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ORIGINAL ARTICLE

How to achieve impacts with sustainability science? Insights from 20 years of work in five biosphere reserves in Europe

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Abstract

Sustainability science aims not only to understand pressing challenges but also to generate positive effects that drive sustainable transitions. However, little is known regarding how well this field achieves the latter goal. To address this gap, we explore the sustainability effects of research projects that have been conducted over 20 years in five biosphere reserves (BRs). Document analysis and expert interviews with BR managers and researchers were conducted to answer: (i) To what extent have BR become model sites in which transdisciplinary sustainable science is implemented systematically to induce sustainability effects? (ii) What factors enable or hinder the creation of positive research effects? Findings reveal that transdisciplinary research is still uncommon in BR but that disciplinary, interdisciplinary, and other smaller projects can also have positive effects. At first glance, this diverse portfolio of effective research types appears surprising because, according to the interviewed experts, key research criteria/principles which promote research effects reflect core aspects of transdisciplinarity, such as the coarticulation of research interests or the involvement of practice partners. These contradictions encourage to rethink sustainability science in BR, thus highlighting the fact that effective science is embedded in productive, short- to long-term science–society interactions that must be established and maintained to systematically generate impacts. Although in larger projects, these interactions can be established within their project framework, for smaller projects, they must be facilitated by a generally beneficial socioscientific environment. BR are important for fostering these environments, thereby serving as long-term intermediaries and knowledge brokers between science and society.

Keywords Sustainability science · Research impacts · Biosphere Reserves · Transdisciplinarity · Transformative science · Science society interactions

Introduction

Humanity is currently facing several unprecedented challenges: climate change, biodiversity loss, and changes in land use are degrading many ecosystems that support biodiversity, human activities, and livelihoods (IPBES 2019; Richardson et al. 2023; Steffen et al. 2015). Finding ways of abandoning current, unsustainable development pathways is thus crucial for efforts to reconcile human activities with ecosystem integrity (UNEP 2024). Sustainability science aims not only at understanding these complex challenges but also at promoting solutions to them (Kates 2011; Sahle et al. 2025) by producing actionable knowledge that practice partners and policy-makers can use to foster sustainable transitions (Clark and Harley 2020; Forrest and Wiek 2014). As a result, sustainability science is often inter- and transdisciplinary in nature and based on collaborative science–society interactions (Lawrence et al. 2022; Sahle et

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al. 2024). Scientists from different disciplines collaborate with actors from beyond academia to jointly define relevant research problems and to generate socially robust and actionable results (see Hansson and Polk 2018; Lang et al. 2012; Wyborn et al. 2019). However, evidence indicating that such research is able to induce sustainability effects has been sporadic (Polk 2014; Wiek et al. 2014), and in general, the literature contains ample discussion of how research approaches can generate transformative impacts (Horcea-Milcu et al. 2024; Jahn et al. 2022).

UNESCO Biosphere Reserves (BRs) are often viewed as potential model regions for sustainability science. They are therefore ideal places in which to study the circumstances under which research can create effects that support sustainability transitions (Barraclough et al. 2023; Reed 2019). The world network of biosphere reserves was introduced in the 1970s to test solutions that could reconcile human development with nature conservation (Bridgewater 2016). Since that time, it has advanced to become a network in which sustainability science is supposed to be implemented (UNESCO 2017, 2025). In accordance with UNESCO's current strategy, BRs are believed to serve as living laboratories that demonstrate how sustainable regional transitions can be achieved in practice and how transdisciplinary research can support these processes (Reed 2019; UNESCO 2017). Research conducted in BRs should therefore have positive effects in the corresponding BR regions and empower local actors to drive sustainability transitions (Barraclough et al. 2023). Although progress has been made in this regard, evidence indicates that research in BRs still rarely meets these high standards. Reviews indicate that at the global level, only a minority of the research in BRs is transdisciplinary but mainly still follows disciplinary lines, with a particular focus on understanding ecosystems (Barraclough et al. 2023; Dabard et al. 2024; Kratzer 2018). Hence, while research in BRs is predominant, research conducted for the sake of BRs or with BR actors seems to be comparably scarce (Dabard et al. 2024; Pool-Stanvliet and Coetzer 2020).

Recently, scientific interest in the factors that enable BRs to become model regions for sustainable development has increased. Ferreira et al. (2018, 2020) and Stoll-Kleemann and Welp (2008) investigated the factors that support or hinder the effectiveness of BR management. Cuong et al. (2017) identified attributes that contribute to the general success of BRs, and Sandström et al. (2025) explored the challenges that prevent BRs from becoming sites of transformational learning. However, despite the fact that research is a core aspect of the BR concept (UNESCO 2017), its contributions to the management effectiveness or success of BRs have been surprisingly underexplored. Among the studies identified above, only Cuong et al. (2017) briefly mentioned research as a factor that can help promote BR success, and Barraclough et al. (2023) acknowledged the general challenges associated with conducting inter- or transdisciplinary research in the BR context.

Furthermore, reviews on the state of research in BRs have hitherto focused only on published papers (Barraclough et al. 2023; Dabard et al. 2024; Kratzer 2018), thus preventing any assessment of the effects of research more broadly. Some studies have evaluated the effects of research (e.g., Malmborg et al. 2022), but these studies have covered only one or a few selected projects. From a theoretical perspective, the task of identifying research effects is also challenging. Although elaborate indicator systems have been developed to assess scientific impact (Belcher et al. 2016; van Drooge and Spaapen 2022), the nonscientific effects of research are often underexplored and more difficult to assess (Polk 2014; Schäfer et al. 2021; Walter et al. 2007). Namely, these effects impact different actor groups, can be intentional or unintentional, and can occur with a time lag or in different geographical areas (Hansson and Polk 2018; Harris et al. 2024; Wiek et al. 2014). As a result, no comprehensive study has yet provided or compared insights into the effects of different types of research in BRs. To close this gap, this study assesses research projects that have been implemented over the past 20 years in five BRs in Europe with the goal of answering the following research questions:

1. To what extent have BRs become model sites in which transdisciplinary sustainable science is implemented systematically to induce sustainability effects?

    a) Which types of research projects in BRs are assumed to have generated positive effects?
    b) What kind of effects did these research projects generate?

2. What factors enable or hinder the implementation of research that generates positive effects?

    a. How should research phases be designed to promote positive effects?
    b. What external institutional influences hinder or enable the implementation of these designs?

The findings offer both theoretical and practical insights regarding the extent to which BRs have become model regions in which research has had positive sustainability effects. This can help sustainability scholars generate impacts with their research and support the world network of BRs reach its sustainability goals.

Analytical framework to capture und understand research effects

To investigate whether BRs have become model regions in which impactful transdisciplinary research is implemented (RQ1), we (i.a.) distinguish between the types of research conducted at the BR and (ib) different conceptualizations of research effects at various levels. To identify enabling and hindering factors for effective research (RQ2), we (iia) conceptualize process principles and quality criteria for different research phases and (iib) potential institutional influences.

BRs as model regions for effective transdisciplinary sustainability research

(ia) Conceptualizing different types of research in BRs

In this study, research is conceptualized as a process that can be divided into several phases in which actors in the realms of science and practice can interact. To capture more complex interactions, we follow transdisciplinary scholars (Brandt et al. 2013; Pohl et al. 2017, 2021) by distinguishing among three major research phases: (i) problem identification; (ii) problem framing and analysis; and (iii) dissemination/use of results (Fig. 1).

The extent of the interactions between actors differs across different types of research. To compare various project types, we follow other authors (e.g., Stock and Burton 2011) by distinguishing among monodisciplinary, interdisciplinary, and transdisciplinary research: In monodisciplinary research, which can be broadly distinguished into natural and social science - methods and concepts of only one discipline are used. Interdisciplinary research involves combining two or more disciplines and integrating their methods and results with the goal of answering shared questions (Klein 2017). Transdisciplinary research goes one step further by aiming to unify knowledge drawn from different scientific disciplines and from nonacademic actors (Lawrence et al. 2022). These actors should be involved in the identification of the research problem, and transdisciplinary results are expected to provide actionable knowledge that can lead to positive real-world change (Hirsch-Hadorn et al. 2008; Jahn et al. 2012; Lang et al. 2012).

