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White Paper

Guiding transdisciplinary synthesis processes for social-ecological policy decisions

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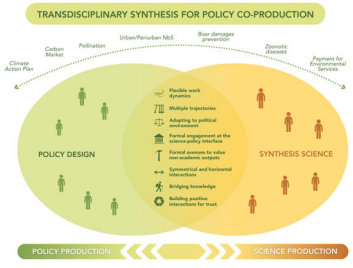
HIGHLIGHTS

- Synthesis science can efficiently leverage the process of co-producing policies when it uses transdisciplinary approaches.
- Adapting interdisciplinary working group model is pivotal for effectively implementing transdisciplinary synthesis approaches.
- We share eight learnings to tackle transdisciplinary syntheses challenges and barriers.
- These learnings allowed us to better deal with mismatches in the implementation space between research and practice.

GRAPHICAL ABSTRACT



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ABSTRACT

Interdisciplinary synthesis research has been promoting significant advances in expanding academic knowledge. However, its application to address social-ecological problems poses challenges, typical of transdisciplinary research and co-production initiatives. Based on the experience of seven working groups from a Brazilian synthesis nucleus dedicated to co-producing social-ecological public policies, we present eight learnings to strengthen transdisciplinary syntheses. Those syntheses require flexibility in the working group dynamics to facilitate collaborative work, with frequent and short meetings held in easily accessible locations (1). They also require flexibility to shape different trajectories, depending on demand urgency, data and knowledge availability (2). Flexibility is also required to adjust to political circumstances, acknowledging that there are trade-offs between responding to urgent political needs and creating novel ideas, knowledge and outputs (3). In addition, the creation of formal institutions, particularly, formal engagement at the science-policy interface (4) and creating formal platforms for disseminating non-academic outputs (5) are key to stimulate the involvement of policy-makers and scientists in collaborative transdisciplinary syntheses. Symmetrical, horizontal interactions within a two-way science-policy linkage (6), alongside collective reflexivity on bridging diverse knowledge, skills, and authorities (7) are crucial for aligning academic knowledge with policy practices. Active involvement of individuals skilled in both scientific research and policy-making, who act as knowledge brokers, further strengthens this alignment. Finally, attention to create positive interactions and transparently communicating help to build trust among participants (8). These adjustments can enhance the potential of transdisciplinary syntheses to generate actionable knowledge at the science-policy interface.

Introduction

The constant aggravation of social-ecological challenges requires new ways of producing actionable knowledge. These challenges, such as climate emergency, biodiversity crisis, and socioeconomic inequalities are often referred to as wicked problems (Roberts, 2014). They are both factually complex - i.e. poorly delimited and difficult to solve due to their multiple socioeconomic, cultural and environmental dimensions (Hou et al., 2022) - and normatively ambiguous, as different values and interests shape diverse perspectives on them. Addressing these problems and supporting decision- and policy-making requires the connection of science to several societal sectors and actors, articulating academic, experiential and strategic knowledge in a horizontal and bidirectional way (Bertuol-Garcia et al., 2018).

Synthesis science is a powerful way to boost knowledge production and to deal with complex problems (Halpern et al., 2020), with the potential to drive solutions to social-ecological challenges. It is characterized by producing new ideas, models, paradigms and theories from the organization, re-analysis, reinterpretation or recontextualization of existing data, through brainstorming and the development of associative thinking in collaborative and heterogeneous working groups (Hampton and Parker, 2011). The premise is that the heterogeneity of these groups encourages associative and creative thinking and, therefore, innovation, which goes beyond traditional disciplinary thinking and organizational mindsets (Baron et al., 2017; Specht and Crowston, 2022).

The science of synthesis emerged about 30 years ago and has been very successful, particularly in dealing with more theoretical and interdisciplinary issues (Baron et al., 2017). More recently, the field of synthesis science has expanded to deal with concrete environmental challenges through a solution-oriented approach (Halpern et al., 2023). In these cases, the working groups are composed not only of a diverse group of academics, but also of different social or governmental actors, including decision-makers, representatives of civil society, and different types of practitioners. Those groups use an integrative and participatory approach to codesign and codevelop solutions, which could be called a "transdisciplinary synthesis approach" (Lynch et al., 2015).

The transdisciplinary synthesis approach goes beyond interdisciplinarity by allowing the articulation of multiple academic disciplines with experiential knowledge of local communities or social movements, and technical, strategic knowledge from practitioners and policy-makers (Alvargonzález, 2011). It promotes a collaborative process between researchers and practitioners for the co-design, co-production, and co-dissemination of knowledge (Dilling and Lemos, 2011; Mauser et al., 2013). This approach helps create alternatives, identify new paths, and support decision-making and public policies under uncertainty in various knowledge domains (Nicolescu, 2014), with the potential to break down institutional barriers through mutual and joint learning processes (Lang et al., 2012; Wiek and Walter, 2009). This definition is broad enough to encompass key characteristics of social engaged transdisciplinarity: the integration of diverse knowledge, the involvement of various social actors, and the co-creation of new knowledge or solutions for societal complex problems. Furthermore, transdisciplinary groups can use participatory methodologies or tools, such as companion modeling (Binot et al., 2015), participatory mapping and modeling (Tourinho et al., 2023), scenario and multicriteria analysis, or consensus conference, to promote consultation, collaboration, and co-decision (Luyet et al., 2012; Turnhout et al., 2020). Under these conditions, the transformative potential of working groups could be highly enhanced.

However, this approach faces several obstacles, some of which are inherent to transdisciplinary and co-production processes. On one hand, these obstacles are related to spatial and temporal mismatches between researchers and practitioners, or to poor communication and lack of topical and institutional alignments (Bertuol-Garcia et al., 2018; Jarvis et al., 2020). On the other hand, they are intrinsically associated with the difficulties in creating trust and a common repertoire, space for contestation, and pluralism in decision by dealing with power asymmetries, and identifying and connecting distinct expertise and abilities (Chambers et al., 2022; Turnhout et al., 2020). The ability of the transdisciplinary synthesis groups to adapt and confront these obstacles will determine their success in supporting decision-making processes.

Despite the growing interest in the transformative and innovative potential of transdisciplinary synthesis groups (Luza et al., 2023; Lynch et al., 2015), to date, there are few reports on their dynamics, and how they are tackling obstacles inherent to transdisciplinary processes. Different ways of co-producing and dealing positively with tensions and unbalanced power have already been identified (Chambers et al., 2022, 2021), but when this co-production occurs in synthesis dynamics, we lack descriptions and evidence to support adaptations and arrangements.

Here we share the experience of a set of transdisciplinary synthesis groups (hereafter referred to as "*working groups*") that belong to a Brazilian synthesis nucleus (the "Biota Synthesis"), which aims to co-design social-ecological instruments and policies with the government of the state of São Paulo, the most populous state in Brazil (over 44 million inhabitants) and home to the nation's largest economy (over 30% of Brazilian GDP). We identified several ways of adapting synthesis research to transdisciplinary approaches, making it possible to accommodate the limitations, expectations, experiences, and abilities of the different participants, while at the same time enhancing their interactions.

