Insights into 15 years of transdisciplinary research on a small Greek island

Small islands offer unique conditions for studying human-nature relations. Our study uses the real-world laboratory concept to reflect on a long-term transdisciplinary research process that aimed to facilitate a sustainability transition for an entire island.

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Abstract
This article introduces a long-term transdisciplinary research process on the Greek island of Samothraki, aiming at sustainability solutions that are not only scientifically sound, but also co-designed, well received and adopted by the local community. We reflect on 15 years of socioecological research by utilizing the conceptual lens of real-world laboratories (RwLs). We present the research approach pursued on the island, based on a sociometabolic understanding of society-nature interaction, by relating local natural resources (and their self-regenerating capacities) to their social utilization and the resulting environmental pressures. We reflect on the research activities by using an established evaluation framework based on the three RwL principles: the "lab context", "experiments", and "interventions". We describe success and setbacks by integrating, as objects of evaluation, the research process, its outputs, outcomes, and impacts. While we can certainly showcase success in terms of research design, scientific outputs, and institutional outcomes, gauging potential impacts poses a more challenging task.

Keywords
island sustainability, real-world laboratory, sociometabolic research, sustainability transition, transdisciplinary research, UNESCO Biosphere Reserve

Islands as hubs for inter- and transdisciplinary research

Today's multiple challenges require research approaches that not only aim to understand society's impacts on natural and social systems but also help define ways forward (Wanner et al. 2018). This often requires researchers to go beyond the analytical realm toward contextualized interventions in societal systems (Schneidewind et al. 2016, Scholz 2017). Real-world laboratories (RwLs) have gained popularity in recent years, as evident by the growing number of collaborative and experimental approaches aimed at facilitating sustainability transitions in real-world settings (Schäpke et al. 2018). In these settings, researchers aim to produce empirically sound and robust data by integrating knowledge from various socioecological subsystems, to help communities address complex sustainability challenges (Huning et al. 2021). Our study uses the RwL concept to reflect on a transdisciplinary (TD) research process that aimed to facilitate a sustainability transition for an entire island region.

Despite their geomorphological diversity, small islands share a set of characteristics, primarily being bounded systems surrounded by water, which lends to their distinctive ecosystems and cultures. Small island economies are often characterized by high vulnerability due to their dependence on external markets and exposure to environmental hazards (Thomas et al. 2018). Some scholars, in contrast, emphasize the resilient, nimble, flex- >

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FIGURE 1: Images from Samothraki (clockwise, starting top left): north-eastern slopes of Saos mountain range, the Fonias river upstream, western agricultural planes, Sanctuary of the Great Gods. © Dominik Noll

ible and adaptable potential of island societies in the context of today's global challenges (Pugh and Chandler 2021). Islands' spatial, ecological and social boundedness urges local communities to act on environmental and socioeconomic challenges more than in mainland contexts – this makes them interesting focal points in a wide range of disciplines (Chertow et al. 2013). Islands have proven to be excellent sites for marine and coastal socioecological research (e.g., Glaser et al. 2018, Boyle et al. 2021) and offer chances for "revitalizing and innovating sustainable human-nature relationships" (Kueffer and Kinney 2017, p. 311).

The open-end TD research process unfolding on the Greek island Samothraki aims to accentuate the resilient and adaptive features of island communities. The goal was to understand and analyze the specific island conditions through the prism of social ecology, and help the local community achieve a transition toward sustainability. At the same time, efforts were made to contextualize these claims: What does sustainable development mean in the local island context? What does sustainability research entail? Can scientific research possibly facilitate a sustainability transition? In this article, we reflect on the research conducted with the aim to present generalized lessons from the TD process, by using RwL as a conceptual lens.

The Greek island of Samothraki

Samothraki (Σαμοθράκη) is located in the north-eastern Aegean Sea, covering an area of 178 km^2 and is shaped by its mountain range Saos (Σάος), rising to 1,611 m. These geographical conditions create distinctive microclimates resulting in lush forests on the northern side, and a more typical Mediterranean landscape on the island's western side (figure 1).

Samothraki has been inhabited since prehistoric times. The population of 2,600 people (Census 2021) engage mainly in agriculture, fishing, and the service sector. Many inhabitants maintain a diversified household economy, based on some degree of subsistence agriculture and animal husbandry, complemented with a seasonal utilisation of tourism opportunities.