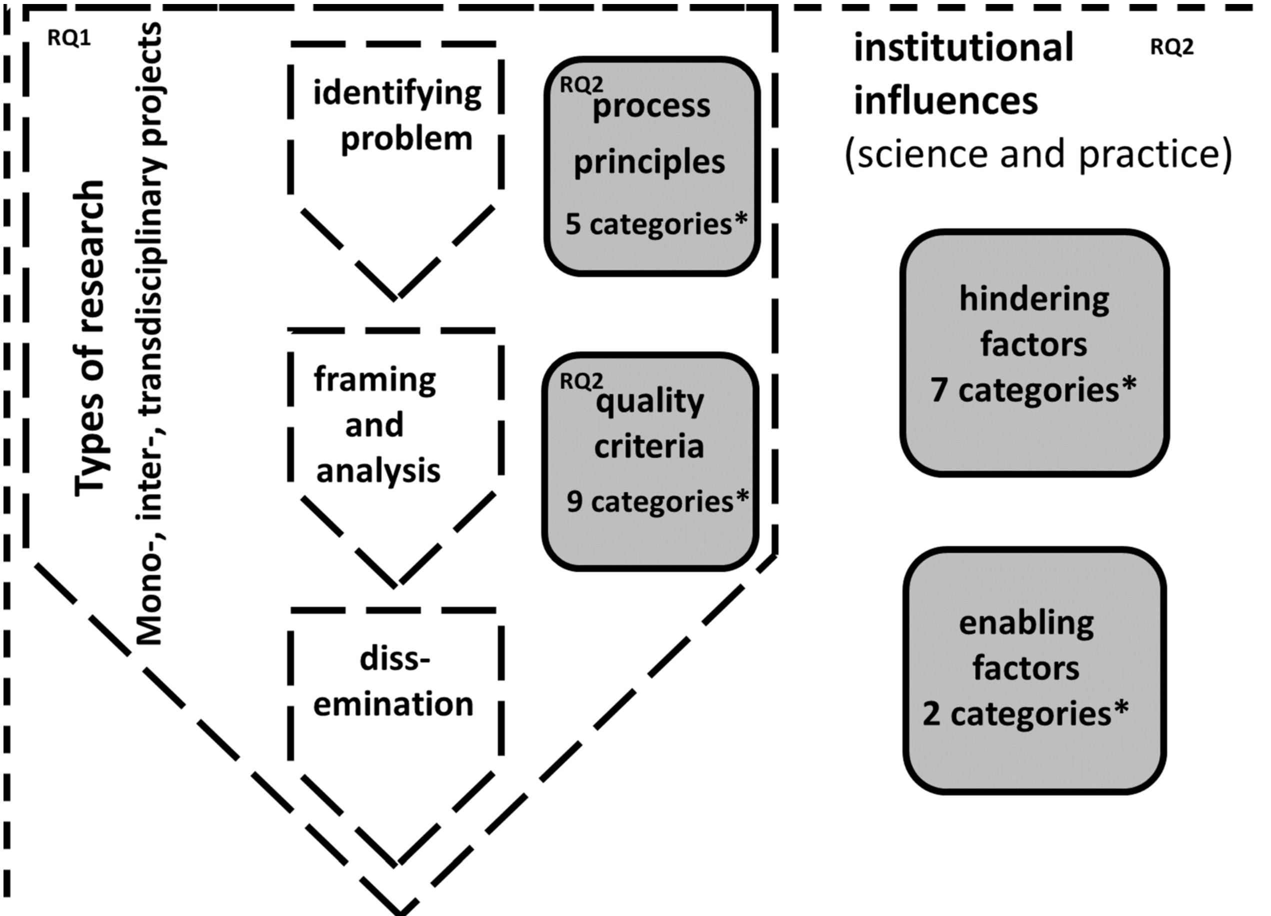
(ib) Capturing research effects

Academic discussions regarding how to evaluate the effects of research (Schäfer et al. 2021) and how to attribute these effects to different research processes have been conducted (Hansson and Polk 2018). Several frameworks (e.g., Belcher et al. 2020; ESRC 2021; Fritz et al. 2019; Mitchell et al. 2015; Wiek et al. 2014) have been created to capture effects, but each such framework has exhibited certain limitations (Schäfer et al. 2021). In this study, the effects of research projects were captured by combining the recent frameworks proposed by Mitchell et al. (2015) and Schäfer et al. (2021). In line with Schäfer et al. (2021), we distinguish between outputs and the broader intended or unintended effects of research. Outputs represent the immediate results of research activities (e.g., academic publications). Broader effects extend beyond research outputs and can be divided into outcomes (the direct effects of results, e.g., the adoption of new dietary guidelines based on scientific studies) and impacts (the broader changes that occur in social-ecological systems, e.g., the improvement of public health due to new dietary guidelines) (Koontz et al. 2020; Wiek et al. 2014). Schäfer et al. (2021) also distinguished among different levels at which effects can occur: first-order (within a research project), second-order (within the close temporal or spatial context of the project), and third-order (changes that extend beyond the context of the project). Schäfer et al. (2021) proposed the existence of concrete types of effects for each level. In this study, we chose to use a more open approach to capture a wider range of effects. Accordingly, the following categories of effects, which extend beyond the production of scientific output, described by Mitchell et al. (2015), are used in this research: improvement of the situation and transformational learning. Both such effects can occur at all levels, as proposed by Schäfer et al. (2021). 'Improvements of the situation' include positive changes in the ecological, economic, and social pillars of sustainable development (Purvis et al. 2019), as well as the connected governance system (Sachs 2012). This type of effect can also include changes within the scientific community. 'Transformational learning' consists of two aspects: First, it refers to changes in the orientation or worldview of involved actors, which can result in altered BR goals and strategies. Second, it refers to the acquisition of new skills and competencies by the groups of actors involved in such a process. Both categories are sufficiently broad to cover most of the types of effects proposed by Schäfer et al. (2021), with one exception: network building. Therefore, this category was added and defined as the creation of new networks or the strengthening of existing networks among actors (see Fig. 1).

Identifying hindering and enabling elements

(iia) Research designs for generating positive effects

To identify enabling and hindering factors with respect to the positive effects of research, we follow Hansson and Polk



	Creation of effects at different levels RQ1		
Levels	Types of effects		
	Improvement of the situation	**Building of networks**	**Learning processes**
1st order effects (within project)	Institutional changes or changes of system conditions during the project 10 categories*	Creation or strengthening of networks between project actors during the project 4 categories*	Acquisition of new skills or new orientation for actors (strategies, goals etc.) during the project 4 categories*
2nd order effects (close to project)	Changes through indirect effects or the re-use of project outcomes 6 categories*	Creation or strengthening of networks between the actors after the project 2 categories*	New skills or orientation after project or other actors 1 category*
3rd order effects (beyond project)	Long lasting changes or changes in other spatial contexts 3 categories*	Creation or strengthening of networks between the actors in other spatial and temporal contexts 4 categories*	New skills or orientation in different spatial and temporal contexts. 1 category*

Fig. 1 Analytical framework used to analyze the effects of different types of research and enabling and hindering factors; *for the actual names of the categories, see Fig. 3, and for a detailed description, see ANNEX 1

