One core team expressed this frustration as follows:

I think, it is crucial to consolidate the final results to a consistent whole at the end of the program. This requires an additional step, in which the results of the different syntheses are discussed within the program and matched with one another. Then it is only another small step to formulate key messages for the media and the general public. [...] This requires time, however, that [...] we did not have at the end.

This poses the question whether to include a final feedback loop in the overall synthesis process in order to discuss and consolidate the integrated results within the research program before these are validated by different actor groups and disseminated to the target audiences (see section 6.1.).

5.3. The dual role of the lead author

The lead author of this paper acted in two roles, as a core team member of the TS 3 synthesis process and as principal investigator of the concurrent research on transdisciplinary integration. As a core team member, she designed and implemented transdisciplinary integration. This involved defining the object and purpose of the synthesis process, formulating common objectives and questions, as well as developing a joint vision for knowledge integration and actor involvement in consultation and collaboration with scientific experts (Authors et al., subm.). Leading TS 3, she experienced the challenge of structuring and systematizing very heterogeneous results from different research projects and of balancing the competing demands of different actor groups. She also faced all challenges related to the overall framework conditions of the four synthesis processes.

As researcher, she triggered regular reflection on transdisciplinary integration at four different levels (Authors et al., subm.). At the personal level and the TS 3 project level, her dual role sparked the critical review of the synthesis process, resulting in some changes in terms of methods and procedures of knowledge integration in the course of the process (Authors et al., subm.). At the level of all synthesis projects, it enabled a process of mutual learning among core team members of all TS by discussing empirical results on transdisciplinary integration and by reflecting on the challenges core team members experienced in their synthesis process. As in the case of TS 3, this reflection triggered some adaptations in the ongoing processes (Author, 2016; Authors et al., subm.). At the program level, her role stimulated the ex-post self-evaluation of the four synthesis processes, using the empirical results of this study (e.g. the mapped synthesis processes) as a starting point for reflection. The self-

evaluation motivated the SNSF to disseminate these results to future leaders of NRP synthesis processes to guide them in their leadership tasks (Authors et al., subm.).

6. Recommendations for future synthesis processes

Our study aimed at reflecting on transdisciplinary integration within large research programs. Interviews and workshops with different actor groups (i.e. core team members, experts from science and practice, steering committee presidents, program coordinators, and implementation officers of past and current NRPs including NRP 61, and representatives of the SNSF, see section 3.2) allowed us to deliberate jointly on the four synthesis projects and reflect on the aspects that went well (or less well), and the things to do differently next time (Blackstock et al., 2007). The research method applied in this study enabled us, on the one hand, to collect data in the course of the four synthesis projects and validate our qualitative analysis empirically. On the other hand, it allowed the different actor groups to share their experiences and perceptions knowing that they could both check our interpretations (e.g. all actor groups involved in this study received two earlier versions of this paper to ensure a balanced view of our interpretations) and generate new knowledge for designing and implementing future synthesis projects.

The results of our empirical study need to be discussed in the context of the overall framework conditions of the four thematic synthesis projects (see Enengel et al. (2012)). For example, all TS projects except TS 1 exhibited identical patterns in the definition of synthesis topics, key messages, and target audiences of final synthesis products, the submission and approval of initial synthesis proposals, as well as the validation and diffusion of final synthesis results (Fig. 1). These patterns trace back to the overall framework conditions of the four TS projects (see section 3.1.). The diversity of approaches adopted in the middle stages, in turn, reflect the creative freedom core teams enjoyed in self-directing their particular synthesis project in terms of knowledge integration and actor involvement (see section 5.2.1.).

Although our empirical results are based on the qualitative analysis of four thematic synthesis projects embedded in one large research program, we suggest that they would also be relevant for other synthesis projects. This contention is supported by the positive feedback we received in discussions with different actors, specifically steering committee presidents, program coordinators, implementation officers and representatives of the SNSF involved in past and current NRPs (see section 3.2.). On the basis of these discussions and workshops that also included core team members and experts from science and practice involved in NRP 61 (see section 3.2.), we formulated general recommendations for future synthesis projects. We consider these empirically derived recommendations (summarized in the following sections) to be generally valid and applicable beyond the given context (see also section 7).