We will thus present and discuss the identified adaptations required for more effective transdisciplinary synthesis focused on policy design or the co-production of actionable knowledge for decision-making and highlight how these arrangements allow to alleviate some of the limitations related to the multiple mismatches existing at the interface of science and practice.

The Biota synthesis nucleus

The Biota Synthesis (https://biotasintese.iea.usp.br/) is a research project with the main goal of supporting the development of Nature-based Solutions (NbS). These solutions are designed to promote ecosystem services and forest restoration in rural and urban areas, stimulate a forest-based economy, promote solutions for controlling zoonotic and vector-borne diseases, accelerate adaptive strategies to climate change, and enable better health outcomes in urban areas (Fig. 1). The Nucleus uses a synthesis approach, meaning it utilizes already collected data to propose or co-create new knowledge and policy instruments.

This nucleus was established following a call from the São Paulo Research Foundation (FAPESP) to encourage partnerships between academia and the state government and/or the business sector to promote "problem-solving" or "mission-oriented" research approaches. Here we adopted a "*policy-driven approach*". This means that the Nucleus not only aims to generate actionable knowledge but also strives to co-produce policy instruments such as plans, programs, and projects.

The initial development of this initiative greatly benefited from personal relationships between some project coordinators and managers from the Secretariat for Environment, Infrastructure and Logistics (SEMIL), which were built over the last 10–20 years. As a result, from the very first planning meeting in 2019, it was possible to foster a co-creation process rooted in trust. This social capital was also crucial in establishing an environment of mutual credibility and legitimacy, which was essential for the project to effectively contribute to decision-making through its synthesis efforts.

Initially, Biota Synthesis was established as an interface between academia and the São Paulo state government (particularly with

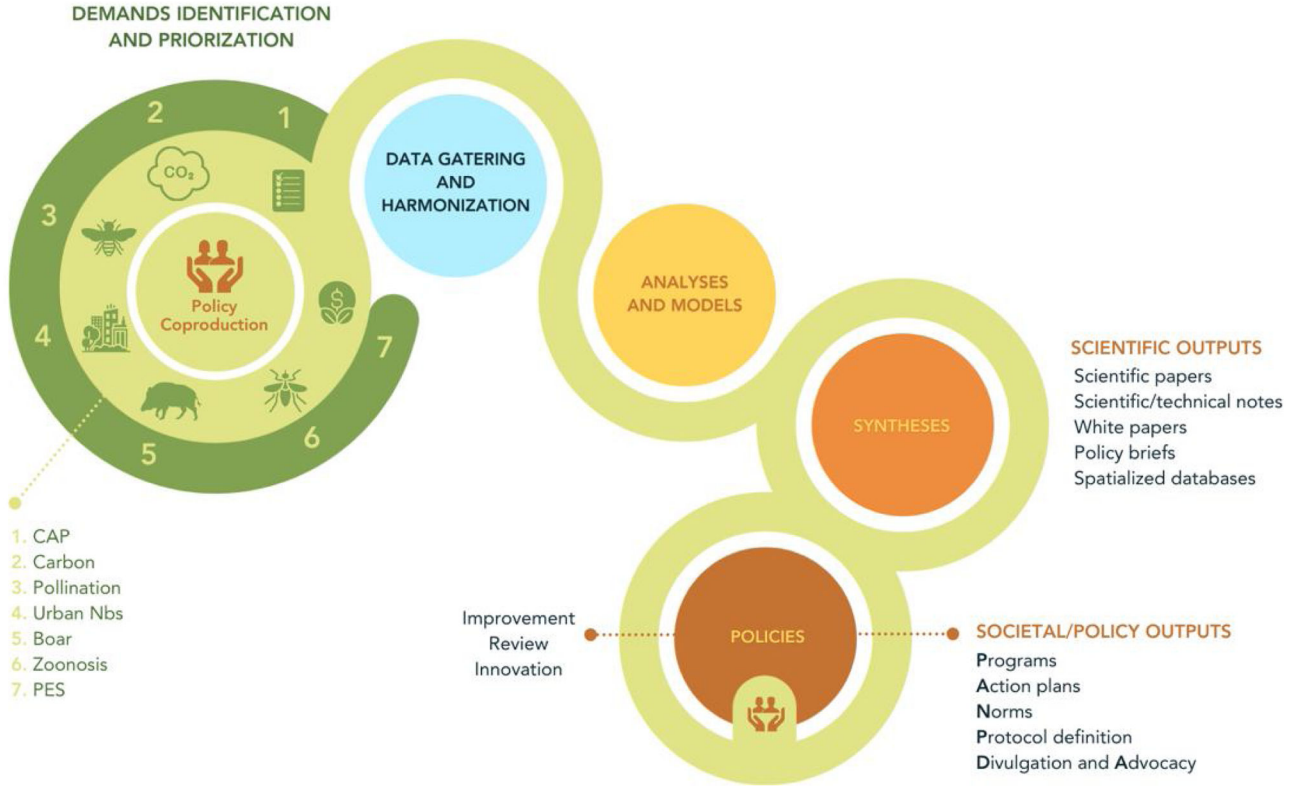


Fig. 1. Representation of the Biota Synthesis Nucleus, with its seven working groups and the coproduction group, collectively working to advance syntheses, analyses, and modeling of existing data. Together, their goal is to create actionable knowledge that can support the revision and development of public policies addressing socio-ecological challenges. CAP: Climate Action Plan of the state of São Paulo; Carbon: preparing for the carbon market; Pollination: valuing pollination service; Urban NbS: planning of urban nature-based solutions; Boar: controlling and preventing boar damages; Zoonosis: preventing zoonotic and vector-borne diseases; and PES: planning new schemes for payment for ecosystems services.

Table 1
Short description of the seven working groups developed within the Biota Synthesis Nucleus between 2022–2024. CAP: Climate Action Plan of the state of São Paulo; Carbon: preparing for the carbon market; Pollination: valuing pollination service; Urban NbS: planning of urban nature-based solutions; Boar: controlling and preventing boar damages; Zoonosis: preventing zoonotic and vector-borne diseases; and PES: planning new schemes for payment for ecosystems services. For more details on those syntheses, please refer to supplementary boxes 1 to 7.