Table 1 Overview of BR case studies

BR	General context	Organizational form	Research structures
Entlebuch (Switzerland)	Endorsed in 2001; 396 km², population 17.000	Association of seven municipalities that cover the area of the BR	Dedicated research coordinator; no scientific advisory board
Engiadina Val Müstair (Switzerland)	Endorsed in 2017; 449 km², population ca. 1.600	The core zone is the Swiss National Park, and the majority of the buffer and development zone is covered by a nature park; these two institutions cooperate with the BR management	Research committee for the BR, national and nature park; research responsibles in nature and the national park; for the BR, the general project coordinator is responsible for research tasks
Berchtesgadener Land (Germany)	Endorsed in 1990; 840 km², population ca. 24.000	BR management is a branch office of the government of Oberbayern; the core zone is the National Park Berchtesgaden	General project coordinator of BR management is responsible for research tasks; A research committee exists only for the national park
Grosses Walsertal (Austria)	Endorsed in 2000; 192 km², population ca. 3.450	Association of six municipalities for regional planning	General manager is responsible for research tasks; no scientific advisory board or similar entity is implemented
Nockberge (Austria)[a]	Endorsed in 2012; 840 km², population ca. 10.890	Former national park; BR consists of two parts in two different states; only the Nockberge part is included in this study; the organizational form is an independent public corporation	General project coordinator of BR management is responsible for research tasks; long-term institutionalized collaboration with universities: "Science-Link"

[a]The BR spans two federal states. This study covers only the Carinthian portion

(2018) by assuming that the societal impact of research is, first, connected to the design of the research phases and, second, influenced by external institutional factors. In terms of the design of phases, we further distinguish between process principles and quality criteria. Quality criteria refer to criteria that, if satisfied, make it more likely that research will have effects. Process principles (see Hoekstra et al. 2020), on the other hand, refer to major approaches to the task of designing a research phase that are intended to ensure quality criteria. Both process principles and quality criteria can be identified for each of the three major phases of research.

(iib) External institutional influences

With respect to institutional influences, we acknowledge that the creation of research designs and the implementation of research processes are influenced by the institutional context in the realms of both science and practice (Pärli 2023). In both contexts, factors that either hinder or enable the implementation of suitable research designs can be identified. Figure 1 summarizes the different parts of our analytical framework and identifies which concepts are used to answer which research questions.

Methods

Research was conducted in five BRs located in the Alpine region of Austria, Germany, and Switzerland. Despite the fact that the selected BRs exhibited an overall similar geographical context, they differ in terms of several key characteristics, such as age, size, and administrative context (Table 1).

A document analysis of the periodic reviews[1] provided by the five BRs was conducted to identify research projects that were implemented after 2000. Bachelor's and master's theses, as well as doctoral theses that were unrelated to research projects, were excluded. Since the information contained in the periodic reviews proved insufficient, additional sources were consulted, including BR-specific project libraries, project reports, and publication lists. Finally, the experts interviewed were offered the opportunity to add additional projects to the final list (see below). Regarding all the identified projects, basic information was collected, including the title, a brief description of the research questions and activities, the participating research institutions, the principal investigators and their disciplinary backgrounds, and the funding agencies. On the basis of this core information, the projects were identified as disciplinary, interdisciplinary, and transdisciplinary projects. Disciplinary projects were divided into natural and social science. Furthermore, the additional category of 'agricultural science' was added, since it proved to be difficult to categorize agricultural research as natural or social science. Interdisciplinary projects were required to involve researchers from different disciplines. Transdisciplinary projects were required to involve nonacademic actors in the research design process and/or project implementation. Following a review of the initial categorization, the two additional categories of 'applied project including accompanying research' and 'citizen science' were added since they represented particular forms of science–society interactions. Table 2 presents an overview of the identified projects.

The second step of the data collection process consisted of semistructured, qualitative expert interviews (Gläser and

[1] i.e., standardized reporting that BRs must submit to UNESCO every 10 years.

Table 2 Overview of research projects conducted in the BRs

Types of research	Entlebuch	Nockberge	Walsertal	Berchtesgaden	Engiadina Val Müstair	Sum[a]
Monodisciplinary	21	7	21	12	24	85
Natural sciences	10	3	14	10	16	53
Social sciences	11	1	6	1	5	24
Agricultural sciences	0	3	1	1	3	8
Interdisciplinary	6	9	2	3	1	21
Transdisciplinary	4	1	5	1	1	12
Citizen science	0	1	2	0	2	5
Other[b]	2	4	1	7	1	15
Sum	**33**	**22**	**31**	**23**	**29**	**138**

The bold numbers indicate the total number of projects for each BR

[a]Double-counting was possible if a project was conducted in two or more BR

[b]Applied projects, or projects that could not be categorized

Laudel 2010). First, members of the BR management who were involved in research coordination were contacted. These individuals were given a list of identified projects associated with their respective BR prior to the interviews and asked to (i) add any missing research projects and (ii) rate the projects in terms of their perceived effects on the social, economic and environmental development of the BR, as well as the connected governance. This rough characterization was used to create diagrams, which served as a starting point for the interviews. In the interviews, the BR staff was asked to (i) describe the effects of highly rated projects; (ii) describe the differences between these projects and those that received lower ratings; and (iii) explain the reasons why higher-rated projects had more effects than the other projects did. In total, 13 interviews with current or former members of BR staff were conducted.[2] Subsequently, researchers who had played a central role in highly rated projects were identified. 12 expert interviews were conducted with researchers to obtain a scientific perspective on the generation of effects and the underlying reasons. The interviews with the BR staff were conducted face-to-face. Interviews with researchers were conducted partly online via Zoom. The durations of the interviews—which were recorded and transcribed—ranged between 30 and 120 min. An inductive-deductive qualitative content analysis was conducted following the suggestions of Kuckartz and Rädiker (2023). The main categories of the analytical framework used for deductive coding were as follows:

- Research effects:
  - type of effects (network building; transformational learning; improvement of the situation),
  - levels of effects (first, second and third order);
- Enabling and hindering elements:
  - research process principles (in different research phases); research quality criteria (in different research phases).
  - institutional influences (enabling and hindering factors).

Within these main categories, more specific codes were created inductively. In total, 35 different inductive codes for effects were created (see Fig. 1). Coding was performed by one researcher under the supervision of other members of the research team with the assistance of Atlasi.ti software (2023). For a detailed description of all the code categories, see ANNEX1.

Finally, the findings regarding enabling and hindering factors related to effectful research according to the expert interviews were discussed and validated at a workshop at Euromab24. Euromab is a biennial meeting of BR managers, researchers, and UNESCO staff. At this workshop, a world café was organized for 9 members of BR staff or actors who were associated with BRs, as well as 9 researchers. The participants were not members of the case study BRs and had not participated in the previous steps of data collection. The participants identified hindering and enabling factors with respect to effective research. The findings were used to obtain a better understanding of whether the results of the interviews could be considered complete and comprehensible.

[2] One of the authors is also a member of one case-study BR management. An interview with that author was conducted. The author in question was not involved in the analysis of his own interview material.