6.1. *Conceiving synthesis processes from the outset as an individual project*

Several authors emphasize the importance of conceiving synthesis processes even at the stage of program development (Bergmann et al., 2005; Defila and Di Giulio, 2015; Defila et al., 2006; Lang et al., 2012). We suggest not only to conceptualize synthesis processes from the outset, but also to initiate a corresponding synthesis project concurrently with all other research projects. The synthesis project should be led by an individual or team (ideally the president of the steering committee or a subset of the committee) committed to leveraging transdisciplinary integration within the research program (see also section 5.2.1.).

Ideally, the synthesis project would involve a phasing-in stage where the project team conceptualizes transdisciplinary integration, involving all relevant actor groups (e.g. steering committee, advisory board, scientific experts, practice experts). This involvement would go beyond *information* or consultation with the aim to (i) define the object and purpose of the synthesis project, (ii) formulate common objectives and questions, and (iii) develop a joint vision for knowledge integration (Defila et al., 2006; Lang et al., 2012; Wiek, 2007). The joint vision would serve as a basis for defining and sequencing different synthesis stages, for determining (for each stage) who contributes what, for which purpose and supported by which methods and procedures (Authors et al., *subm.*; Krütli et al., 2010; Lang et al., 2012) and thus for ensuring the right level of actor involvement throughout the process (see also section 5.1.1). Our results underline the need to balance all three types of actor involvement (*information*, consultation, or collaboration) in a „functional and dynamic way“ (Krütli et al., 2010) (see section 5.1.3.), but to favor consultation and/or collaboration over *information* in order to analyze and prioritize data and results (see section 5.1.4.). This would prevent actors' disappointment (Barreteau et al., 2010) and create ownership and increase legitimacy for the final integrated outcome.

Initiating a synthesis project concurrently with all other research projects would allow the project team to steer the individual research projects and commit researchers to achieve the common objectives (Blackstock et al., 2007; Defila et al., 2006; Lang et al., 2012). It would allow researchers, in return, to orient their research activities towards answering the common questions as argued by one core team member:

One task of the synthesis project would be to focus and commit researchers [...] on the common objectives, and thus to prevent research activities from drifting apart - at the expense of answering the common questions. This would also mean that those responsible for the synthesis project would not only act as a rapporteur for the researchers, but also retroact on them. For this purpose, they must necessarily accompany the research process from the beginning and reflect and comment on

it. [...] This would also allow for identifying and bridging some particularly striking gaps that only become evident when looking at the research process in its entirety.

Similar to a phasing-in stage, the synthesis project would ideally involve a phasing-out stage where final synthesis results are first consolidated within the research program and then validated in consultation with all actor groups (e.g. the steering committee, the advisory board, as well as experts from science and practice) and diffused among the target audiences.

However, designing synthesis from the outset as an individual project with an initial phasing-in stage, an intermediate stage of intense transdisciplinary integration and a final phasing-out stage would require some flexibility in terms of funding, time and people (Pohl et al., 2015). This would require that the allocated funding can be distributed over time so that the increasing workload in the intermediate stage (e.g. bridging potential research gaps) can be adequately managed.

6.2. Recruiting the right people to lead synthesis processes

In our empirical study, several core team members emphasized the need to recruit the right people to lead synthesis processes within large research programs. In this regard, one core team member argues:

Apart from structural and methodological aspects, the whole stands and falls with the people. I would suggest selecting people carefully. [...] Selection criteria should be, of course, expertise in the specific research field, but also the willingness and ability for investing some time. [...] The person should have management skills [...] and integrative capabilities to bring people together and, of course, intellectual abilities to get complex things to the point. [...] The person should also bring along an interest in and openness towards the research carried out by the people in the program.

Leaders of transdisciplinary integration must possess both professional competences and management skills, although successful researchers are often still promoted to leadership positions based solely on their professional expertise (Adler et al., 2009). They must be familiar with ongoing disciplinary, interdisciplinary and transdisciplinary research in the field and be capable both of providing an integrative, comprehensive and balanced view on the research topics and of promoting intellectual exchange among experts. They require strong management skills including abilities to: design, conduct, and evaluate synthesis projects; assemble and manage teams; identify and manage multiple interests and expectations; monitor project budgets and schedules; and determine and resolve potential conflicts (Davenport and Prusak, 1998). In addition, they need to be able to devote enough time to their leadership tasks. The demanding set of criteria suggests that a small project team (with sufficient resources and support) may be more effective than a single individual in leading synthesis processes (Krainer and Lerchster, 2015).

