EXPERIENCES OF INTER- AND TRANSDISCIPLINARY RESEARCH – A TRAJECTORY OF KNOWLEDGE INTEGRATION WITHIN A LARGE RESEARCH CONSORTIUM

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Summary: Although inter- and transdisciplinary research has found its way to the forefront of calls, funding and publications, interdisciplinary projects often start from scratch constructing their research environment. In this article we will point to the enormous potential, the learnings, as well as some of the difficulties and pitfalls frequently encountered in large interdisciplinary project consortia. With this in mind, we aim to transparently document and reflect upon our research process, reminding the readers that the authors are not academic specialists in the field of inter- and transdisciplinarity nor in the sociology of knowledge. To explain our motivation, we want to share valuable experiences and point to some learnings, especially regarding the interdependencies between inter- and transdisciplinarity. After a brief historical retrospective of the expectations towards science, the article describes the trajectory of knowledge production and integration of a rather large research consortium attempting to overcome typical communicative and conceptual hurdles while negotiating the strict preconceptions of the respective disciplines. During the process of knowledge integration, scientific recognition and time budgets remain the crucial challenges. Besides joint field research, the construction of four storylines and the continuous integration of data into the various and increasingly interlinked models that ultimately culminate in our future scenarios led to constant communication and disputes among the subprojects involved. During the course of the project, it became obvious that a new generation of young scientists is developing: scientists working in interdisciplinary and transdisciplinary thought communities with a grasp of both fundamental science and transdisciplinary practice, combined with the soft skills necessary to reconcile both worlds.

Zusammenfassung: Obwohl inter- und transdisziplinäre Forschung in aller Munde ist, beginnen Forschungskonsortien in der Regel ganz von vorne, wen sie ihre Forschungslandschaft aufbauen. In diesem Artikel werden wir auf die großen Potentiale und Lernprozesse sowie auf die Schwierigkeiten großer interdisziplinärer Forschungskonsortien hinweisen. Es ist unser Anliegen, unseren Forschungsprozess transparent zu dokumentieren und zu reflektieren. Wir weisen darauf hin, dass die wissenschaftlichen Schwerpunkte der AutorInnen nicht bei der Erforschung von Inter- und Transdisziplinarität liegen und wir auch keine Wissenssoziologen sind. Die Motivation dieser interdisziplinären Forschergruppe ist es, wertvolle Erfahrungen zu teilen und einige Lernerfahrungen besonders hervorzuheben. Nach einem kurzen Rückblick auf sich wandelnde Wissenschaftsbegriffe, beschreiben wir den Verlauf gemeinsamer Wissensproduktion und Integration im Carbiocial-Konsortium.; die Überwindung kommunikativer und konzeptioneller Hürden gehörten ebenso dazu, wie die Verhandlungsprozesse disziplinärer Grenzziehungen bzw. ihrer Lockerung. Hinsichtlich des Prozesses der Wissensintegration, bleiben die knappen Zeitbudgets und die mangelnde wissenschaftliche Anerkennung inter- und transdisziplinärer Wissensproduktion die wesentlichen Herausforderungen. Gemeinsame Feldforschung, die Konstruktion der vier Carbiocial-Storylines sowie der fortlaufende Prozess der Datenintegration in die im zunehmenden Maße verlinkten Modelle und letztendlich Zukunftsszenarien, führten zu kontinuierlicher Kommunikation und Disput zwischen den jeweils involvierten Sub-Projekten. Während der fünfjährigen Projektpraxis wurde deutlich, dass eine neue Generation junger WissenschaftlerInnen ausgebildet wird, die ganz selbstverständlich in inter- und transdisziplinären Zusammenhängen arbeiten und denken, die einen Zugriff auf Grundlagen wie transdisziplinäre Forschung haben und über die nötigen soft skills verfügen, beide Welten in Einklang zu bringen.

Keywords: interdisciplinarity, transdisciplinarity, knowledge integration, knowledge communities, scientific cultures

1 Introduction

Inter- and transdisciplinary science has found its way to the forefront of calls, funding and publications, and systematic research on the nature of scientific cooperation in transdisciplinary projects (e.g. Binder et al. 2015; Defila and Di Giulio 2016; Scholz et al. 2015) is being published. *Nature* stated in a special issue on interdisciplinarity, "*Done correctly, it is not mere multidisciplinary work - a collection of people tackling a problem using their specific skills - but a synthesis of different approaches into something unique.* (Nature 2015). The scientific evaluation of the design of inter- and transdisciplinary research processes has been examined in publications from environmental sociology and philosophy by Gross (2010) and Gross and Stauffacher (2014) who reflect on the important contributions of interdisciplinarity to environmental sciences, especially regarding man-nature relationships; Wuelser et al. (2012) analyse the potential of problem-oriented research and science to contribute to sustainable solutions. Scholz (2011) stresses the importance of transdisciplinarity since knowledge integration and mutual learning among science and society are essential when striving towards socially embedded orientations for sustainable development. The researchers Bodin and Tengö (2012) and Collins et al. (2011) discuss the development of transdisciplinary knowledge of multiscale socioecological systems, while Bergmann et al. (2010) provide a comprehensive overview of methods of transdisciplinary research in reference to sample projects. For this article, the approach of Hirsch Hadorn et al. (2008) who points critically to the practical challenges that arise by transgressing disciplinary boundaries and engaging in transdisciplinarity was especially helpful: getting a common grasp on the complexity of the problems, take into account the diversity of scientific and societal perspectives on problems, link abstract and local knowledge and direct the knowledge-based solutions towards a presumed common good.

As Jahn et al. (2012: 2–5) describe and illustrate, interdisciplinary research works and develops the interfaces of different scientific disciplines towards the problem-specific integration of knowledge and methods, whereas transdisciplinarity tackles the interface between those scientific questions and societal demands and interest groups. However, inter- and transdisciplinarity as modes of research are far older than the modern terms used to describe them. Already in the 1930s, Fleck (1935), in his theory of science, elaborated on the idea of thought communities, which unite people who continuously interact with one another and thus become bearers of historic developments. Each thought community entails its own thought domain, contributing to the knowledge and cultural base and ultimately representing a special style of thought. Fleck noted that greater insights could be achieved when members of different thought communities interacted and cooperated, enabling progress beyond the rigid conceptualizations of each community's style of thought. As an immunologist, Fleck was attempting to solve medical problems with strong societal contexts. In our inter- and transdisciplinary project, "Digging Deeper" (described below and in Strey et al. 2017, this volume) we came close to the ideal of such a thought community.