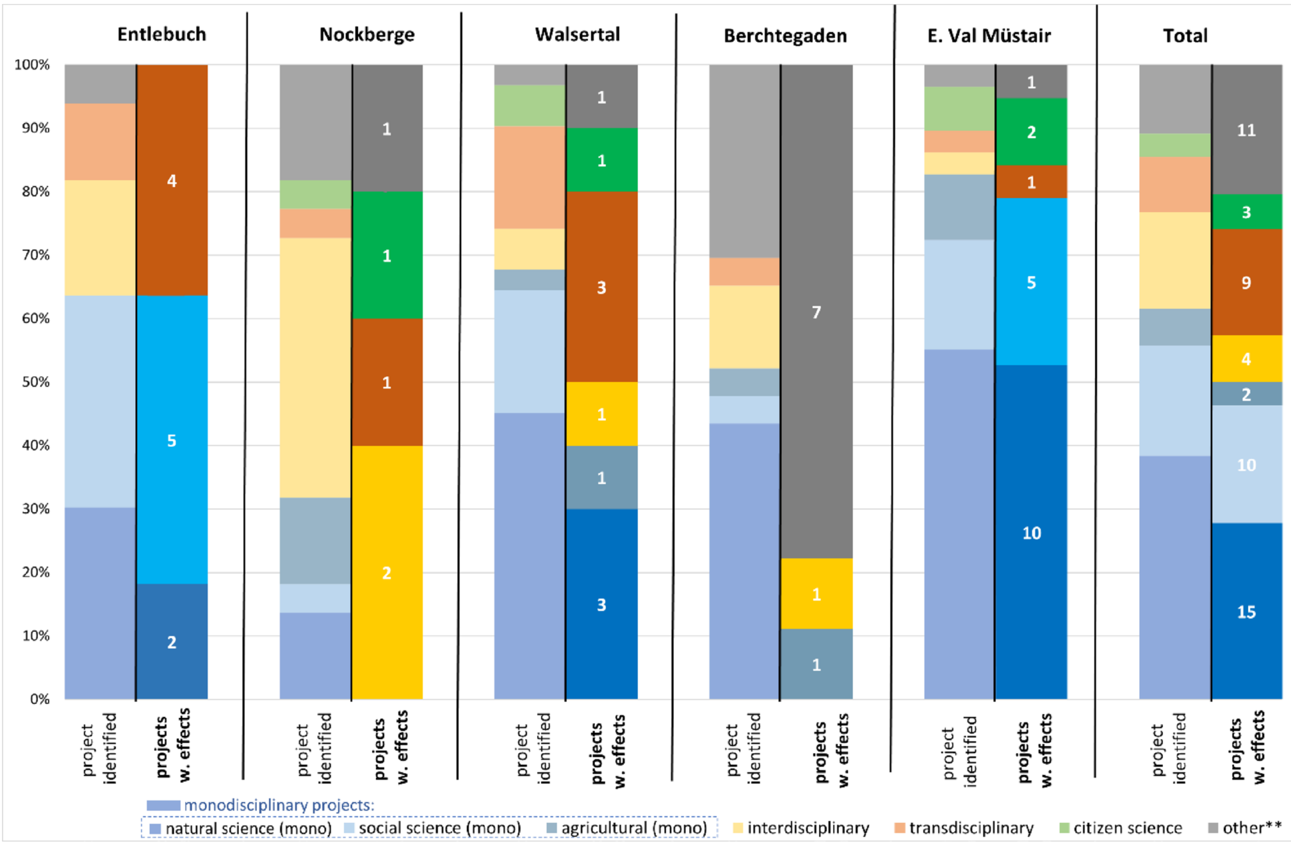


Fig. 2 Prevalence (as a percentage) of different types of research projects among all identified projects (left column of each BR with transparent colors) and among the pool of projects with effects (right columns with full colors). The numbers in the right columns indicate the number of projects that had effects for each type of research. The numbers of overall identified projects for each are presented in Table 2. **All 'other' projects with effects represent smaller applied projects. 'Other' projects in the overall pool of projects (left columns) also partly include projects that could not be categorized

Results

Biosphere reserves as model regions for sustainability science

Research projects and their effects

Most of the research projects conducted in the case-study BRs are monodisciplinary (85 out of 138 projects; see Table 2) and focus predominantly on natural sciences. Interdisciplinary, transdisciplinary, and other projects were also conducted, albeit to a lesser extent. Among the total of 138 projects, the interviewees considered 54 projects as having noticeable effects, as defined in our framework. Consequently, the following results are derived from these 54 projects.

A wide variety of project types are considered to have effects (Fig. 2): (i) applied projects with a regional economic or conservation focus, in which predefined research tasks were assigned to research institutions (in total $n=9$); (ii) monodisciplinary natural science research that focused mostly on biology, nature conservation or geoscience, including some monitoring projects ($n=15$); (iii) monodisciplinary agricultural research projects (n=2); (iv) monodisciplinary social science projects such as surveys or economic impact assessments ($n=10$); (v) interdisciplinary projects ($n=4$); (vi) transdisciplinary projects ($n=9$); and (vii) citizen science projects ($n=3$). Furthermore, despite being excluded from the document analysis, interviewees from Engiadina Val Münstair mentioned the importance of bachelor's and master's theses.[3]

In comparison to the overall set of identified research projects (Table 2), some project types were more frequently identified as having effects than others were (Fig. 2, right columns). This point is particularly applicable to transdisciplinary projects, applied projects, and citizen science projects, at the expense of monodisciplinary natural science and interdisciplinary projects.

The share of project types that are considered to have effects varies strongly among the case-study BR (Fig. 1).

[3] These theses are not depicted in the table, but their impacts are described in the following sections.

Entlebuch features the highest share of transdisciplinary projects and a comparably high number of monodisciplinary social science projects, such as economic impact assessments. Nockberge considers all types of projects, other than monodisciplinary research as having effects. In comparison to the other BRs, interdisciplinary research is more prominent in this context. Grosses Walsertal features a large number of research projects with effects, in which context monodisciplinary scientific projects and transdisciplinary projects occupy prominent positions. Engiadina Val Müstair is characterized by a high number of monodisciplinary natural science projects, which were often conducted in the national park, alongside a strong prevalence of citizen science. In Berchtesgadener Land, mainly smaller, applied projects are generally viewed as having effects. This variation highlights the importance of the diverging context conditions of the five BRs under research (see Table 1). For example, Entlebuch is the only case-study BR to feature a dedicated research coordinator, whichcould explain why that BR is able to engage in many larger transdisciplinary projects. Engiadina Val Müstair features a strong research commission run by the national park, which directs research jointly with the BR management, thus maybe explaining why natural science projects are viewed as having effects. In contrast, the mission of Berchtesgadener Land focuses on regional development, and its research ties with its enclosed national park are less intensive.

Effects generated through research in BRs

A wide range of effects cover all aspects of the analytical framework (Fig. 3) have been identitied.

Network building: Interviewees consistently acknowledged the fact that activities in all types of research projects contributed to network building. Depending on the individuals who participated in the projects, networks can be established among different types of participants: BR managements and researchers, BR managements and practice partners, researchers and practice partners, or multiple BR managements. Projects that involved collaboration or frequent exchange among actors contributed more strongly to network building. With respect to effects beyond the context of the immediate project (i.e., second-order effects), the interviewees acknowledged that sometimes, new networks were created after the end of a project. For example, different actors connected again because they remembered the success of an earlier research project and established new networks to develop follow-up activities. The continuous growth of the personal networks of the BR managers and project coordinators was also mentioned. This growth