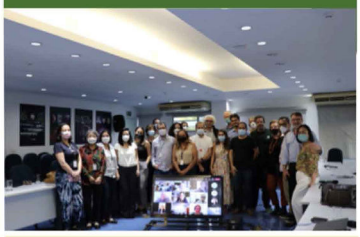
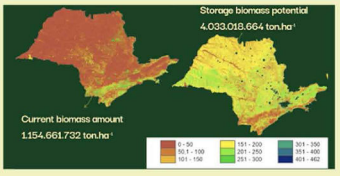
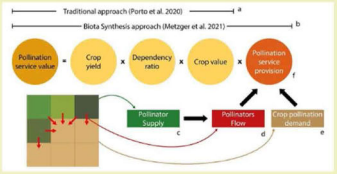
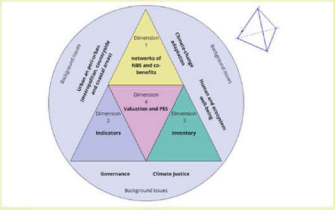
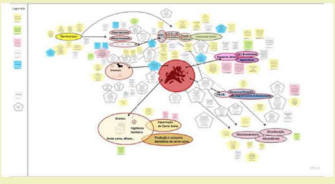
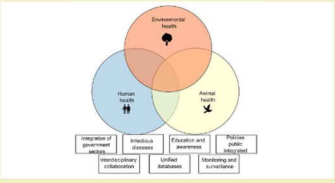
SYNTHESIS INITIATIVES	MAIN OBJECTIVE	SHORT DESCRIPTION AND LEARNINGS	ILLUSTRATION
CAP	Support the Climate Action Plan of the state of São Paulo	This synthesis highlights the need to adapt to political environment when supporting policy development. São Paulo State committed to becoming carbon neutral by 2050, prompting the creation of a Climate Action Plan within a short timeframe. This synthesis provided scientific evidence on the feasibility and benefits of large-scale forest restoration, completed within just two months. Despite time constraints that restricted the depth of analyses, it effectively informed government policies, supported the development of a forest-based economy program, and laid the groundwork for future syntheses. This synthesis emphasized the importance of flexibility to attend to urgency, as a way not only to seize political opportunities, but also to create trust and cohesion across participants from different organizations and professional cultures, acting as an important seed for collaboration.	
Carbon	Prepare the state of São Paulo for the carbon market	This synthesis underscores the importance of setting up data and involving key actors before initiating a synthesis process. In response to São Paulo's ReflorestaSP program, the synthesis began by mapping the state's carbon accumulation potential and identifying the socio-ecological factors crucial for carbon-financed restoration projects. This foundational work included data analysis, capacity building, and strategic planning, ensuring that the necessary groundwork and stakeholder awareness were in place before advancing to more collaborative synthesis activities.	
Pollination	Support the creation of a pollination market	This synthesis emphasizes the challenges when the perception of future benefits is too incipient to generate clear policy requirements. Despite recognizing the importance of pollination services, there were no explicit demands from the State Secretariats to link this knowledge to public policies. To address this, the synthesis team developed a spatially explicit pollination model and began exploring its practical applications, such as monetary valuation and the impact of vegetation restoration. By involving a transdisciplinary group, the aim is to identify new public policy applications and open policy opportunities for integrating pollination services into agricultural and conservation strategies.	
Urban NbS	Plan Nature-based Solutions to increase climate resilience and prevent diseases in cities	This synthesis illustrates the advantages of formal engagement at the science-policy interface and adequate time in constructing actionable knowledge. Initially, without a clear policy mandate, the synthesis focused on the shared understanding that well-planned Nature-Based Solutions (NbS) could significantly improve urban health in São Paulo, a highly urbanized state facing rapid urbanization, climate change, and social inequality. The process involved engaging local practitioners and municipal professionals, leading to the identification of key restoration opportunities and the importance of local governments in implementing NbS. Key lessons emphasized the importance of broad participation and time for co-production, which are essential for building trust, aligning goals, and developing effective solutions.	
Boar	Plan new solutions for wild boar control	This synthesis underlines the challenges faced when political shifts disrupt collaborative efforts. The wild boar, an invasive species causing significant agricultural damage and health risks in Brazil, prompted urgent action from São Paulo's Secretariat of Agriculture. Despite initial progress through discussions with various stakeholders, a change in state government led to a shift in priorities, halting further collaborative efforts. This situation underscores the vulnerability of science-policy partnerships and the impact of political changes on addressing urgent environmental issues. Biota Synthesis adapted by focusing on academic research and risk modeling, awaiting a new opportunity for policy engagement.	
Zoonosis	Develop solutions or actions to reduce the risks of spreading zoonotic diseases	The synthesis features the challenge of aligning policy needs with availability of data. Stakeholders from various institutions, aimed to identify government needs, discuss nature-based solutions (NbS), and explore collaboration opportunities. However, the meetings revealed a lack of clear needs from government agencies, with priority given to health issues like arboviruses and sporotrichosis based on current outbreaks. Complications included inadequate data reporting and limited connections to NbS. To address these challenges, a strategy was developed to leverage policy opportunities, particularly focusing on Dengue fever outbreaks due to their strong data support and NbS relevance.	
PES	Develop financial mechanisms to enable funding for climate action and biodiversity conservation	This synthesis highlights the successful alignment of policy requirements with actionable scientific knowledge. Following the approval of federal law that frames the legal basis for PES policies, there is now a push to transition local and regional experiences into long-term policies. The São Paulo state Secretariat of Environment, leveraging extensive local and international experience, initiates a PES synthesis process that bridges practical and scientific knowledge. This collaboration, marked by trust and mutual understanding, focuses on designing a PES program and developing a funding strategy to support long-term initiatives, addressing critical demands through innovative resource mobilization from private and multilateral organizations.	

Table 2
Different contexts or conditions in which the synthesis dynamics occurred and that can constrain their dynamics to support decision-making processes, particularly in the formulation or improvement of public policies. CAP: Climate Action Plan of the state of São Paulo; Carbon: preparing for the carbon market; Pollination: valuing pollination service; Urban NbS: planning of urban nature-based solutions; Boar: controlling and preventing boar damages; Zoonosis: preventing zoonotic and vector-borne diseases; and PES: planning new schemes for payment for ecosystems services.

KEY ASPECTS (SUPPLEMENTARY BOXES)	DEFINITION	CAP (1)	CARBON (2)	POLLINATION (3)	URBAN NBS (4)	BOAR (5)	ZOONOSIS (6)	PES (7)
Alignment of research and policy interests	How well defined is the problem faced by the government organizations responsible for creating or improving public policies, and how this aligns with academic interest and research potential	Policy-making needs are clear since the beginning and aligns with research interest	Policy-making needs are clear since the beginning and aligns with research interest	No clear policy-making need, but there is a mutual interest to collaborate toward a pollination market	The problem is being co-defined along the synthesis dynamics considering both policy and research interests	Policymaking need for boar control is clear since the beginning and aligns with research interest	No clear policy-making need, but there is a mutual interest to collaborate toward a better regulation of zoonosis	Policy-making needs are clear and align with research interest and accumulated knowledge
Policy urgency	Level of urgency for a solution or product to be delivered	Very urgent (3 months)	Urgent (< 1 year)	Low urgency	Low urgency	Moderate urgency (1-2 years)	Low urgency	Urgent (< 1 year)
Policy opportunity	Policy opportunity to transform actionable knowledge into legal instruments (e.g. policy decrees or regulations)	Immediate (high) opportunity	Medium to short-term (1- year) opportunity to regulate a carbon market at the state level	The policy opportunity is being co-produced	There is interest, but yet no clear policy opportunity	There was a policy opportunity, but it was closed before the end of the synthesis	The policy opportunity is being co-produced	High-Medium opportunity (response to a national policy implementation)
Data availability and access	Status of existing data or databases required for the synthesis: availability (if data exists or not, or if it is sufficient) and access (if it is or not open access, or accessible after queries/demands)	Available and accessible	Partially available and accessible (require previous treatment), and partially being produced	Partially available and accessible (data requires previous treatment)	Mostly available (requires new analyses)	Partially available and accessible (require previous treatment)	Available but need authorization to access	Partially available and accessible (require previous treatment)
Working Groups composition	Composition in terms of institutional representation (e.g. balanced composition of the different participating organizations, particularly, representatives of society, government and academia) and involvement of "knowledge brokers" (those who connect different knowledge pools)	Good institutional representation and a broad participation of knowledge brokers	Limited representation, but with knowledge brokers	Limited representation of agriculture managers and practitioners	Good institutional representation and a broad participation of knowledge brokers	Broad representation, but not aligned coordination	Limited representation of public health managers	Good institutional representation and a broad participation of knowledge brokers

SEMIL). Over time, this governmental partnership expanded to involve two other secretariats (Health and Agriculture), as well as the direct participation of municipal governments (São Paulo, Campinas, and Santos), further increasing the complexity and scope of the challenges.