Since the first report of the Club of Rome in 1972, inter- and transdisciplinarity experienced a revival due to the complexity of the limits of growth (Blaikie 1985) and the necessity to join forces to tackle real world problems. The limits of growth are still at the bottom of LUCC and climate change research in the Amazon. Yet, in the 1990's, Helga Nowotny, Peter Scott and Michael Gibbons (Gibbons et al. 1994), as science sociologists, labeled the context-driven, problem-focused and interdisciplinary knowledge production that also tackles the dialectics of the structural conditions in the processes of knowledge production, as the Mode 2 approach, distinct from Mode 1, looking for fundamental and disciplinary knowledge. During this decade of the UN world conferences, since the Agenda 21, § 38 (UNDP 1992) to the UNESCO science debate (2015), science assumed a more and more prominent role as an enabler of sustainable development. Currently, the expectations from the global society towards science are best expressed by the UN 10-Member Groups statement (2016), "Harnessing the Contribution of Science, Technology, and Innovation for Achieving the 2030 Agenda and the 17 Sustainable Development Goals", describing the role of science and the respective research agenda for the achievement of the Sustainable Development Goals within the Technology Facilitation Mechanism. Although the pledge for inter- and transdisciplinary sustainability science is unmistakable, the starting points of such inter- and transdisciplinary research continues to be the respective subject area. The need to construct a common research objective presupposes explicit disciplinary authority, since the contents and methods of the researcher's own discipline must be explained thoroughly to scientific *and* societal actors who are not familiar with it. On the other hand, scientists and societal actors need to be interested, patient and respectful towards scientific and societal approaches outside their own experiences. This scientific process is a research mode that aims to produce applicable scientific solutions for societal problems for which knowledge integration is the crucial challenge.

As we have observed, inter- and transdisciplinary sciences face various challenges:

1. Inter- and transdisciplinarity are not precise concepts but are still being negotiated; in fact, everybody uses the terms differently.
2. Inter- and transdisciplinarity often start without concrete plans for the most effective execution of the research process or the dissemination of results.
3. It can be challenging, although necessary and sometimes even complementary, to integrate fundamental research within the new research collaboration structures because PhDs and publications are predominantly assessed based on specialization.
4. The definition and establishment of inter- and transdisciplinary links within a research consortium are time-consuming and may not be considered in the time and financial budgets of research projects.
5. Reward systems such as publications and career paths are not aligned towards inter- and transdisciplinarity.
6. Communication among different disciplines and, at the same time, with interested stakeholders expecting solutions, is a scientific and practical challenge in its own right.
7. The scientific benefits and potential of inter- and transdisciplinary research is difficult to anticipate – particularly before a project has even begun.

Huge interdisciplinary project consortia enjoy opportunities but also face risks when tackling comprehensive research and dissemination topics. In this article, we offer the example of our own trajectory of attempting to integrate knowledge while overcoming communicative and conceptual hurdles and sacrificing the strict preconceptions of the respective disciplines. We will also highlight some difficulties and pitfalls that a project of this dimension normally entails. The next section, our case study, presents the project in detail. Thereafter we analyze the advantages of collaboratively produced results, encountered difficulties, certain structural limitations, and discuss possible pathways for improving the structural basis of innovative *"thought collectives"* (Fleck 1935). To achieve a clear picture of the applicability of theoretical concepts of inter- and transdisciplinarity, we hypothesized that a continuous process of dialogical knowledge production in all project stages avoids misunderstandings between disciplines, research traditions and non-academic research partners, pointing out that inter- and transdisciplinarity will hardly become a self-carrying process even if integrated to the project structure itself, but it remains as a constant learning process.

2 The case

The objective of Carbiocial was to explore the interdependencies between land use change and climate change on different scales, focussing on the scope of viable carbon-optimized land management strategies for maintaining ecosystem services under changing climate conditions in Southern Amazonia (Gerold et al. 2014), and aiming for applicable results.

Our research region, the Brazilian Cuiabá-Santarém highway 163 stretching almost 1,800 km, was the subject of widespread geographic and institutional research foci with equally heterogeneous stakeholder groups.

Carbiocial is structured in 12 subprojects within four thematic clusters: climate, landscape, soils and water, and society (Fig. 1); this structure, in addition to the dimension of the research region and an insufficient Brazilian-German lead time to consolidate a consortium led to a fragmentation of Brazilian scientific partners from different cities, universities and faculties who only gradually came to know each other during annual Carbiocial meetings or joint field research (Fig. 2).

During five years, Carbiocial passed through an exciting although fragmented process of thematic and methodological exchange and at times, carried out truly interdisciplinary research and transdisciplinary learning (see Tab. 1). We worked with a multitude of methods which needed to be mutually understood in order to identify linking points for knowledge integration; additionally, we relied on different objects of study to provide the basis for a variety of analytical aims and to reduce biases from single-minded approaches. The methods used at the farm level, included field experiments and measurements of specific chemical and physical soil parameters and properties, and at a regional scale, techniques such as remote sensing-based data assessments, statistical and spatial modeling and data-anal-