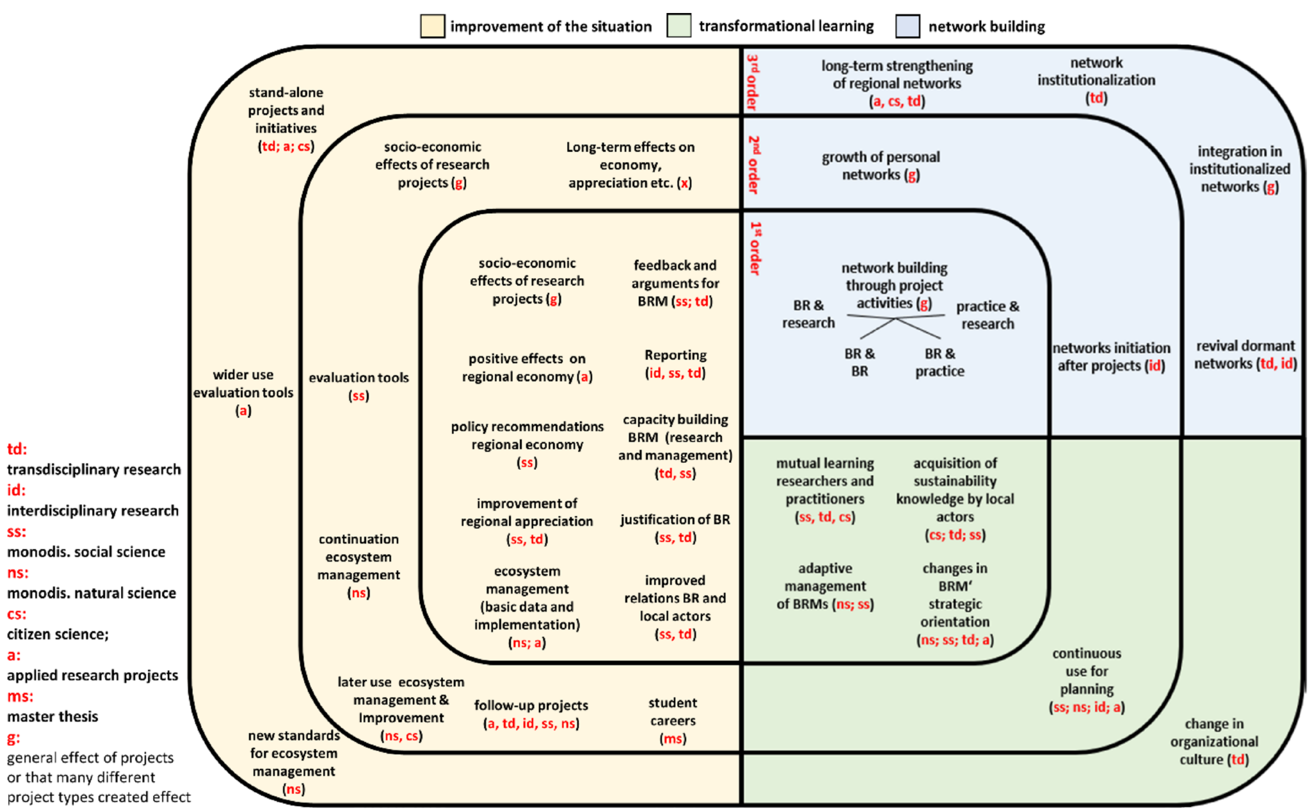


Fig. 3 Identified effects resulting from different types of research projects. Note that this figure provides only an overview of the portfolio of effects and does not indicate their strength

represents a positive feedback loop, in which successful projects lead to wider personal networks, which subsequently result in more requests to participate in research projects. At the third level, we noted that transdisciplinary projects caused the revival of networks that had been dormant for some time and also the institutionalization of networks (e.g., the formation of committees to manage certain initiatives). Furthermore, transdisciplinary and applied projects led to the long-term strengthening of networks among local actors. For example, one applied project contributed to the establishment of a label for BR products. The introduction of the new product line led to increased collaboration among food manufacturers, BR management, and touristic businesses. Finally, different project types led to the integration of BR managements into existing institutional networks, such as research platforms.

Transformational learning: Most of the effects that were observed within a project framework were connected to learning by members of BR management. Learning was often noted as being used for adaptive management. For example, remote sensing data drawn from a natural science project were used to improve the management practices of mountain meadows. Some monodisciplinary-, interdisciplinary, and transdisciplinary projects caused changes in management plans or even the strategic direction of a BR; e.g., a social science project induced new strategic initiatives, such as efforts to involve younger generations in BR activities. To a lesser extent, the acquisition of broader sustainability knowledge by local actors, such as learning in citizen science projects or mutual learning between practice partners and researchers, was mentioned. The identification of broader, higher-order learning effects generally proved to be more difficult. Nevertheless, certain project results were noted as having subsequently been used repeatedly to facilitate adaptive management and strategy evaluations, for example, the creation and use of species inventories for monitoring purposes. These results were mostly studies in which baseline data concerning the BR in question were collected. With respect to one transdisciplinary project, the interviewees also noted that its results were able to partially change the organizational culture of the BR management, which is considered to constitute a long-term effect.

Improvement of the situation: As a result of the broad definition of this category, various effects have been identified. First-order effects: An initial group of frequently identified effects included project results that were directly useful for the BR managements in their daily work, such as results that provided important feedback concerning past decisions or evidence-based arguments pertaining to ongoing discussions. Other effects in this category include the following: results demonstrating the economic or social values of the BR, such as added value studies or people's identification with the BR; research that improved the relationship between the management of the BR and local actors, for example, through participatory project designs that unified management with other relevant actors; and research that improved the management capacity of the BR, either by providing funds to hire new staff or by introducing new tools to facilitate tasks. The second group of effects was socioeconomic in nature. Some interviewees mentioned that research conducted in a BR usually affects the BR region in question because money is spent by researchers and new contacts are made. Some projects produced policy recommendations aimed at improving the regional economy, which were distributed to local actors. Other project results had direct effects on the regional economy, for example, because they formed a basis for the introduction of new product labels. This group mostly included applied projects. Finally, transdisciplinary projects or those involving social studies, in which residents were asked about their opinion on the BR, improved regional "appreciation" by fostering people's identification with and appreciation of the region in question, e.g., through participatory processes. The third group of effects was caused mostly by natural science research and improved the ecological situation, either by providing baseline data or by improving ecosystem management.

Second-order effects: Many of the identified second-order effects can be assigned the same category types as the identified first-order effects, such as socioeconomic effects of the research itself, effects on the regional economy, feelings of regional identification/belonging, or ecosystem management. The difference in this regard lies in the fact that some of the project outputs had effects after the project was completed. Additionally, certain effect types that were more unique to the second level were identified. These types include the creation of new management evaluation tools as a result of social science projects that were subsequently reused by BR management, the acquisition of follow-up research projects, efforts to promote the future career development of students who wrote bachelor's or master's theses, and the conservation of ecosystems through the transfer of responsibilities to local actors.

Only a small number of projects that exhibited third-order effects were identified. At the highest level, we identified the development of more widely used research and evaluation tools. For example, we identified a social science project in which a method for assessing the added value of the BR was developed and subsequently used as a standard in other contexts. Another project led to the establishment of new norms for ecosystem management. In this context, a long-term natural science study revealed how the negative impacts of hydropower facilities on biodiversity could be avoided by changing management practices. Finally, some