As it operates at the science-government interface, Biota Synthesis is co-directed by a researcher (JPM) and a São Paulo state official (RBC) and includes a mixed composition in all its working groups, with representatives from different sectors. These groups ranged in size from 17 to 36 members, with approximately 40% from academia (universities and research institutes), 50% from state and municipal governments, and only 10% from NGOs – see Table S1 for detailed composition). We have thus been engaging more with government actors than with those from NGOs and the private sector. This limitation is likely tied to the fact that Biota Synthesis was conceived with a 'policy-driven' approach, focused on co-creation of public policy tools in partnership with governmental actors.

The project includes a group of 4 coordinators, around 10 principal investigators, and 8–10 postdoctoral researchers, in addition to 14 managers from the SEMIL who are actively involved and meet regularly. Beyond this core group, approximately 80 participants are occasionally involved in specific syntheses or follow the project's semiannual meetings. The coordination of all efforts for the co-production of public policy instruments is managed by a co-production group (2–4 core investigators/practitioners and one postdoctoral researcher).

The Nucleus started its activities at the beginning of 2022 and has already experienced seven working group initiatives (Table 1, Boxes S1 to S7). Each of these initiatives occurred under different conditions, particularly concerning the alignment of policy and research interests, policy urgency and opportunities, data access and availability, and the governance structure of the working group (Table 2). All those experiences have provided different insights on how to accommodate and support a transdisciplinary synthesis process.

Learnings and recommendations

Based on the experiences of the seven working groups, eight key lessons are highlighted here, which may be useful for other transdisciplinary synthesis groups.

These lessons do not stem from a systematic analysis of quantitative data or interviews but rather from individual and collective reflections, as well as the sharing of experiences and practices that were successful or unsuccessful. This process took place over multiple meetings

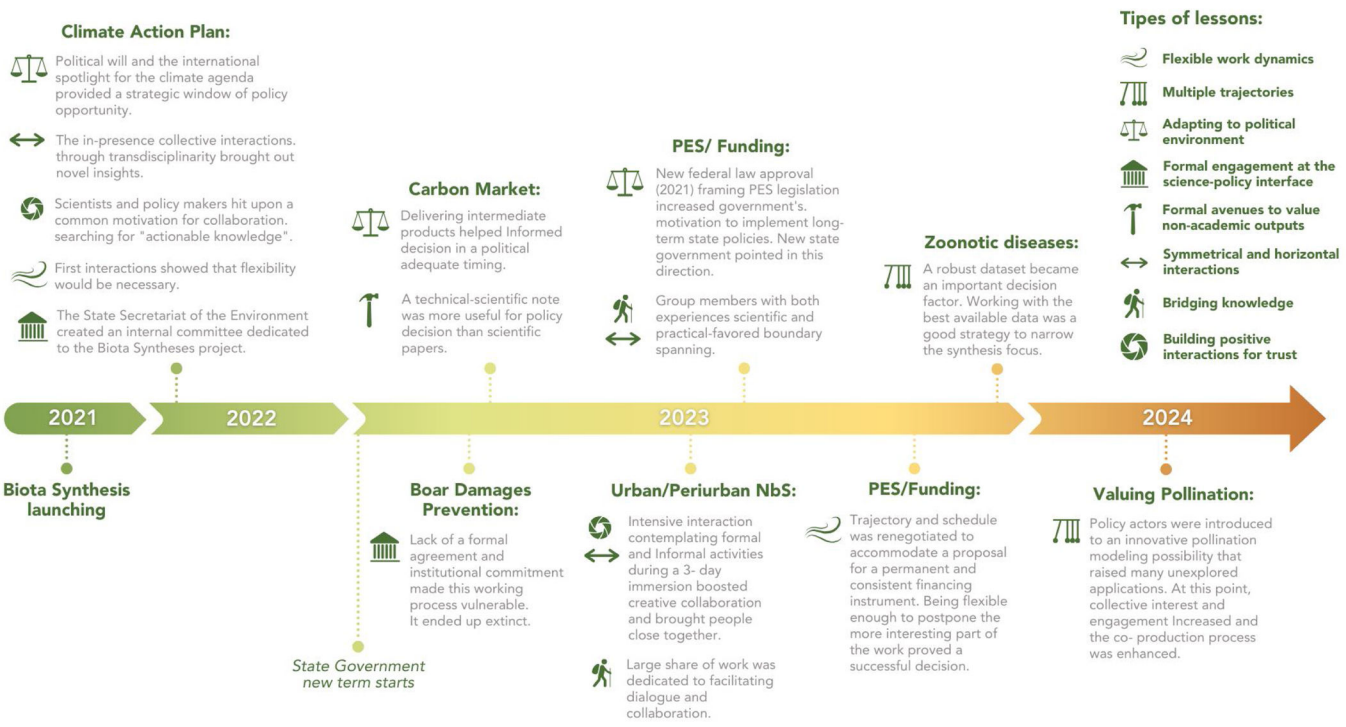


Fig. 2. Timeline showing the temporal sequence of the syntheses and respective learnings arising from them. PES: Payment for Environmental Services; NbS: Nature-based Solution.

throughout the project, whether with the coordination group (monthly meetings), or with the coordination team alongside the main stakeholders and postdoctoral researchers (bimonthly meetings), or with the broader group of researchers and involved individuals (semiannual meetings). The fact that we had synthesis initiatives operating under different conditions (Table 2) allowed the comparison of these situations to inspire insights into what works for the productive involvement of government actors in transdisciplinary syntheses, and how to handle challenges related to aligning governmental and scientific expectations, urgent demands, lack of organized data or difficulties in accessing data, absence of clear demands, or lack of political opportunities.

These insights evolved over time, with some key realizations gradually becoming collectively accepted practices (Fig. 2). This process was not a series of disconnected events, but rather a continuous progression of discussions to reach consensus that, as they solidified and intertwined with new agreements, strengthened the bonds of collaboration and empathy among Biota Synthesis members. This process facilitated the alignment of a common culture and repertoire, promoting a productive co-production process.