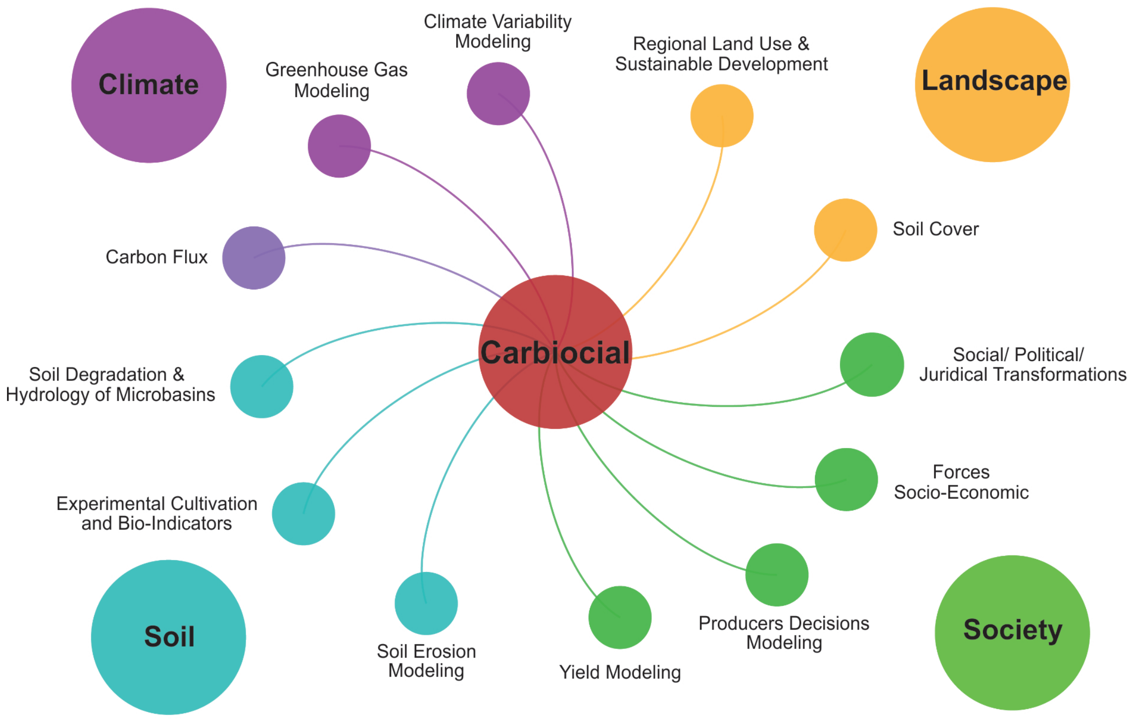

Fig. 1: Thematic structure of the 12 Carbiocial sub-projects

ysis. Stakeholder dialogues and interviews with land users and decision makers, workshops with local and international experts, biographical interviews – often with stakeholders who were already involved through on-site-farming, agricultural long-term micro-level field studies, extensive literature reviews, joint storyline development, and, finally, the modeling of future scenarios complemented the experiments. We engaged in continuous dialogue between disciplines and with local stakeholders primarily during joint field research, enriching our knowledge base and sparking new insights. Additionally, early results were directly integrated into our storylines and the consolidated results to the various and increasingly interlinked models, leading to constant communication among the relevant subprojects.

3 Results and discussion

Altogether, the challenges to an inter- and transdisciplinary joint research project are manifold (Jahn et al. 2012: 4-5) and the options for determining the terms of collaboration have to be tailor-made. In the case of Carbiocial, research sites, academic and governmental research partners, relevant government and non-government organizations and local stakeholder groups are situated thousands of kilometres apart, in different cultures and climate zones, leading to changing collaborative constellations (see Fig. 2). It took us at least two years to truly understand the dynamics of our research region and the potential contribution of our fellow researchers from different disciplines regarding GHG-relevant land management options.

In the following, we discuss learnings and effective practices as well as challenges and structural limitations of the project, illustrated by examples derived throughout the five year project.

3.1 Best practices and learnings

3.1.1 Communication

We found deeply ingrained images of the *„other"* being the first hurdle to overcome, as we observed prejudices not left behind at the gates of the scientific world: natural scientists tend to believe that social scientists do not practice science; social scientists tend to believe that natural scientists are too specific to understand overall contexts; agrarian engineers

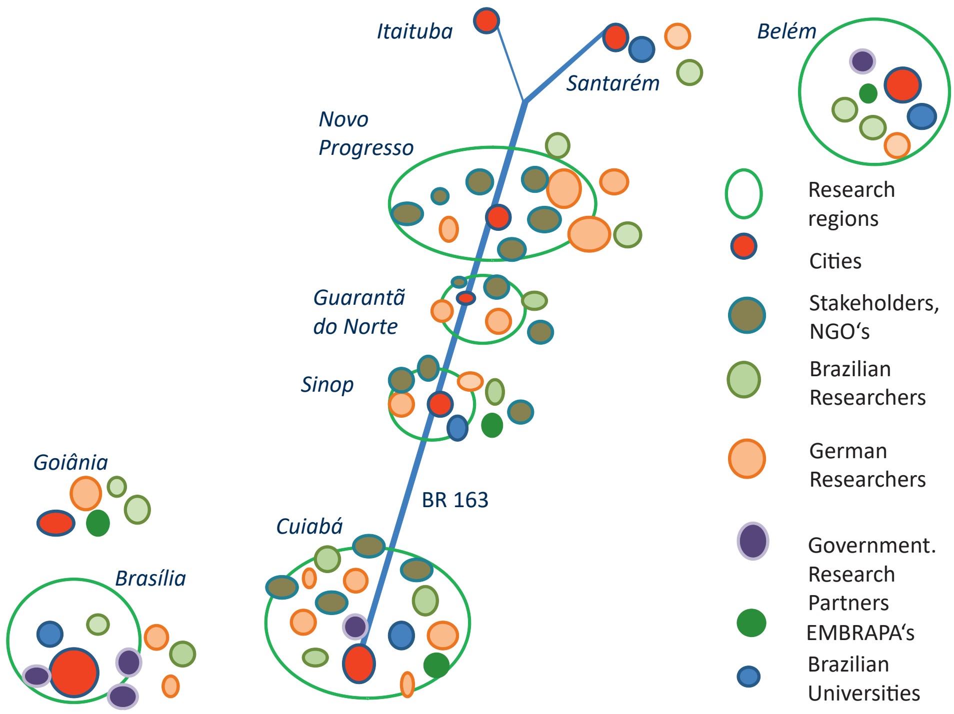

Fig. 2: Actors and locations of Carbiocial field research at BR 163

and economists tend to believe that ecology is romantic, etc. Only under happy circumstances, such group conflicts can be transformed into a foundation of a common spirit. In the case of Carbiocial, it was during the kick-off workshop in 2011 where we assessed why each participant aimed to work in the Amazon and the reasons for doing so in a multi-disciplinary research group. In retrospect, this world café was the beginning of a common project identity. Rather romantic discourses on the need to stop deforestation, the loss of biodiversity and protecting the environment and the indigenous populations led to the scientific communities' perception of the Brazilian Amazon – a perception which would substantiate during the execution of the project, and which helped to create a "common 'flag' and to pursue common goals" (Stobbelaar and Pedroli 2011). The second step was developing internal scientific communication at regular workshops to overcome the aforementioned stereotypes and to create trust and respect within the project. Instead of confronting each other with unfamiliar concepts and approaches, such as research based on *lifehistories* or on modelling, we started a discussion on the *meanings* of research questions, methods and results. This led to the meetings being transformed into learning events, capitalizing on the sudden interest in insights from previously unknown disciplines. This peer-learning process, especially during joint field research and conferences, also proved to be the starting point for various interdisciplinary endeavors. Gradually, natural scientists began to regard mindsets and interests outside of the natural conditions of our testing fields as determining factors in understanding land use and its possible orientations. The latter we obtained from the perspective of our stakeholders: They were making rational choices and we understood that the respective composition of rationality needs to be ascertained locally.