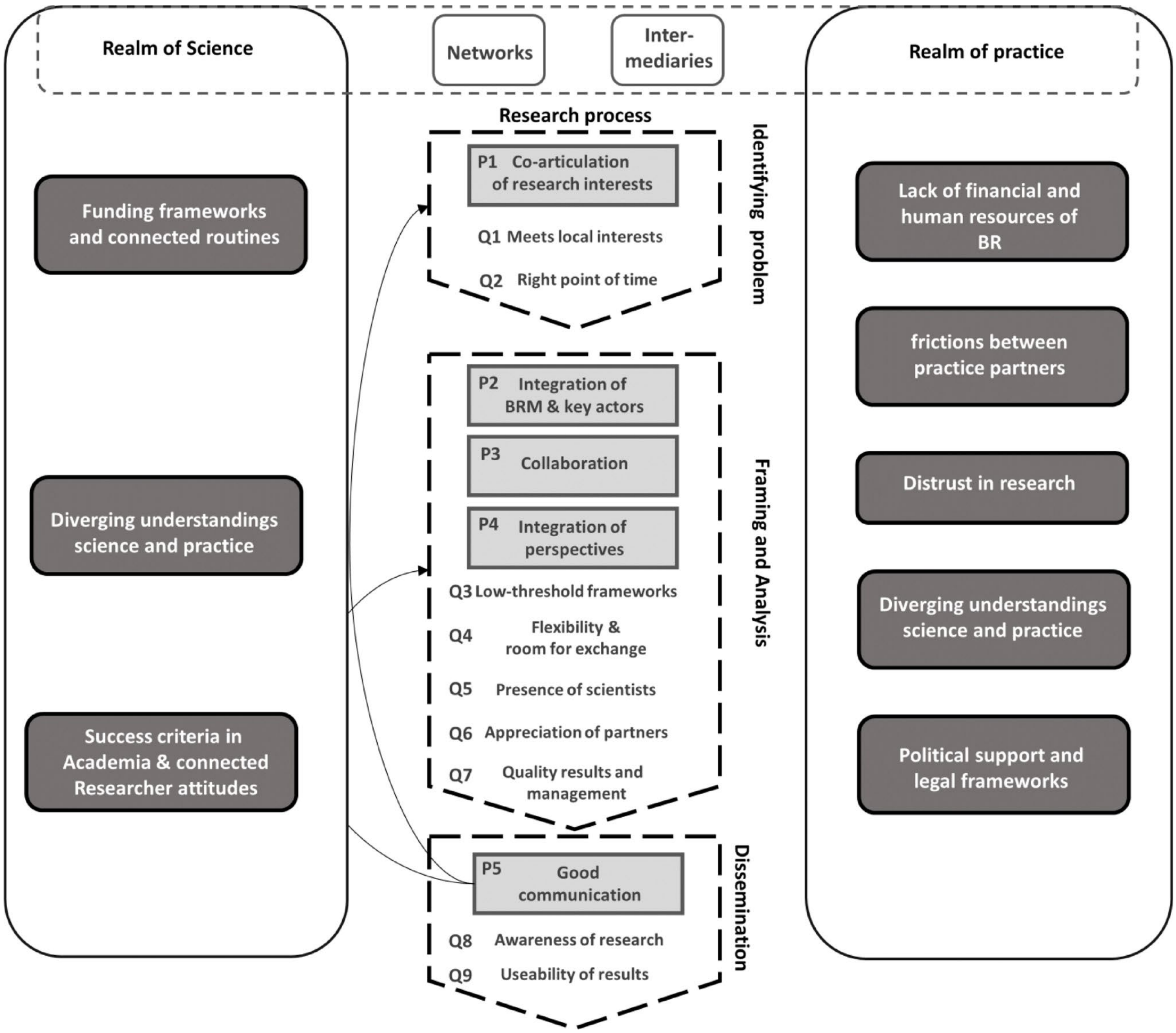


Fig. 4 Process principles, quality criteria, institutional influence factors that can promote effects; process principles (P1–5): light gray squares within research phases; quality criteria (Q1–9): text in the research phase; Institutional barriers: dark gray squares; institutional enabling factors: light green squares

transdisciplinary and applied projects resulted in stand-alone projects and initiatives that positively impacted the regional economy. For example, in Entlebuch, the idea of using the yearly return of cattle from alpine pastures (Alpabtrieb) for tourism was developed during a research project. The Alpabtrieb is currently one of the most successful tourism events in the BR, attracting 10,000 people and generating income for local farmers and retailers while simultaneously preserving the region's cultural heritage.

What factors enable or hinder positive research effects in BRs?

Research designs for effective research

Nine quality criteria for different research phases emerged from the interviews, representing a checklist of characteristics that, if implemented, should lead to sustainability effects in BRs. In addition, five main process principles pertaining to different research phases were identified, each of which represents a main strategy for satisfying one or more quality criteria (Q1–9 and P1–5 in Fig. 4).

For research to have effects, the research problems identified within the first phase of research must (Q1) be in line with the interests and needs of local actors and (Q2) be addressed at the appropriate time. These criteria entail that such problems must be addressed before important decisions are made or when resources are available to implement research-based measures. To achieve this goal, the BR managements and scientists interviewed viewed the coarticulation of research interests (P1) as crucial. From the perspective of BR managements, context-specific research interests within the BR region must be articulated by the management or practice partners. From the researchers' perspective, an additional task involves reconciling these interests with the state of the art, thus ensuring that the questions are valuable to both practice and science.

With regard to the second research phase, several quality criteria were identified: (Q3) projects should rely on low-threshold frameworks (i.e., terms and concepts that are easily understood) and avoid abstract project designs; (Q4) the research process should allow for sufficient flexibility to adapt to local needs and to provide space for exchange; (Q5) researchers should be present in the region and engage in exchange with local actors; and (Q6) practice partners must feel appreciated in the context of research processes. Finally, (Q7) high-quality results must be generated through professional management. The first important process criterion pertaining to this phase stipulates that the BR management and other key affected actors should be involved in the framing and operationalization of the research problem (i.e., the formulation of questions and selection of methods), as well as in the implementation of the research project (P2). This approach can help avoid abstract project designs, adapt processes with the aim of increasing their value to local actors, and ensure that the actors themselves feel appreciated. In addition, as researchers often noted, BR managements can play a crucial role in the processes of bringing researchers together with key actors and potential research participants in the region. They also can support research, and communication activities. The second important process criterion that was identified by BR managements and researchers is good collaboration between science and practice (P3). Participatory or collaborative research activities that allow actors to participate in research can grant them a voice. Depending on the type of project in question, participation can range from participating in surveys to cocreating knowledge. Collaborative research can bring scientists and practice partners together and foster exchange. This approach is likely to promote the use of lower-threshold frameworks and make research easier for practice partners to understand. In general, the integration of different perspectives from different scientific disciplines and from both academic and nonacademic actors was viewed as positive (P4). Only a few interviewees pointed out the risks and additional management burdens associated with these more complex, collaborative processes.

With regard to the third research phase, it was viewed as crucial to ensure that (Q8) relevant actors are aware of the research and that (Q9) the results are presented in a format that is usable for practice partners. With respect to both main process principles in this phase, the effective communication of results (P5) is essential. This process includes the translation of scientific results into a form in which they can be understood and valued by practice partners. However, the communication of results and activities should not only occur at the end of a project but also be a continuous task throughout the research process. Ongoing communication increases interest and is an important component of efforts to establish relationships between researchers and local actors. BR management can support this process through their communication channels. Regarding the use of results, it becomes obvious that the process and quality criteria are interrelated across the boundaries of the different research phases (as indicated with arrows in Fig. 3). For example, the coarticulation of research interests also increases the usability of results.

A broader range of institutional factors that influence research design

A distinction in institutional influences is made between factors that pertain to the realm of science and those that pertain to the realm of practice (Fig. 4). With respect to the first set of factors, the structure of research 'funding frameworks and connected academic routines' are often viewed as a hindrance to the coarticulation of research interests. Writing proposals requires both time and resources. Often, BR managements cannot invest in such activities because of a lack of resources or expertise, especially given the highly competitive nature of calls for proposals. Similarly, researchers are busy with academic work and rationales, and they often express little interest in involving BR managements or practice partners in proposal-writing processes. As a result, practice partners are often contacted only after the main points of a proposal have been defined. The barrier labelled as 'success criteria in academia and connected researcher attitudes' reinforces this dynamic: Research careers depend on publications and the acquisition of project funds. In both respects, in comparison with disciplinary studies, transdisciplinary research is often viewed as entailing certain disadvantages. As a result, researchers are viewed as less interested in coarticulating research interests and collaborating with practice partners and more focused on publishing in academic channels than on target-group-oriented communication.

In the realm of practice, an essential barrier is the 'lack of financial and human resources of BR', which prevents relevant actors from actively participating in the processes of shaping research designs and partaking in research activities. BR managements often lack the necessary capacity and cannot staff research coordinators, thus hindering both the coarticulation of research interests and the integration of BR management into the research process, as well as effective communication. Second, the 'distrust in research' exhibited by local actors can make it difficult to involve them in collaborative research processes. The COVID-19 crisis was identified several times in the interviews as a factor that further undermined trust in research and made collaboration more difficult. In addition, 'friction between practice partners' can similarly hinder collaborative research approaches and the coarticulation of research interests. Finally, a 'lack of political support and legal frameworks' may limit impacts because the necessary support of decision-makers cannot be acquired or because legal frameworks hinder impact creation.

One barrier that pertains to both research and practice is represented by 'diverging understandings in science and practice'. Interviewed researchers sometimes highlighted practice partners' lack of understanding of how science works and what it can do, which can lead to unrealistic expectations. Similarly, BR managers noted that some researchers do not understand the livelihoods of their practice partners, thus leading to inappropriate project designs and results that are not of interest to local actors.