This entire learning process was facilitated by a co-production group, whose primary goal was to encourage these collective reflections, promote engagement and address power asymmetries (Box 1). The group consisted of researchers and decision-makers with extensive experience at the science-policy interface, aiming to facilitate the meetings of the working groups. This group fosters the science-policy interface, creating space for the co-production and generation of high-quality, policy-relevant research that is communicated clearly, promptly, and inclusively. Although this co-production group did not have specialized training in meeting mediation, they often acted as knowledge brokers, bridging the practices and constraints between the world of knowledge generation and public policy development.

The consolidation of these lessons was carried out by the authors of this article, who include 18 researchers affiliated with a research institution, 9 government representatives (including managers from the state secretariats of environment and health, members of an applied research governmental institute, and a forest management agency), and one author from an NGO (connected to the field of One Health).

This process led to a set of proposed adjustments needed to enhance transdisciplinary synthesis approaches aimed at co-producing actionable knowledge and supporting policy decisions (Table 3). Additionally, it resulted in the development of a portfolio of key learnings to improve transdisciplinary synthesis initiatives (Table 4), which are detailed below. We acknowledge that the methodological approach developed here is more qualitative, based on reports and the experiences of a group, and that the insights are context-dependent. However, we believe that the learnings may inspire other transdisciplinary synthesis groups working in territorial contexts or in the co-creation of public policies. These learnings have been grouped into three broad categories (Table 4): **flexibility** (the ability to make quick, practical adjustments that facilitate collaboration); **creating formal institutions** (formalizing agreements, rules, and structures between sectors and organizations); and **reflexivity** (critically and transparently reflecting on our assumptions and values, and how they influence our actions, interactions, and research, to enhance communication, collaboration, and shared perspectives).

Learning 1 – Flexible work dynamics

As soon as the various working groups began their activities, we recognized that each organization has unique routines and dynamics. This realization prompted us to adjust our synthesis approach to better facilitate engagement and collaboration across groups. For instance, long immersions were very hard to fit into the schedules of government representatives. They were also impractical to conduct when policy needs were urgent, as in the case of the transdisciplinary synthesis to contribute to the Climate Action Plan of São Paulo state. In this case, the chosen option was to hold two events over a two-day meeting in the city of São Paulo. In other cases, advancing group collaboration required several shorter, online meetings. For example, the zoonotic diseases working group conducted a series of individual meetings to gain access to integrate data from various organizations.

We learned that a variety of different meeting configurations (in

Box 1
Reflecting collectively on co-production through Q-methodology - the Biota Synthesis experience.

Planning and creating spaces for collective reflection on these key interaction aspects, recognizing power and risk asymmetries, and valuing and integrating diverse skills and authorities have been the strategies Biota Synthesis employs to foster horizontal, collaborative work. In a 3-day immersion period with main project members, we developed a series of activities focused on reflecting on how co-production is understood, what it requires, and which are its main challenges, on bringing to light conflicts and barriers, and on discussing ways to deal with them (*Fig.* Box 1). The activities were based on Q-methodology, a technique from psychology, for eliciting viewpoints or perspectives on complex topics. By considering a guiding question, participants were tasked to evaluate and rank in terms of agreement, one in relation to the others, a set of statements concerning the topic of interest. Careful reflection is necessary to rank and organize such statements and to explain the reasons behind the final proposition. Collective mediated discussions to share individual reflections led to the perception of the diversity of perspectives on co-production and the construction of an agreement on its essential features. This then prompted reflection on smaller groups on which have been the challenges of co-producing in BS working groups, followed by a collective discussion to categorize main challenges and identify ways to confront them (*Fig.* Box 1).

The process was effective in creating a common understanding on how interactions among project members should be, as well as a common repertory that facilitates communication. It also allowed collective recognition of the critical relevance of sharing discomforts and disagreements as well as being attentive and reflexive towards, and welcome, these sharings. We argue that periodic meetings such as this are crucial in transdisciplinary synthesis projects. They commonly involve large (15–30), heterogeneous groups, in which many are working together for the first time, some are inexperienced in co-producing, and asymmetries - and a great diversity of background experiences, knowledge and values - are in action. Taking for granted that all members share a common understanding on how the group should work will then frequently lead to tacit conflict and poor communication, hampering collaboration and creativity, central to the success of these projects.

Figure Box 1 - The 3-day immersion meeting with the main members of Biota Synthesis project. During the meeting, participants individually evaluated and ranked a set of statements (A, example of statement in B) on four dimensions of co-production, following a guiding question (C). This prompted a discussion to collectively identify and categorize main challenges faced by project members to co-produce and find ways to confront them (D).

Table 3
Main differences between interdisciplinary and transdisciplinary working group dynamics.

	INTERDISCIPLINARY WORKING GROUPS	TRANSDISCIPLINARY WORKING GROUPS
Composition	Heterogeneous groups in terms of research topics, skills, seniority, gender balance	Heterogeneous groups on the same criteria of interdisciplinary groups, but also with a balance between academics and different types of practitioners, from different organizations (e.g., state or local government, NGO and private sector representative)
Meetings		
Type	Immersions	Regular meetings and sparse immersions
Frequency	Every 6-12 months	Need to be more frequent in the early planning stages (every 1-2 months)
Time	Around 5 full days	Need to be shorter, one or two days, with additional immersions possibly longer (~3 days) to strengthen bonds or make decisions
Place	Away from the participants' workplace, to allow full immersion	Usually at the workplace or an easily accessible place, with the longer immersion in a more remote, but easily accessible location
Training or preparation before synthesis dynamics	In general, no special preparation is required before work begins	It may require workshops to build capacity and share knowledge to provide a better basis for discussions during the synthesis
Group dynamics	Groups are generally animated by one or two academics (e.g., proponents of the synthesis), who seek to facilitate discussions, with or without professional mediation or facilitation tools	Ideally, groups should include academic and/or practitioner "knowledge brokers", who should be particularly attentive to issues of imbalance of power between participants
Data management and modeling	Process generally centered on a postdoctoral researchers or IT technician	Process centered on postdoctoral researchers or technicians (when available), but access to data often requires authorization from involved organizations. An environment of trust is needed to resolve conflicts and to allow data sharing between organizations that do not usually work together
Multi-organization governance	In general, not necessary	Synthesis groups involve stakeholders from various organizations. For their representation to be legitimate, these stakeholders need discussion spaces within their organizations. Additionally, these organizational working groups must connect to the main synthesis working group. This integration enhances representativeness and lends greater legitimacy to organization representatives.
Expected outputs	The main expected outputs are academic products such as peer-reviewed articles.	In addition to academic products and postdoctoral training, there is a high expectation for products that are of easier access by a wider audience (e.g., technical notes, position papers) and that present actionable knowledge (e.g., maps, scenarios, models or decision-making tools). Those products can impact more directly (compared with academic outputs) government documents (e.g., resolutions, decrees, standards, laws).
Expected outcomes	The primary outcome is the training of postdoctoral researchers to work in collaborative networks, connecting disciplinary knowledge	Beyond postdoctoral training, another expected outcome is the proper process of collaboration, networking, and engagement between actors, who become more able to articulate different academic and non-academic knowledge to generate solutions and knowledge that support policies. In addition, it is also expected a longer-term relationship and trust between organizations and their representatives.
Time allocation/ dedication level	Participants' dedications to working group activities (immersions, discussions between immersions) usually fall within their regular academic time or schedule allotment	Usually, there is an unbalanced time dedication: while some academics can dedicate more time to synthesis initiatives, practitioners have limited time officially dedicated to the co-production process (except in cases of urgency or high political interest). Ideally a more equitable dedication between academics and practitioners needs to be sought, allowing a less biased co-production process. For both academics and practitioners, it is crucial to value the time spent on co-production, as it is essential for generating impactful products and transformative processes.