Applicability presupposes awareness of the knowledge requirements of possible user groups and a continuous dialogue with the respective stakeholders. Ideally, this process starts simultaneously with the formulation of the research proposal. In our case, several Carbiocial subprojects undertook joint research journeys alongside our project region, the highway BR 163, but not until after the project had started. Presenting Carbiocial research questions to local land users and their representatives and learning about the actual knowledge requirements through dialogs with stakeholders in 2012 raised our awareness about serious gaps in our initial research designs, especially regarding the knowledge demands of local stakeholders. In the follow up evaluation workshop to this field trip, it became obvious that we would have to recalibrate research questions in several subprojects and that certain aspects of local realities of land use management such as the causes and cures of widespread plant diseases, which represent a challenge regarding the move towards intensification, were missing. In this case, that even meant that a whole discipline, phytopathology, was missing. The subsequent discussions within the subprojects and within Carbiocial touched basic ethical questions on how to return the results and how far local demands should be met. At that moment, we perceived what kind of interwound project design, fed by locally collected demands, would have been necessary to do true transdisciplinary research. Since it was already three years into the project, we realized that we would have to improvise. It was this joint field visit that triggered deeper inter- and transdisciplinary engagements within Carbiocial, as described in the following paragraph.

3.1.2 Cooperation

Digging Deeper is the name given to a special interdisciplinary cooperation within Carbiocial. In the context of severe conflicts on land use and forest protection in our research area, a research team of soil scientists and social scientists engaged in a joint research process on the measurement of deep soil organic carbon in a primary forest, together with a local indigenous group. Synergies between ecological and anthropological questions, and research and communication processes opened up various new fields of study such as, for example: organic carbon quantification down to 10m soil depth in a forest preserved by an indigenous group; opening a window of opportunity for dialog with the mostly inaccessible group of stakeholders inhabiting the research area and developing a common terminology to discuss *carbon*. Moreover, it facilitated a study of our very own endeavor: the process of scientific knowledge production by soil scientists. Finally, we could provide the indigenous group with a scientific data set on carbon stocks beneath their territory they may potentially use to apply for a future REDD+ project (see Boy et al. 2016 and a short film: http://bit.ly/2eLGmsq).

It became increasingly clear that social science results such as certain leitmotifs of the registered stakeholder biographies (Schumann et al. 2015), understanding decision patterns, knowledge of relevant legislation and of the conditions for law enforcement would need to feed into Carbiocial storylines and scenarios. To start the process of integrating qualitative data into models, we engaged in a participative storyline development as a basis for Carbiocial scenarios (Schönenberg et al. 2017). In parallel with this, the task of linking models was undertaken. Models which focus on the description, traceability and prediction of different environmental systems (climate, soil nutrient cycling, erosion, etc.) already existed, but mostly have been developed and tested under conditions different from those in South America, and Brazil in particular. Consequently, new parameterizations and the integration of newly gained knowledge (through field measurements or even discussions and interviews with farmers and stakeholders) provided the opportunity to better adapt models to Brazilian conditions.

3.1.3 On linking models

When in 2009 the Carbiocial research project consortium gathered for the first time, the scientifically interesting possibility of combining the biophysical, process-oriented yield model MONICA (Nendel et al. 2011) with the agent-based, economic decision-making model MPMAS (Schreinemachers et al. 2011) was identified. Such a combination was seen as a central core for other modeling activities which could result in a decision support software package to inform farmers in Brazil about possible consequences of climate change and land management options to help maximize their farm income. MONICA simulates the process of growing a series of crops on the same plot of land, indicating how the water circulates in plants and soil, how nutrients are released from organic residues and taken up by the plants, and, finally, what kind of crop yield can be anticipated. The concept of MPMAS, however, relies on a statistical distribution of crop production at the farm level. When the model concepts were explained in detail, it became clear that MPMAS does not take into account which exact (tempo-spatially explicit) plot is and was used for, e.g., wheat production and which other field produced carrots. However, such information is essential for MONICA, due to "historical" nutrient cycling. In MPMAS, crop rotations are used in the optimization process only to allocate the available farm land for each production system. In this context, the important multi-period feature of MPMAS is the financial and economic development of the farm business and its investments over the simulation period. These two approaches were fundamentally different and any carryover effect of water and nutrients in the soil from one simulated crop to the next – MONICA's unique feature – was impossible to transfer to MPMAS. Now, another two years later, great efforts have been made to bend both models towards a more effective combination, opening up the perspective that within another year both concepts can be merged as initially intended (Carauta et al. 2017).

Throughout the process of model integration, the communication among subprojects proved to be equally ambitious. Figure 3 shows the different models that were used within CARBIOCIAL and their inter-linkages. Modeling approaches can roughly be divided into four sections. As described above, management decisions on farm level ("Farm modeling") and crop growth ("Crop modeling") were simulated with MPMAS and MONICA. For calculating land-use change on the regional and landscape scale ("LUCC modelling") the LandSHIFT model (Schaldach et al. 2011) in combination with the alucR model (Gollnow et al. 2017) was applied. Environmental impacts of land-use change ("Environmental impact modelling") were analyzed with different process-based and empirical models. The SWAT model (Arnold et al. 1998) was applied to simulate the impacts of land-use change on hydrological processes within 2 selected macro catchments (Lamparter et al. 2016). The impacts on soil erosion were investigated with the EROSION 3D model (Schmidt 1991). Finally, greenhouse gas emissions (GHG) and changes in soil carbon stocks on the regional level were calculated with an empirical approach as described by Meurer et al. (2016).

The model input is derived from scenarios that cover qualitative and quantitative information on regional and global development (e.g. population and agricultural production, protected areas, law enforcement) as well as information on climate change (Schönenberg et al. 2017). The latter was calculated with a nested regional climate model also within the CARBIOCIAL project. The recent integration of the different models seems to fulfil our expectations for modelling land-use change and its environmental impacts at different scales quite effectively (Fig. 3).