Finally, two enabling factors that pertain to research and practice can facilitate positive effects by connecting these two realms: the existence of 'networks' and 'intermediaries'. Both of these factors can help overcome barriers and enable the implementation of process principles. Networks refer to productive and long-term relationships among researchers, BRs and practice partners. Intermediaries are organizations that can link research with practice. In our findings, BR management was often observed to play this role.[4]

Discussion

BRs as model regions for sustainability science?

This study aimed to close the knowledge gap regarding the sustainability effects of research in BRs and the role of BR in facilitating these effects. Accordingly, the extent to which BRs serve as model sites in which transdisciplinary sustainable science is implemented systematically to induce sustainability effects (RQ1) and how such effects can be enhanced by appropriate research designs and institutional factors that influence their implementation (RQ2) were assessed.

With respect to RQ1, the findings suggest that despite UNESCO's push for BRs to serve as model regions for transdisciplinary sustainability science (Pool-Stanvliet and Coetzer 2020; Reed 2019; UNESCO 1996, 2017), this goal has not been achieved to a high degree. Confirming the findings of previous studies (Barraclough et al. 2023; Dabard et al. 2024; Kratzer 2018), research projects conducted in the five case-study BRs were mostly monodisciplinary. Transdisciplinary projects represented a minority. Furthermore, only 54 of 138 projects were determined by the interviewees to have had noticeable effects. This indicates that there is still potential to increase the impact of research in BRs. While transdisciplinary research plays a prominent role in the process of creating effects, a variety of other types of research are also perceived to generate such effects. This finding supports claims that not only ideal-typic transdisciplinary but also monodisciplinary, interdisciplinary or applied projects play a role in promoting sustainable development (Jahn et al. 2012; Scholz and Steiner 2015). When the identified effects are examined more closely, it becomes clear that many of them are connected to the fundamentals and practices of BR management. Examples include the adaptation of BR strategies on the basis of scientific evidence, the strengthening of management capacities, network building, or the improvement of the relationship between the BR management and local actors. According to our framework, these effects qualify as outcomes of research projects rather than impacts. Accordingly, the effects are initially mostly related to changes in the practices of BR management and do not directly change the social, economic and ecological systems in the BR regions. For example, many projects lead to changes in the strategic orientation of BR and the integration of BR into wider networks, or they provide new evaluation tools or facilitate BR reporting. However, these outcomes can increase the BR management effectiveness (Ferreira et al. 2018) or success (Van Cuong et al. 2017). As a consequence, these outcomes can have additional indirect positive impacts in the long term, since they enable BRs to achieve their management goals more effectively. For example, in one case, network building led to new collaborations that allowed for improved ecosystem management through the establishment of cooperation with new practice partners. Similarly, outcomes that make the tasks of BR management easier, such as the development of new evaluation or reporting tools, can free up resources that may then be used for activities that directly improve social, ecological and economic systems.

[4] Findings obtained at the validation workshops at EUROMAB24 largely support these results. Further details can be found in ANNEX 2.

With respect to RQ2, we identified principles and quality criteria pertaining to research processes that are believed to promote research effects and revealed that these elements reflect key aspects of transdisciplinary sustainability science. The process principles identified in this context—the coarticulation of research interests, the participation of relevant actors, and target group-oriented communication aimed at generating actionable knowledge—have been suggested to serve as core components of transdisciplinary research (Brandt et al. 2013; Jahn et al. 2012; Lang et al. 2012; Pohl et al. 2021; Steger et al. 2021). The quality criteria thus identified can also be viewed as a checklist for efforts to achieve effective sustainability science, as they contribute to the credibility, relevance, and legitimacy of research (Belcher et al. 2016; Cash et al. 2002; Polk 2014). Our analysis also identified institutional barriers that can hinder the implementation of effective research processes. These findings partly reflect previous studies (Djinlev et al. 2023; Hansson and Polk 2018; Polk 2014; Wyborn et al. 2019) but are here connected to the identified research principles and criteria, thus allowing them to provide additional insights into how impactful research can be promoted.

How can effective research and constructive research environments be promoted?

Scientific literature on barriers to effective research has suggested improvements to the quality of science–society interactions (e.g., by fostering relationships, supporting meaningful collaboration, or managing power relations) or the capabilities of the actors involved (e.g., by accepting ambiguity or developing transdisciplinary skills) (see, e.g., Harris et al. 2024; Kok et al. 2021; Thagard 2014). These general suggestions also seem to be applicable to our case studies. However, (i) identifying institutional barriers, required research designs, and the links between these two elements and (ii) exploring different framework conditions in the case study BR allows us to provide more concrete recommendations in this regard.

In terms of overcoming identified hurdles, three suggestions can be made with respect to the coarticulation of research interests: First, funding bodies should strengthen their approaches to seed money, thus allowing researchers and BR actors to develop research ideas jointly in open formats and with little administrative burden. These research ideas can then progress to a second stage, where full proposals are written. This approach would provide BR managements with the resources required to engage in research processes. Second, funding programs could be made more receptive to the research needs of BR. In the process of preparing calls for proposals, the needs of BRs could be collected and integrated into the mission of the calls. The existing national committees of the MAB program could provide platforms for this process and try to convince funders to launch BR-specific calls. Third, BR could take preemptive action to develop research agendas. These strategies can specify local research needs and standards of good research that should be met when BR managements invest time and resources in a given project. Such an agenda would provide incentives for researchers to consider the interests of a BR when conducting research in it.

During the process of research framing and analysis, a major obstacle lies in the fact that BR managements often lack the capacity necessary to participate in the operationalization of research ideas and to support participatory processes. In this context, research projects that actually facilitate capacity building in BRs would be highly valuable (Barraclough et al. 2023). Furthermore, to make research more relevant to BRs and use windows of opportunity, the design should be sufficiently flexible to allow adaptations within the projects and even be open to sudden new developments (Polk 2014).

With respect to the dissemination and use of results, previous research has emphasized the important role of effective communication (e.g., Lang et al. 2012; Wiek et al. 2014; Wyborn et al. 2019). In addition, our study highlights the fact that it is not only the communication of results that is important but also the communication of planned, ongoing, and realized research activities (including communication before the start of a project). Constant, effective, and targeted communication regarding research should be viewed as an essential element in the process of establishing strong relationships among researchers, management, practice partners, and the public.

Finally, as discussed, the establishment of networks between science and society is key to overcome many of the identified challenges. BR managements can play a crucial role in this context by serving as intermediary organizations that connect researchers and local actors. Certain existing examples of good practice reveal that collaborations between BR and researchers have been institutionalized with the goal of promoting the ongoing identification of research interests and their translation into research projects (see, e.g., Falkner and Rauch 2020). Furthermore, structures such as institutionalized transdisciplinary platforms, in which scientists, BR, and local actors collect and frame locally relevant and scientifically interesting research questions or develop research agendas, should be promoted (see Schneidewind et al. 2018).

A comparison of the multiple BRs considered in this context highlights the fact that context-specific recommendations are needed for different BRs. The findings of this research offer the first insights into how BRs that feature different governance contexts and either more or less resources can navigate the challenges associated with promoting impactful research. BRs with fewer resources, for example, face difficulties in terms of engaging in complex research collaborations and are thus particularly suitable for research projects that can support the capacities of BR managements. Predefined research agendas can help these BRs invest their limited resources more effectively. In contrast, BRs with solid financial resources can engage more directly in research acquisition or the establishment of institutionalized forms of science–society interactions. Another example of the importance of context is that, according to the findings of this research, the nature of relationships with any enclosed national park can have a major influence on whether natural science projects are viewed as generating effects. Stronger cooperation between BR and NP in this context can help add value to these projects.