terms of frequency, duration and space - in person or virtually - see Table 3) were necessary in the initial stages of all syntheses to deal with the constraints in time availability and establishing collaborative ties. So, gatherings typically occur more frequently, such as monthly or bi-monthly, compared to traditional synthesis meetings. They also include shorter immersion periods (1–2 days) held in easily accessible venues. Additionally, these meetings often alternate between in-person and hybrid formats, always seeking to maintain the momentum for collaboration (Srivastava et al., 2021).

However, as immersive meetings are essential for consolidating engagement and commitments, several working groups conducted them, even if shorter than 5 days. This was the case of the urban working

Table 4
Snapshots of the main learnings to improve the impact of transdisciplinary synthesis groups at the interface of science and policy.

SHORT NAME	MAIN LEARNING	CHALLENGE	TYPE OF MISMATCH (JARVIS ET AL. 2020)
FLEXIBILITY (Refers to fast and feasible adjustments that facilitate collaborative work)			
Flexible work dynamics	*Flexibility in the duration and frequency of meetings*	Actors have different time availability and deadlines.	Temporal, institutional
Multiple trajectories	*Flexibility to shape different trajectories*	There is no single path to all syntheses.	Temporal, priority, institutional
Adapting to political environment	*Flexibility to adjust to political circumstances*	There are trade-offs between responding to urgency and creating novel ideas, knowledge and outputs.	Priority, temporal, institutional
CREATING FORMAL INSTITUTIONS (Refers to formalizing agreements, rules and structure between involved sectors and organizations)			
Formal engagement at the science-policy interface	*Creating formal mechanisms of designation and recognition of the engagement in science-policy interfaces*	Usual roles of policy-makers do not commonly value the engagement in collaborative science-policy interfaces.	Institutional, communication, priority
Formal avenues to value non-academic outputs	*Creating formal platforms for disseminating non-academic outputs*	Engagement in collaborative transdisciplinary processes is undervalued in academia, leading to many outputs from these syntheses being overlooked.	Communication
REFLEXIVITY (Creating formal institutions refers to formalizing agreements, rules and structure between involved sectors and organizations)			
Symmetrical and horizontal interactions	*Collective reflexivity to foster symmetrical, horizontal interactions.*	Transdisciplinary syntheses focused on the co-design of public policies is not the common way of interaction between academia and governments.	Priority, institutional
Bridging knowledge	*Collectively reflexivity on how to bridge different knowledge, skills and authorities.*	Connect distinct rules, norms and culture, and varied interests, concerns, goals, risks, knowledge, experience and authorities of the actors coming from different organizations.	All, mainly institutional
Building positive interactions for trust	*Collective attention to create positive interactions and transparently communicating to build trust.*	Sharing knowledge, data and collaborating require building trust among participants.	Communication

group that managed to organize a three-day immersion with academics and four government organizations out of town, in a pleasant place, close to nature that helped raise insights, engagement level, the establishment of bonds of trust, and the deepening of the proposals (Box S4). Although many practitioners have limited time for this type of immersion, we recommend at least one moment like this during a transdisciplinary synthesis process, possibly after initial meetings to organize activities, define the scope and establish collaborative networks.

Such adaptive organization in the format of transdisciplinary meetings also helps to cope with the tensions that may appear throughout the process (Chambers et al., 2022).

Learning 2 - Multiple trajectories

Transdisciplinary synthesis across the different working groups could not be effectively guided by a standardized implementation approach; instead, each required tailored strategies. The distinct motivations behind the formation of each working group illustrate this uniqueness. For example, the Payment for Ecosystem Services (PES) working group was initiated in response to a convergence of accumulated academic expertise and public-sector interest, seizing a political opportunity to develop a PES policy based on scientific knowledge. The data and knowledge were available. Consequently, this group

immediately focused on formulating public policy instruments (Box S7).

However, when data does not exist, is not available, or needs to be initially organized, harmonized or even pre-analyzed, the first phase of the work may be, for instance, analysis and modeling. This was the case with the dynamics related to the carbon market and pollination (Boxes S2 and S3). In the case of carbon, the needs were clear: how to prepare the state of São Paulo to enter the carbon market with a competitive differential? However, to have this discussion, data was needed on current ecosystem biomass, potential biomass gains, eligibility of areas to reach the carbon market requirements, and risk of biomass loss by future extreme events and fire. This data needed to be prepared upstream of the synthesis. The same happened with pollination: to discuss a policy for valuing pollination or including it in the payment for ecosystem services schemes, it was necessary to map where the demand and supply for pollination are, where the service occurs and where it is demanded but not provided.

In sensitive cases – when it evolves the use of confidential and protected data- as for health syntheses, participants may be resistant to engage, and the processes may be lengthy and demand applications to ethics committees (Box S6). In these cases, initial efforts may be related to institutional engagement and commitment. The initial steps of synthesis processes are important not only for jointly identifying focal problems but also for getting people to interact, engage and subsequently agree upon the best working dynamics.

Thus, regular coordination and working group meetings were employed to discuss context, assess progress, and refine the trajectories of the transdisciplinary syntheses such as the cases described above. Being flexible was crucial in enhancing the diversity of approaches through which we were able to support policy and decision-making processes.

Learning 3 - Adapting to political environment

Throughout the project, key opportunities to influence public policy have emerged. Those opportunities, often arising in response to urgent needs, can increase the likelihood of implementing solutions. This was the case of the Climate Action Plan of the São Paulo state, for which the government asked for contributions at the beginning of the project. To seize this opportunity, the project developed a three-month task force to provide the best possible contribution with the available data and knowledge (Box S1).

However, it is important to note that high urgency can create tensions and hinder effective co-production processes. Building trust, reciprocity, and balance among diverse stakeholders takes time. The need for accurate, high-quality data can extend research timelines, both of which can be at odds with the immediacy required for decision-making in government. For instance, in early 2023, as the state government assessed the state's potential in the carbon market, restoration researchers created a map to illustrate this potential (Box S2). Unfortunately, due to tight deadlines, the map was developed using only coarser available data (Nascimento et al., 2024). There was insufficient time for effective co-production involving the participation and contributions of multiple stakeholders. With less urgency, the government could have had access to a higher quality product, characterized by better resolution and meticulous data validation. However, failure to seize the opportunity could possibly have made the better, though later, maps useless.