In the course of modeling it became obvious that by studying complex climate change-related research problems, the inter- and transdisciplinary work with the other groups helped improve own scientific skills, mainly for the following reason: the participants were forced to communicate each method in such a way that their colleagues could follow the thread and a fruitful collaboration became possible. This contributed to self-reflection upon the typical theories and methods inherent to a particular discipline. In order to understand the other groups, it was necessary to change the usual perspective of approaching research problems. This

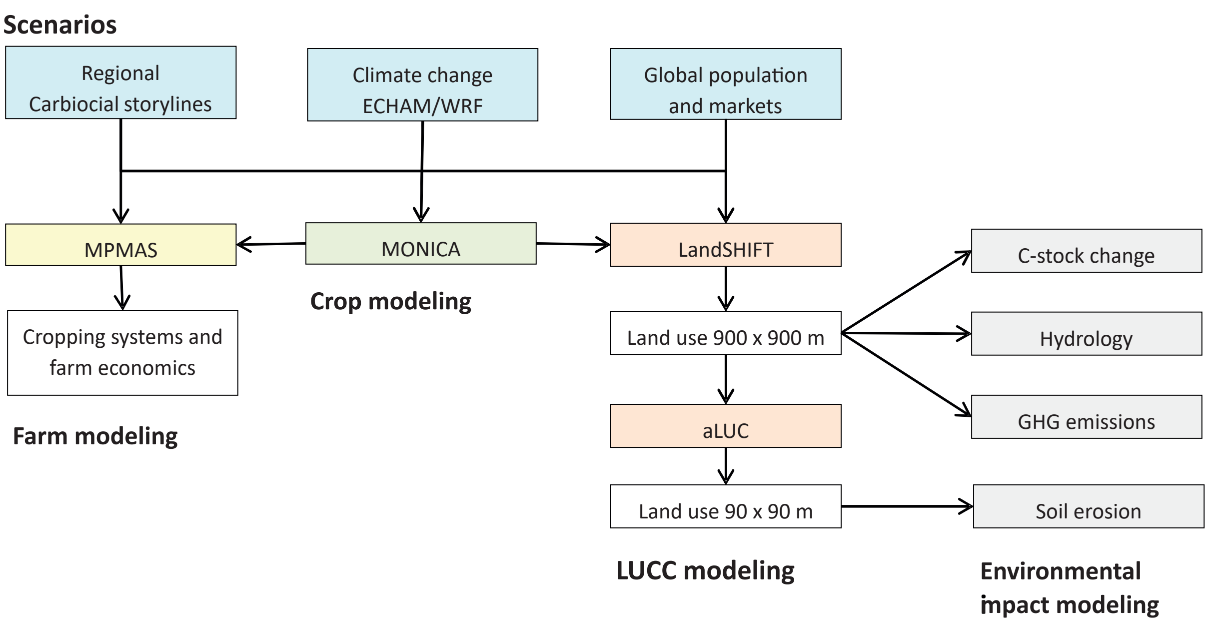

Fig. 3: Carbiocial model integration

"opened the horizon" and boosted the awareness that a system could and should be observed, studied and/or analyzed from different angles.

3.1.4 The landscape level

At the landscape level, the exchange of knowledge is the starting point for any achievement. In our project we had manifold meetings to discuss how to integrate different views into storylines and scenarios. Moreover, data exchange plays an important part when it comes to direct interaction in terms of running experiments together or linking different models, as is the case with downscaling land use change from global to regional to landscape level, or in linking land use change, climate change and carbon balances. To present a platform for systematic data exchange, our spatial data infrastructure and technologies for documenting data and sharing data in a web-based approach proved very useful. One example is the online presentation of maps of land cover change and the (future?) scenarios of land use change via web services (gdi.carbiocial.de).

As a first step, spatial information and underlying spatial data were exchanged within the project; later they were also made available to stakeholders and the public: All data were published on a data platform, http://gdi.carbiocial.de/; we distributed Carbiocial USB sticks with selected data sets, articles, maps, etc., to our scientific partners, public policy partners and stakeholders, and, we designed nine comprehensive Policy Briefs for all stakeholders delivering the results at one glance. Along the way, we identified several challenges regarding the need for data privacy (concerning data on individuals, acquired data, etc.), clearly stated rules for data exchange, publication of individual research findings (before official publication) and the willingness or duty to submit results from all participants for an open sharing environment in such a project. Communicating the additional benefits of geospatial data management turned out to be a difficult and time-consuming task.

3.1.5 Integration

To achieve an inter- and transdisciplinary exchange, the establishment of trust through open communication – be it with fellow project participants or with the stakeholders – is necessary but not sufficient. Looking back on the whole 5 year process, transdisciplinarity, in particular, can only work satisfyingly if initiated from the very start; this means the construction of a common research aim and an institutionalized feedback pattern as part of the partner structure of the project during the setup phase.

Joint projects offer an abundant learning platform, without usually disposing of any additional funding or time budgets. As participants learn to consider additional perspectives beyond their own discipline, however, the limitations with regard to content become obvious. In particular, the shift from fundamental research to transdisciplinary research poses significant challenges for the different research groups. If natural scientists engage in inter- and transdisciplinary research, they will have to double their efforts, since they will find it difficult to refrain from using fundamental science to answer their research questions. If the integration of both perspectives can be realized successfully, the knowledge surplus will be considerable. This very article is a clear example of such knowledge integration: fifteen authors representing 10 academic disciplines communicated for about 10 month live, on skype and via email to achieve the integration of all aspects that appear important from the various perspectives to describe the Carbiocial trajectory of knowledge production.

Moreover, all disciplines will need to reflect upon and communicate their results continuously with respect to their significance to the overall research question. This mechanism contributes to the necessary feedback effects between inter- and transdisciplinary research. All of the scientists involved will have to invest more effort in the formulation of hypotheses, the design of experiments and in field research in general. Regarding the concluding knowledge integration, translation and discussion of final results with local land users and regional and national institutions, the already rehearsed research practice proves to be highly beneficial. Currently, while picking up ongoing Brazilian discussions on land use, environmental and climate policies and their implementation, we are processing and presenting our results on GHG-relevant land use strategies in the context of debates on the role of future LUCC in Southern Amazonia to reach the aims of Brazil's National Climate Plan (MMA 2016), impacts of the New Brazilian Forest Code (FAEP 2016), intensification, rotation and rehabilitation strategies, and the grounds for decisions and available support.