823

824 *6.3. Nurturing Communities of Practice*

825 The tasks that leaders of synthesis processes face are complex and call for reflection (Adler et al.,
826 2009; Truffer, 2007). In agreement with Adler et al. (2009), we encourage leaders to participate in and
827 promote Communities of Practice (COP) (Wenger, 2008; Wenger et al., 2002). Such groups of
828 committed leaders share an interest for coordinating, managing, or leading transdisciplinary
829 integration, practice it and learn from each other how to do it better. In this regard, one core team
830 member stated:

831 I think it would have been useful to exchange from the beginning among us [the four core teams]
832 on how to proceed to integrate the research results, on the methods and procedures that exist to
833 bring things together. [...] It would have been helpful, if we would have seen, that some are
834 organizing workshops to jointly develop the report with scientific experts, others are conducting
835 expert interviews to bring things together.

836 Engaging in a COP that develops a shared set of resources (e.g. experiences, tools, methods, and skills
837 for addressing recurring challenges of transdisciplinary integration) will take time, trust, and sustained
838 interaction among the COP members (Cundill et al., 2015). It will allow for mutual learning beyond
839 the boundaries of individual projects (Lang et al., 2012) and for co-developing new approaches (Adler
840 et al., 2009) to transdisciplinary integration within large research programs. It will also strengthen the
841 “learning-by-doing and doing-by-learning” principle where developing theoretical knowledge and
842 testing it through practical experience (learning-by-doing) and developing empirical knowledge and
843 testing it against the theory (doing-by-learning) takes place at the same time (Grin et al., 2010).

844 Two such COPs were set up by the lead author to support leaders in successfully managing
845 transdisciplinary integration: One COP is in her own home institute and includes current research
846 platform/program managers who share a common interest in leading integration at the interface
847 between science and practice. The other COP (initiated together with one core team member of TS 1)
848 spans different Swiss research institutes and universities and links project/program managers who are
849 responsible for knowledge and technology transfer in Swiss energy and water research.

850

851 **7. Conclusions**

852 Empirical studies on synthesis processes within large research programs are lacking. By adapting
853 Enengel et al. (2012)’s analytical framework, we describe, analyze, and compare transdisciplinary
854 integration across four thematic synthesis processes. On this basis, we present core challenges of
855 transdisciplinary integration as perceived by those leading the four processes and formulate
856 recommendations for designing and implementing future synthesis processes. Our results are

857 embedded in the specific context of one large research program, and were discussed with leading
858 actors in past and current NRPs. We consider them relevant for other transdisciplinary programs. The
859 empirical evidence for our results could, however, be strengthened by complementing our study with
860 qualitative studies of larger samples representing different research programs in different contexts. In
861 depth interviews and broader surveys with leaders of synthesis processes and other involved actor
862 groups would help to validate and refine our recommendations and to substantiate our argument that
863 leadership in transdisciplinary integration requires both professional competences and management
864 skills in order to successfully pursue the scientific endeavor of synthesis.

865 Our analytical framework proved to be useful to describe and analyze synthesis processes in terms of
866 knowledge integration and actor involvement and to structure ex-post self-evaluation of completed
867 synthesis projects. Used in a formative evaluation, the framework could support (i) critical reflection
868 on and adaption of transdisciplinary integration, (ii) identification of evidence-based challenges of
869 transdisciplinary integration as experienced by different actor groups involved in synthesis projects,
870 and (iii) formulation of recommendations for improving future synthesis projects. We thus consider
871 our framework a suitable reference frame for the comparative analysis of synthesis processes within
872 large transdisciplinary research programs. Application of our framework to research programs in
873 different contexts could provide insights into the effects of the overall framework conditions of
874 synthesis processes on the success (or failure) of transdisciplinary integration within such programs.

875 Our empirical study benefited from the dual role of the lead author as both core team member of one
876 synthesis process and principal investigator of the concurrent research on transdisciplinary integration.
877 Wearing these two “hats” enabled the lead author to experience directly the challenges that synthesis
878 processes pose in terms of knowledge integration and actor involvement. These insights would have
879 been difficult to gain in a more distant role, for example, as a formative evaluator of the four synthesis
880 processes. It also enabled the lead author to generate new knowledge by reflecting on transdisciplinary
881 integration at the personal, project(s) and program level. We therefore conclude that synthesis
882 processes would benefit from a leader that – if not experienced in transdisciplinary integration – has
883 enough time to reflect on transdisciplinary integration. This would ensure that the scientific endeavor
884 goes in the right direction and would allow a change in direction if necessary (Blackstock et al., 2007).

885

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