In contrast, when the problem or gap is clear, but not urgent, in-depth engagement and discussion between actors, and better solutions are possible. For example, the urban group identified the peri-urban region as a promising area to bring forest ecological restoration closer to where people live, enhancing its relevance for climate change adaptation. Here, restoration efforts would extend beyond rural areas (where most restorable lands are located) to the urban periphery, where impacts on human well-being are more pronounced (Box S4). This shift would also broaden the focus from climate change mitigation to adaptation, addressing more localized needs (Morecroft et al., 2019). While this initiative was not immediately applicable, the group had sufficient time to collaborate and develop innovative, promising ideas that could evolve into future policies.

Transdisciplinary synthesis should balance two competing factors: the urgency that can compromise quality yet create policy opportunities, and the lack of clear problem definitions and deadlines, which may slow progress and hinder solution-oriented engagement but provide more time for co-producing thoughtful and innovative solutions. Being flexible to adjust to political circumstances is key to be ready to recognize and take advantage of political opportunities for action.

Learning 4 - Formal engagement at the science-policy interface

Because participating in transdisciplinary synthesis or research projects at the science-policy interface is not among the main or designated roles of policy-makers within governmental organizations, they usually are overloaded and have little time, support, and recognition to be able to participate in these activities. This creates fragility for long-term engagement and greater susceptibility to political and government change.

This became particularly clear during the change of state government, between 2022 and 2023, in the case of the wild boar synthesis. At the beginning of this initiative, policymakers had a pressing initial demand and full engagement, but when the new administration arrived, designations changed, particularly at the Agricultural Secretariat, removing the demanding actors and consequently freezing the synthesis effort (Box S5, Fig. 2).

On the other hand, this political rupture did not occur with the Secretariat for Environment, Infrastructure and Logistics for two reasons. In addition to the memorandum of agreement they had signed at the start of the project, they established an internal committee (Fig. 2) that was closely interacting with the Biota Synthesis working groups (particularly for the climate action plan, carbon market, urban planning and PES). This committee strengthened the bonds among its members (~15 people meeting twice a month), among the different units that these members represent within the secretariat, and with the secretary (political position). This process creates a sense of belonging, and allows to incorporate some lessons learned from co-production into their work, thus potentializing commitment and resilience.

These contrasting situations highlight the critical importance of building, formalizing, and aligning collaborative ties within and among partner organizations. Doing so enhances the legitimacy and credibility of institutional representatives during synthesis discussions and strengthens the overall collaborative network. Formalization and recognition by government organizations of the roles of policy-makers within the transdisciplinary synthesis confer thus greater legitimacy and stability to the process of co-producing actionable knowledge, making it more likely to influence public policy.

Learning 5 - Formal avenues to value non-academic outputs

In Brazil, as in many countries worldwide, research funding agencies, including those financing transdisciplinary research, and job selection processes for researchers (e.g. in universities and research institutes) do not value non-academic products or collaborative, transdisciplinary experiences. Academia prioritizes high-impact scientific work but continues to undervalue the societal contributions of researchers. CVs are assessed almost exclusively based on scientific publications. This system had a major negative impact on the earlier career researchers searching for a permanent position, such as the postdocs of our team.

Researchers play an essential role in addressing societal challenges, fostering a closer relationship between scientific efforts and society. Despite the challenges, it is crucial to place greater value on a researcher's potential social impact, not just their academic contributions,

to encourage engagement in socially impactful research.

The outputs of transdisciplinary syntheses are far more diverse than those of traditional academic syntheses. Alongside peer-reviewed articles in international journals, transdisciplinary synthesis generates products tailored to meet the needs of various organizations, including technical notes (e.g., Metzger et al., 2024), maps, scenarios, models, and decision-making tools (Table 2). These science-policy interface outputs are essential for bridging research and policy, promoting a more direct societal impact.

At Biota Synthesis, we invested in developing new indexed platforms specifically dedicated to publishing these types of products and results. An example is the "Biota Synthesis Series," a self-published digital booklet series that is fully indexed (with DOI, ISSN, and ISBN), making it more easily discoverable. Within this synthesis, we published the contributions to the climate action plan (Metzger et al., 2024), to the state carbon market (Nascimento et al., 2024), as well a financing mechanism report (Sousa et al., 2024) and a framework to model and value pollination service (Moreira et al., 2024). We believe that these initiatives not only enhance accessibility and dissemination of valuable outputs but also allow for citation, which we hope will increase recognition from funding agencies as valuable products and publications.

Learning 6 - Symmetrical and horizontal interactions

As the working groups progressed, we began to notice that many of us - both policy-makers and academics - were influenced by a culture of one-way, asymmetrical interactions between science and policy. In this dynamic, a problem or demand is defined by governmental organizations and addressed by expert scientists in a way that closely resembles a consulting arrangement. This culture impairs collaborative definitions of problems and creatively articulation of novel solutions that characterize transdisciplinarity. Together with the urgency in policy formulation and the different skills and knowledge between practitioners and academics, it generated difficulties in communication that - if not cared for - could erode trust and cohesion and collaborative interactions within the team.

To deal with this challenge, we understood that we should move from a paradigm of transferring knowledge to one focused on co-producing actionable knowledge (Halpern et al., 2023; Kirchhoff et al., 2013), a shift from one-way to two-way linkage between science and policy/practice (Bertuol-Garcia et al., 2018) (Fig. S1). To construct a shared perspective and repertoire in what is transdisciplinary co-production within the project, what it requires, its challenges and advantages, we organized 3-day internal immersion (Box 1). By devising a strategy to stimulate and share reflections on these themes, we unveiled dissent and articulate agreements on such definitions and on tenets to guide the interactions and work within the team. We also collectively devised actions to support and value different skills, roles and perspectives.

This project internal immersion transformed synthesis groups' dynamics, allowed more bottom-up and consensus decisions, and made it possible to identify and capitalize on political opportunities. The relevance of such two-way interaction was evident, for example, in the case of the PES synthesis that rapidly embraced the political opportunity for the development of a broader instrument for financing climate actions with a particular emphasis on incorporating benefits for biodiversity (Box S7, Sousa et al., 2024). Based on a well-balanced relationship, the group was sensitive to the originally not identified demand, recognized the opportunity, and managed to reorganize itself to go beyond its original scope.

This paradigm shift also allows us to move away from the logic of consultancy, where the government asks for a product and demands a solution that should be created by external parties (a company, or a group of recognized experts). In this novel approach, we acknowledge practitioners from partner organizations as pivotal contributors in the solution-building process, moving beyond the passive role of merely receiving and applying solutions. On the other hand, this also encourages researchers to move, at least partially, from an exclusively curiosity-driven science to a solution-oriented science (Kirchhoff et al., 2013).

Learning 7 - Bridging knowledge

We soon learned that creating and maintaining dialogue among diverse actors required a great deal of planning, including devising participatory activities, moderating discussions, openly identifying and dealing with dissent, and synthesizing and communicating agreements across and in-between meetings. All working groups, and particularly those that manage to engage a larger number of actors and to advance in the collaborative work, required an immense amount of work - time and energy - spent on these bridging activities. This created an overload of work for team members - either post-doctoral fellows, scientists or policy-makers - who had previous experience in these activities and engaged in planning them.