3.2 Challenges

3.2.1 Project design

Looking back on the history of our research consortium, the first sin occurred even before the project had begun, during the drafting phase of the Carbiocial project, when the very heart of Carbiocial – the "bio" – was literally removed by the donor. Without the biodiversity aspects, the carbon as well as the social was missing a core reference point. When the funding agency did not approve the biodiversity subprojects (ornithological and botanical), on the grounds that the respective knowledge already existed, we did not anticipate the negative effects throughout the whole project. In retrospect, this unfortunate move represented disciplinary thinking leaving aside the important difference in understanding, e.g., carbon sequestration of soils with or without biodiversity processes, hence, aspects of integrated knowledge production.

Working with inter- and transdisciplinary approaches can trigger unpredictable side effects as the following example right in the beginning of the project illustrates:

3.2.2 The selection of research sites

Amongst the interdisciplinary group of scientists in Carbiocial, a group of related natural science disciplines pursued a common interest in investigating different land use and soil type combinations in order to derive knowledge about the effects of land use change in their respective subjects. Unquestionably, shared study areas offer a range of advantages: primarily, shared resources (e.g., automobiles), assistance and exchange of data (e.g., climate and soil information). Since experimental approaches could not cover all soil, land use and management combinations, the most important ones had to be selected to allow a compatible, representative, model-based description of the most significant landscape processes.

However, each discipline came with necessary predefined conditions, such as the need to meet particular model requirements to enable the investigation of their individual research question. Figure 4 shows the schematic structure of an experimental setup satisfying the scientific needs of the different disciplines.

Hydrological research, for example, demands the investigation of complete micro-watersheds with a uniform land use type, whereas greenhouse gas, carbon stock and soil fauna research focuses on different land use types (incl. management, such as different intensity of grazing or contrasting cultivation and tillage techniques) and soil types with a sufficient number of repetitions. Furthermore, erosion studies need both, since the effect of different combinations of soil, land use and land management needs to be investigated in small catchments to allow the calibration of applied models. The awareness in and communication among the sibling disciplines of the preconditions for the selection of the study area (Fig. 4 is an example) was definitely a task which proved difficult at the time.

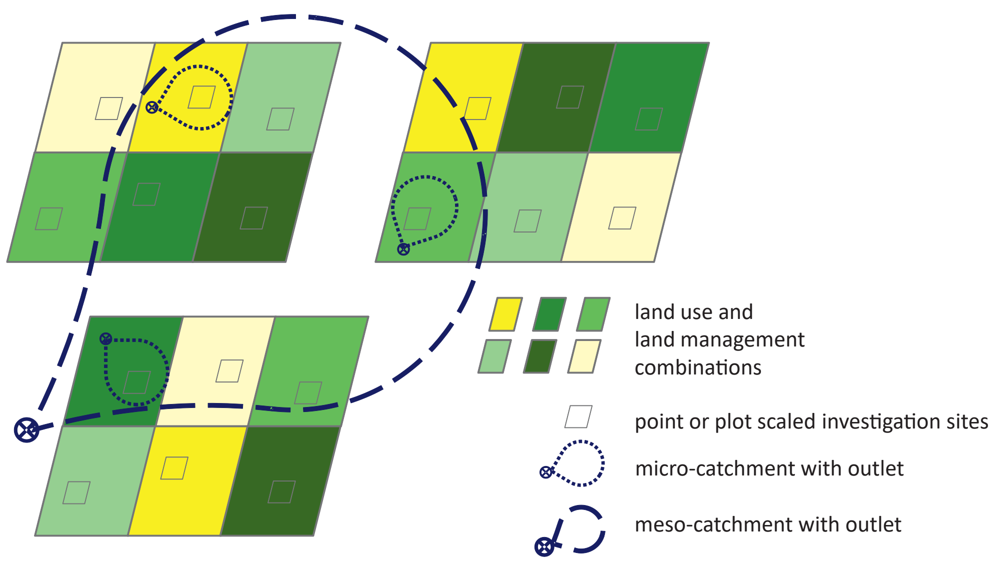

Fig. 4: Example of an area selection scheme of Carbiocial

Also, the localization of suitable sites along the more than 1,000 km transect with regards to the scientific requirements was a great challenge.

In addition, possibly even more restricting were the actual conditions on site (e.g. obtaining access to farmers and farmland) and the dependency on the experience, resources and previous work of our local partners. This dependency was especially pronounced due to the initially significant language barrier for the natural scientists (who had no language training in advance). The selection process became linked with the general feeling of impatience due to its drawn out nature in the face of the eagerness and time restrictions of the individual researchers. This phase would surely have been even more unsatisfactory without the Brazilian partners. However, clear and commonly discussed selection criteria were missing throughout the process.

Finally, the selection of field sites was a difficult compromise between scientific necessities and the feasibility restrictions of research in unknown and remote areas. Given such a high potential for conflict, the selected sites are surely a compromise to be satisfied with, as well as an early indication of the tensions of interdisciplinary research. For future projects we suggest compact research sites close to the project base.

Unfortunately, during the early selection of the research site, social sciences were not adequately involved because the correlation between the natural sciences research sites and the social sciences research region revealed itself only during the research process. Social sciences subproject 14 was only able to identify the relevant stakeholders according to previously constructed macro-identities and the analysis of all organized bodies such as farmers unions, land workers unions, associations, governmental institutions on the different governance levels and NGOs. Since we could not change the project's early mistakes, we engaged with the individual farmers and their environment to feed in their life histories to the book, *Sempre pra frente – histórias da vida da BR 163* (Schumann et al. 2015).

3.2.3 Stakeholder involvement

Stakeholder involvement is a multilayered process. Analyzing the different levels of interest and power regarding land use, stakeholders were then assigned to their respective macro-identities (Fig. 5): direct economic, environmental, indirect economic and topical/strategic. Whereas we identified actor-groups with indirect economic interests as best equipped with power resources and most interested in the industrialization of agriculture, actual land users living and working on their land were the most interested in economically and ecologically sustainable change. Consequently, Carbiocial researchers invested in building up trust and mutual understanding primarily with the farmers and ranchers and their representatives at respective research sites along highway BR 163. A careful bottom-up stakeholder analysis at each research location alongside BR 163 was the starting point of our attempts to produce multi-scaled stakeholder involvement: at the level of farms, municipalities and pioneer towns; the state and federal level as well as non-governmental and international organizations we instead approached via research partners from GIZ (Gesellschaft für Internationale Zusammenarbeit), a German development agency.

The first step, the stakeholder workshop, always had the aim of involving land users in the specification of research questions, refining research with regard to local specifics and actually involving them in the understanding of the respective research problems such as erosion, access to water, soil deterioration, etc. Soil deterioration, in particular, proved to be important for the credibility of results: verifiable information is easier to believe – even though it might conflict with presuppositions.