Two surprises to rethink the role of sustainability science in BR

Two particular findings of this study further encourage us to rethink the role of sustainability science in BR, as well as more generally. First, our results highlight the contradictory fact that, on the one hand, the proposed process principles for the generation of positive research effects clearly mirror well-established features of transdisciplinary research (e.g., Brandt et al. 2013; see above). This finding reinforces the impression that transdisciplinary approaches are needed to create such an impact. On the other hand, we also identified a large number of nontransdisciplinary projects that were perceived as exerting considerable impacts. This contradiction raises the question of how such a diverse portfolio of projects, many of which lack transdisciplinary elements, can still have positive effects. Hence, our results indicate that the aforementioned quality criteria (e.g., finding the right research question at the right time) can also be met by means other than transdisciplinary research projects. In light of our findings, we emphasize the importance of looking beyond research in the context of single-project frameworks (see also Dabard et al. 2025; Horcea-Milcu et al. 2022) by highlighting the entire network of existing projects over a longer time period: our findings indicate the crucial role played by long-term, productive science–society interactions (Spaapen and van Drooge 2011), thereby facilitating continuous exchange between researchers and local actors and establishing a constructive socioscientific environment (see Schneidewind et al. 2018). These environments allow key characteristics of transdisciplinary research to be established beyond the scope of individual projects. As a result, such environments also help smaller disciplinary projects have relevant effects because they can address the research needs of local actors that have been articulated in advance or use established channels of communication to disseminate results. The hypothesis is that (see also Harris et al. 2024; Wyborn et al. 2019) creation or strengthening of these environments would allow different types of research to have effects, and it is precisely at that intersection between science and society that BRs could increasingly play a role: BR managements as effective intermediary organizations, could effectively fulfil a pivotal function in the relationship between scientific and local networks and increasingly serve as brokers between science and practice (Hilger et al. 2021; Wiek 2007). Our case studies indicate the presence of ample potential to improve the capacity of BRs in this respect, since even in the rather well-funded Middle European context, only one BR features a scientific coordinator.

Second, we would like to revisit the finding that many effects are not equivalent to direct impacts in the BR regions but rather improve the management effectiveness of BRs (Ferreira et al. 2018, 2020; Stoll-Kleemann and Welp 2008). On the one hand, this situation could raise concerns that sustainability science is far from reaching its goals, since its effects are often restricted to research outcomes (see Wiek et al. 2014). On the other hand, however, the findings of this research could offer a more productive perspective on how research could more easily achieve positive sustainability impacts: In practice, most research activities initially generate only scientific outcomes. From this level, the generation of genuine impacts can involve a lengthy process (Wiek et al. 2014; Klein 2017). As our findings reveal, this process involves many obstacles, and smaller or more discipline-oriented research projects lack the necessary means to overcome them. The dichotomy between science and practice, which is often reiterated (see Hilger et al. 2021), can give rise to the idea in sustainability science that researchers on one side must generate impacts for practice on the other side. This gap might be too large for many nontransdisciplinary research projects to address. The findings of this study suggest a potential pathway by which this gap can be bridged. They highlight the fact that organizations such as BRs could serve as recipients of many research outcomes, thereby ensuring that those outcomes are being constructively used and enabling them to have genuine impacts. Sustainability scholars should be aware of the limitations of academic frameworks and should not aim to generate direct impacts in cases in which doing so is unrealistic. Additionally, research programs that specifically asking for such impacts should be aware of these limitations; instead, if they want to have impacts, they should actively search for allies who can serve as intermediaries to practice, as in the case of BR.

Limitations of this research

First, the main method used in this study to assess the effects of research relied on expert interviews with members of the BR management and researchers. While we believe that the insights provided by these experts are valuable, we acknowledge that they could also introduce bias in comparison to other, more objective forms of impact assessment. For example, effects that are closely connected to BR managements could be emphasized more heavily, whereas effects that are not could be underemphasized. Second, the selected research design focuses on the positive sustainability effects of research, and participants were asked to rate projects in terms of their positive sustainability effects. Negative impacts were not spontaneously mentioned during the interviews, with the exception of one instance in which the implications of conducting research on the socioeconomic conditions of small villages were named. Finally, despite the comparison of multiple BRs with varying contexts performed in this research, the findings obtained from our five case studies can only be generalized to a certain degree. This point is particularly applicable since all case-study BRs are located in Western Europe, and certain aspects that play important roles in other contexts (e.g., the involvement of indigenous communities; see Reed 2019) are therefore not addressed in this article. However, the findings of this research can still provide initial insights into context-specific challenges associated with BRs, since also at the global level, BRs differ in terms of features such as the availability of resources or institutional connections to other protected areas. Therefore, the variety of the cases considered in this research allowed us to propose initial hypotheses regarding challenges and opportunities to generate research impacts in different "general" types of BR. In this context, our findings have been affirmed by researchers and BR management staff who were not involved in the case study of BR at Euromab24. Further research that can focus on other geographical and socioeconomic contexts may complement our findings.

Conclusion

This study is the first to investigate the potential ability of BRs to serve as a model region for sustainability science by examining the positive effects of such research on multiple BRs and exploring ways in which those effects can be promoted in the future. The findings of this research indicate that BRs have not yet become model regions that systematically implement transdisciplinary sustainable science and that the potential of research to generate regional sustainability impacts has not been fully exploited. Only a fraction of the projects that have been implemented in the past 20 years in the fivecase study BRs are transdisciplinary in nature, and only a limited number of projects were considered to have had sustainability effects. Moreover, this research identified a large variety of research effects. Some of these effects qualify directly as impacts on social, economic or ecological systems in the BR, whereas others increase the management effectiveness of BRs and thereby have indirect impacts. Effects were generated by a diverse portfolio of project types, in which transdisciplinary projects occupied a leading position. However, applied projects, disciplinary natural and social science studies, citizen science and interdisciplinary projects also proved to be capable of generating meaningful effects. The diversity of research types implemented across the BRs can be partly explained by reference to their differing contextual framework conditions with respect to research-related activities. This resulted in varying research needs, capabilities and opportunities to participate in research. Consequently, different types of research play a role in the process of promoting regional sustainable development in BRs. Considering this diverse portfolio of effective projects, the fact that the identified quality criteria and process principles that are supposed to promote research effects closely mirror the core components of ideal-typic transdisciplinary research (such as the joint articulation of research interests, the participation of local actor groups, and the communication of actionable results) may seem to be contradictory.

However, our findings offer two important insights into ways of promoting impactful sustainability science and the role that BRs can play in this context. First, the discrepancy between the diverse project portfolio and supposedly necessary transdisciplinary research designs indicates that sustainability science must progress beyond the "projectification" of research. One key to effective sustainability science lies in the establishment of productive science–society interactions that can facilitate the production and use of actionable knowledge. Although in larger, transdisciplinary projects, such interactions can be realized within project frameworks, for other project types, they must be established through the creation of good research environments. Second, the large number of effects that enhance the management effectiveness of BR highlights the limitations of research projects with respect to direct sustainability impacts. Sustainability scholars should be aware of these limitations and avoid striving for direct impacts in cases in which such results are simply unrealistic. Instead, they must find allies that can serve as intermediaries between science and practice, who can translate and transform research outcomes into practice, thereby transforming those outcomes into impacts and fostering broader transformative effects. BRs can play a core role in both respects: namely, they can help establish productive research environments by maintaining strong relationships with scientific organizations and local actors. Consequently, BRs can serve as a broker between science and practice, and they can select research outcomes to generate tangible, positive impacts.

Several barriers that prevent BR from playing these roles were identified in our study, thus helping explain the gap between UNESCO's proposed role and the actual role that BR currently plays with respect to research. We provide initial suggestions regarding ways of overcoming these barriers, taking into account the different institutional contexts in which these BRs act and operate. Further research is needed to generalize and refine these findings at the global level. Nevertheless, our results constitute an evidence-based foundation that can enable BRs to take advantage of the potential of research to have positive sustainability effects and to move closer to meeting UNESCO's ambitious goals more effectively.

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