Creating and maintaining dialogue among diverse actors requires skills and time, which must be accounted for. Solutions may involve hiring specialized knowledge brokers or boundary spanners, ideally among people already acquainted with or involved in the transdisciplinary synthesis. This was not possible for Biota Synthesis, as the project cannot hire personnel. Instead, we relied on team participants that had extensive experience on the interface between science and policy. This includes individuals with expertise in both scientific research and public policy formulation and implementation—those who can more readily bridge diverse knowledge pools or communities (Matous and Wang, 2019; Dworkin, 2024). Such individuals have already proven essential to advancing synthesis work, even within interdisciplinary (rather than fully transdisciplinary) synthesis efforts (Schröter et al., 2023).

Part of those individuals formed a transversal group within our project - named "co-production group", which acted to support the bridging activities of the different working groups. The coproduction group also planned activities to create space for the people taking these bridging roles to expose the difficulties they were facing, stimulate reflection and recognition within the team, and collectively devise actions to reduce overload and facilitate learning of skills and practices associated with bridging activities among other participants (Box 1).

In Biota Synthesis, complex and nuanced issues, such as establishing climate change mitigation and adaptation goals and promoting more sustainable landscapes, were addressed more effectively and successfully when facilitated by these actors, particularly in the case of the Climate Action Plan, PES, and urban planning groups (Boxes S1, S4, S7, Fig. 2).

We stress that recognition and valuing of the role played by these key actors is a critical challenge in transdisciplinary syntheses, which depends on institutional changes in the way governmental organizations value the engagement at the science-policy interface (learning 4) and academia evaluates and rewards researchers (learning 5).

Learning 8 - Building positive interactions for trust

At certain points of the project, progress clearly hinged on the level of trust among participants. In the zoonotic diseases working group, for instance, accessing organizations' databases was an action that fundamentally depended on policy makers' trust on the research team and on the collaboration under construction. Similarly, in the PES working group, a shift in the direction of the group's work schedule could risk the achievement of some agreed goals. Thus, the successful implementation of a new work schedule definition also relied on mutual trust between group members. The development of trust among the participants in the syntheses was gradually built through meetings, particularly during the longer immersion sessions that took place in the urban synthesis and in the group's discussions on co-production (Box 1).

It is worth noting that, in some working groups, participants already knew each other from other professional environments or had experience in the relevant sectors. This allowed pre-existing relationships and networks to help establish a potent foundation of trust.

As an example, we worked on a transparent and frequent communication to ensure that everyone feels included in the processes and informed about the progress of the groups. Communication is important for establishing bonds of trust and creating healthy spaces for collaboration. As part of a process, it cannot only take place at the end of the knowledge production process. Sharing throughout the process is important, which includes sharing problems and not just solutions, sharing intermediate products with their uncertainties and potential misinformation, and sharing on the co-production process itself (Box 1).

We organized regular meetings to share progress, results and uncertainties. We also made efforts to communicate results whenever possible (e.g. through presentations), and prioritized collaboration, ensuring that the diverse perspectives and needs of each organization and participant were taken into account. Respond to specific political demands in a way that supports the work of policymakers within their institutions, such as in the case of the carbon map (See 'Adapting to political environment' learning), has also proven to be part of the interactions that build relationships of trust.

Transdisciplinary synthesis at the interface of science and policy - perspectives

A transdisciplinary synthesis dynamic provides a space for discussion and dialogue where actors from different organizations can express their needs, priorities, as well as the urgency and opportunities for solutions. Being a space for communication and co-construction, it is expected that the main mismatches between scientists and practitioners (Jarvis et al., 2020) can be jointly assessed, seeking the best solutions to address them on a case-by-case basis (Tables 3,4). The experiences of Biota Synthesis show that this process can be enhanced under certain circumstances, particularly when the synthesis format is adapted to the possibilities and constraints of the involved organizations, and when there is institutional engagement and commitment to the co-construction of knowledge and solutions. Moreover, it is important to count on mediation from academic and governmental knowledge brokers, which requires effort in training and institutionalization of these actors. When there is a balance between the urgency of decisions and the time to establish innovative solutions, the utilization of policy opportunity is more solid. In some cases, it is necessary to allow time for data analysis and for sharing more complex concepts among the actors before synthesis, otherwise, solutions may not be viable. Finally, respectful interactions and communication throughout the entire transdisciplinary synthesis process is necessary, valuing not only the data but also its uncertainty and limitations, as well as the group effort.

Transdisciplinary syntheses present particular challenges due to the diversity of organizations and actors involved, each with their own cultures, demands and working practices. The experiences of Biota Synthesis highlight this complexity, but also underline the potential of these groups to innovate, expand actionable knowledge and co-create more robust solutions to support policies.

Tangible results in this regard are already evident within Biota Synthesis, notably in the co-production of the officially launched Climate Action Plan, Refloresta-SP (restoration) program and climate finance mechanisms. Firstly, our scientific-technical note (Metzger et al., 2024, Box S1) contributed to the Climate Action Plan and informed the organization of the Agriculture, Forestry, and Other Land Use chapter—one of the six key sectors in this state-level Plan, which is currently active and guided by State Decree 65.881/2021. Secondly, the science-based Refloresta-SP application, launched in 2023 to help landowners design and implement profitable multifunctional forests, includes active participation from Biota Synthesis, which is also represented on its Committee (SEMIL Resolution 3/2023). This ensures ongoing contributions within the official governance framework. Finally, in 2024, São Paulo state introduced its first blended finance mechanism for climate funding (State Decree 68.577/2024), featuring a co-produced framework to scale up ecosystem restoration with multiple benefits (Sousa et al., 2024) and governance and financial components co-designed by the PES synthesis group.

While other initiatives are ongoing, organization (and personal) links have been created and, in many cases, databases and preliminary analyses have been organized and completed, laying the foundations for developing future socio-ecological solutions and policies.

We view the formal publication of government instruments—such as plans, programs, and projects issued through decrees, norms, and resolutions—as essential to successful co-production. For the Biota Synthesis team, this means a dual focus on advancing knowledge itself and creating policy through this knowledge. We propose that this policy-oriented approach holds great promise for future synthesis initiatives aiming to maximize societal impact.

The success of these initiatives has been based on an adaptation of current interdisciplinary synthesis dynamics and the institutional involvement of actors. However, this process is fragile and can be disrupted by political changes, such as those associated with election periods, among others. These factors indicate that Biota Synthesis continuity will be more tangible if it formally positions itself as a boundary organization, whether through an association with government, academia, or as an independent institution.

Transdisciplinary synthesis is a promising model for acting at the interface of science and policy. Using existing data and involving transdisciplinary groups in the discussion and formulation of innovative socio-ecological solutions accelerate the generation of actionable knowledge. This model can certainly be replicated to other scales and contexts (states, countries, regions) where data is available for synthesis and where government and academic organizations demonstrate willingness to collaborate throughout the process of coproducing policies. The set of learnings presented here facilitates transdisciplinary synthesis initiatives at the science-policy interface.

Declaration of competing interest

There is no conflict of interest.

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Appendix A. Supplementary data

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