The research methods used throughout the whole process of stakeholder interactions varied depending on the respective goal of the interaction. Expert interviews were mainly used to understand the knowledge resources and sources land users would refer to when they explained their situation, motivations and decision criteria or to give their opinion, e.g., on our scenarios; attending meetings and trade fairs served to better understand internal power relations, and biographical interviews helped to understand the underlying processes of migration, land use, land use change and political alliances.

Throughout the entire process, our goal was to link ongoing processes and contextualize our research in light of important discussions in the region, such as intensification of agricultural production and farming, availability of water and advantages or disadvantages of local agricultural systems. These debates highlighted the significant gaps between local knowledge and scientific knowledge systems, making it clear that all actors in the transdisciplinary processes would need to concentrate on mutual learning and joint problem-solving methods. The main challenge was to initiate a transdisciplinary dialogue on research processes and results to link scientific, theoretical and abstract epistemics with real world-based experiential knowledge

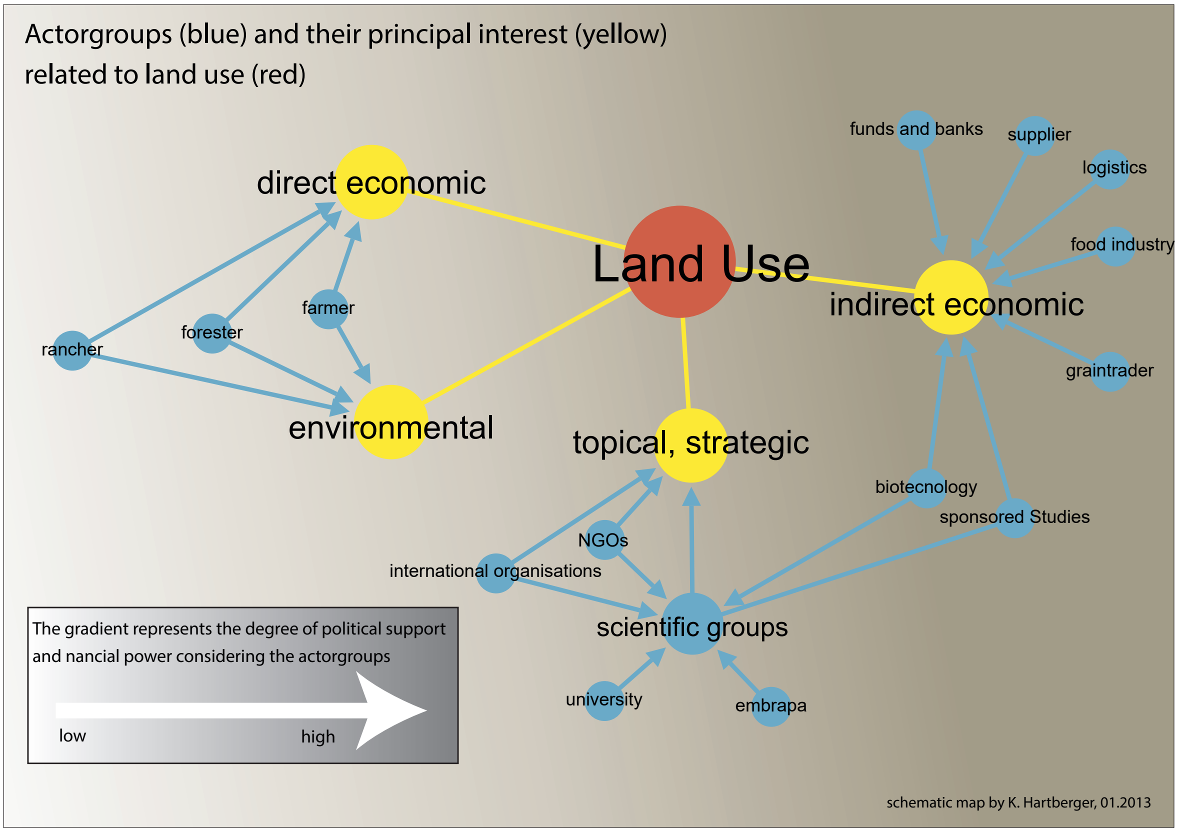

Fig. 5: Actor groups and their principal interest related to land use

outside of academia. This led to fundamental questions about the extent of knowledge integration and respective knowledge transfer necessary to foster sustainable decision-making processes. The fact that we already had to explain our disciplinary results to our colleagues and work on integrating different aspects greatly facilitated our communication with local, regional and national stakeholders in Brazil. However, it remained a constant challenge that local interest in our research and results correlated with our ability to take up and address problems currently relevant to the respective stakeholders.

3.2.4 Structural limitations

In the case of Carbiocial, we suffered three structural limitations in the course of project realization. First, the construction of a common research subject linking science and society in Brazil and Germany did not take place beforehand but occurred haphazardly during the implementation of the project. Consequently, the research questions only partly matched the needs of the actual land users and had to be frequently adapted. Secondly, the fact that the biodiversity subprojects were eliminated by the financing agency led to additional work for several subprojects and restricted the balance and connectivity of our findings. Third, the fruits of common efforts during the implementation phase during the fifth year are limited by the termination of most PhD contracts after three years. Since the PhD students did the majority of the field work, their valuable personal contacts were no longer available during the implementation phase. The latter fact was aggravated by financial limitations on the part of the Brazilian partners, leading to restricted participation in actual field work during the whole research process.

3.3 Summing up achievements and challenges of inter and transdisciplinary research

Two tables with an overview of the research subjects, methods and results considered achievements (Tab. 1) and challenges (Tab. 2) that sum up the processes that structured our inter- and transdisciplinary research throughout the project.

Tab. 1: Inter- and transdisciplinary achievements

Interdisciplinary research subjects	Transdisciplinary research subjects	Methods: initiated by the social scientists	Common Results
LUCC & social transformation		Data + literature analysis on a disciplinary basis, and internal **communication** on the diverse disciplinary perspectives on LUCC	First mutual understanding of the different perspectives and possible linkages towards a common and more holistic understanding
	LUCC & social transformation	Expert + biographic interviews Internal **communication** on the meanings of the results	Better understanding of the interdependencies of both aspects; identification of practice partners; internal learning on the ambiguity of social relations at BR 163
Stakeholder, change agents, innovation-potential analysis		Internal **communication** on the potentially involved actors from each disciplinary perspective	Extended set of possible stakeholders contributing to LUCC
	Stakeholder, change agents, innovation-potential analysis	Expert + biographic interviews; stakeholder workshops + transfer back to the research group	Identification of stakeholder-groups, potential change agents and bearer of social innovations regarding LUCC
Decision-making		Internal **learning** on technically possible decision-making fields and the underlying socio-cultural and eco-economic processes	Extended approach to processes of decision- making
	Decision-making	Expert + biographic interviews; stakeholder workshops + transfer back to the research group	Joint understanding of the complexities of decision-making processes
Digging Deeper: Deep carbon measurements within Indigenous lands		Defining of multiple scientific and political dimensions of deep carbon	Results on carbon concentration below 1 meter, contribution to the REDD+ debate
	Digging Deeper: Deep carbon measurements within Indigenous lands	Implementation of the measurement project with the help of the Kayapó	Empowerment of the Kayapó
Storyline- and scenario development		**Communication** on the necessary input factors and the whole process of modelling; Brainstorming on 4 storylines within the German Amazon research community	Four storylines comprising natural and social sciences parameters
	Storyline- and scenario development	Cross-checking the storylines with research partners alongside BR 163 and in Brasília (expert interviews and focus group discussions)	Four storylines comprising natural, social sciences, local, regional and national parameters
Model integration		Constant **communication** between the modellers and the sub-projects, integration workshops	Common understanding of the modelling and coupling processes; consensual integration of data

Tab. 2: Inter- and transdisciplinary challenges

Structural limitations	Implementation deficits	Learnings
Short German-Brazilian lead time	Fragmented project start: construction of common flag started during the first year; Stakeholder involvement was improvised on insecure grounds; The selection of research sites was not fully concerted by all interested parties which was detrimental to later research and dissemination activities	Research subject should be constructed commonly before project proposal is handed in; Stakeholder involvement should be negotiated, predominantly during the construction of the research subject; The selection of shared research sites has to consider the desired common result of the project and be relevant to model integration
Biodiversity subprojects were cut by donor agency	During project implementation, the biodiversity-led topics had to be assumed additionally	Subprojects have to be fine-tuned in their complementarity to each other; complementarity has to be communicated to the donor agency in its meaning for the overall project objectives
Researchers' contracts did not correspond with dissemination activities towards the end of the project	Dissemination phase in Brazil was suffering from the fact that the researchers personally acquainted were no longer available to bring the results to the stakeholders	PhD contracts should include additional time for dissemination, at least for the personal research sites and regions

From our point of view, the interdisciplinary discussions that forced each subproject to be precise on its own science well prepared and enabled transdisciplinary interactions. It's worth noting that almost all above outlined activities were not previewed in the initial project application.

4 Conclusions

Inter- and transdisciplinary collaboration requires the development of communication and continuous exchange among the scientists involved. The need to simply take time to understand each other's scientific languages and meanings stands in contrast to the increasing pressure for young scientists to publish within their specific research fields. In other words, inter- and transdisciplinarity call for lengthier collaborations, the establishment of thought communities and respective science management (i.e., funding, publications and careers), in addition to rethinking research beyond disciplinary boundaries rather in terms of societal and environmental relevance.

Transdisciplinary research together with and at the demand of stakeholders is known to be the greatest challenge in such large projects. Our experience with this project was that the stakeholders we had identified at the beginning were not those with whom we were collaborating with in the end. What we can learn from this is to carefully choose and select collaborating partners in advance and to aim at formulating the project proposal in continuous dialogue with all actor-groups – particularly, when the research topic involves different target stakeholders with extremely opposing interests. Ideally, a problem and research statement should be co-formulated by the stakeholders themselves a priori to encourage collaboration and strengthen interest and ownership.

Location matters: What we learned from this project is that location can be used as a central "container" for the collection of different scientific perspectives on the processes. Different views and understandings can be integrated and exchange can be stimulated by investigating the same site and actor-groups from different angles (e.g. changes in land use, the constellation of political power and carbon content in soil). Even though there is of course the question of scale (from carbon content in specific plots and single actors or farmers to global processes of soybean demand), it proved to be a good starting point for collaboration.

The interdisciplinary production and integration of knowledge requires a strong grasp of disciplinary knowledge, since specialized insights must be frequently explained to people with very different backgrounds and mindsets. It helps to respect and to be interested in the research agendas of each discipline and to aim for integration at a higher level. The joint construction of story lines and the interlinking of various modelled futures provided support for a professional process of knowledge integration. The whole process supports any transdisciplinary communication since the exercise to explain scientific knowledge understandably is already part of the project culture.

Contemplating potential roles for scientists between basic, inter- and transdisciplinary research, the Carbiocial group learned a lot about science itself. Observing the inter- and transdisciplinary engagement, especially of the PhD students, it became clear that in interdisciplinary research consortia of a new generation of young scientists is developing who offer a grasp of both science and practice, combined with the necessary soft skills to reconcile both worlds.

Unexpected insights from previously unknown scientific worlds bear synergies for the own subject area, especially with regard to processes of dissemination. However, in the realm of fundamental research and abstract results, the added value is obtained from more mature settings of inter- and transdisciplinarity.

5 Outlooks - recommendations for restructuring scientific communities and scientific culture

To profit from the experiences outlined above, science would have to examine itself critically to break up broadly accepted scientific cultures and to integrate new elements. We suggest a step-by-step plan for joint projects to produce applicable results:

Funding agencies should take into consideration the need to budget for additional financing and length of project duration, including a preparatory phase, as well as for grants for intercultural and transdisciplinary exchange.

The inter- and transdisciplinary determination of the research topic should include the involvement of anticipated partners and stakeholders in joint workshops.

The project planning should consider the interdisciplinary processing of research questions and the integration of methods.

An inter- and transdisciplinary communication culture appropriate for joint field work should be established from the beginning.

The research process should include the integration of feedback processes in workshops with all respective stakeholders, as well as the possibility of adapting research questions to the dynamics of local demand.

Joint publications – produced through the cooperation of different disciplines and nations – should be an aim of any inter- and transdisciplinary research group.

The involvement of the boards of academic journals in discussions of transdisciplinary knowledge production would help to disseminate knowledge of the comparative process .

With our current experience of inter- and transdisciplinary processes, we would now need time to feed it back into scientific practice, time not currently available within Carbiocial. But the members of this research group will certainly apply inter- and transdisciplinary methodologies to their next research projects.

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