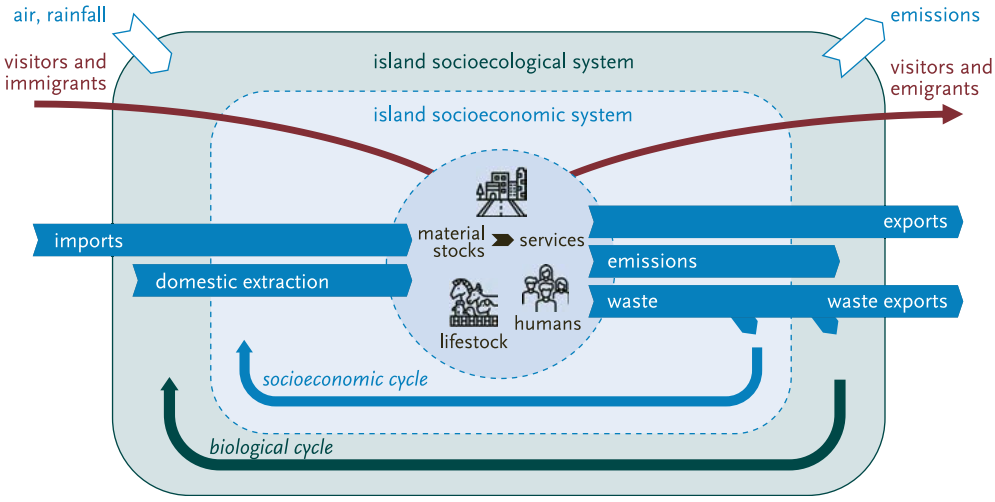

FIGURE 2: Sociometabolic research on islands is based on the assessment of biophysical stocks on and flows through island economies and their associated environmental pressures.
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Developments of recent decades brought about higher standards of living but also environmental challenges such as overutilization of biomass and marine resources, degradation of traditional water management systems, expansion of infrastructure and buildings, import dependence and solid waste (Skoulikidis et al. 2019, Fischer-Kowalski et al. 2020, Noll et al. 2019, 2020, 2022). In addition, limited employment possibilities, a short tourism season, lack of higher education and a not fully equipped hospital increase the risk of continuous population decline. Finding solutions to these challenges defines the TD research agenda and choice of conceptual tools.

Conceptual framework

This contribution draws on TD research conducted by the authors on Samothraki over the past 15 years. While funded through different schemes, and conducted by various researchers in collaboration with diverse stakeholders, all this research shares a joint conceptual framework pertaining to 1. a sociometabolic approach to sustainability and 2. the co-creation of a vision for a sustainable island future.

A sociometabolic approach to sustainability

Our analysis follows a dynamic sociometabolic approach (Haberl et al. 2019, Fischer-Kowalski et al. 2020), linking local natural resources (and their self-regenerating capacities) to their social use and the resulting human benefits, both from input (resource extraction) and output (waste and emission flows) perspectives (figure 2).

Following this understanding, social systems, beyond maintaining communication flows, need to reproduce themselves biophysically, by drawing material and energy from their environment, or importing from other systems. The ability of Samothraki's socioecological system to reproduce itself depends on whether material and energy flows required for deriving services can be organized, and resulting wastes can be handled. To strive towards sustainability, in this context, means to develop and maintain a social metabolism that serves the needs of the people without disturbing the natural environment, while being resilient to changing contexts. Our research process therefore was the following: first we identified key conditions of self-reproduction of the socioecological system and then assessed key sociometabolic indicators across time (Noll et al. 2022). Based on this, we made recommendations on how to tackle challenges on certain subsystems and find viable pathways to a sustainable functioning.

Co-creating a vision for a sustainable island future

Research involvement on Samothraki was originally kicked off when a local environmental action group approached a visiting researcher in 2008, asking for guidance. The challenge was how to preserve biodiversity and the special character of the island, and to create a vision for the community that would frame local conditions not as "backwardness" but as an asset to be developed in a sustainable way. This could only be successful if the local population anticipated clear benefits from such a perspective. The researchers proposed to make an effort for the entire island to become a UNESCO Biosphere Reserve. This idea helped kick off a research agenda (Fischer-Kowalski et al. 2011).

With regard to ethical concerns, we strictly chose a democratic pathway: based on systemic analysis, scientists made efforts to expose social and ecological impacts of viable options, enabling stakeholder groups to make informed decisions. We employed a process-oriented approach (Avelino and Wittmayer 2016), with local citizens co-defining the agenda and acquiring competencies to effectively pursue it. This process created an evolving TD research agenda for supporting the island inhabitants and their administration in achieving sustainable development goals (Petridis et al. 2017, Fischer-Kowalski et al. 2020).

Table 1 (p. 38) reflects on 15 years of collaboration between local actors and researchers, and summarizes the visions, research agenda, and response strategies developed, based on identified challenges. Not all challenges were apparent from the start, >

TABLE 1: A socioecological co-design consisting of challenge definition, visioning, design of a research agenda, and implementation of multi- and transdisciplinary response strategies on Samothraki. Issues are categorized according to main type (environmental, social, and economic), but most have repercussions at multiple levels. LTER = Long-term Ecological Research.

CHALLENGES	VISIONS	RESEARCH AGENDA	RESPONSE STRATEGIES
ENVIRONMENTAL			
■ overgrazing, leading to severe soil erosion ■ overfishing, depletion of fish stocks; impoverishment of small fishermen ■ inadequate freshwater management ■ illegal logging for firewood ■ large maintenance requirements of local material stocks with increasing waste generation ■ die-out of mountain forests due to overgrazing by free-roaming goats	■ sufficient protection of *Natura 2000* areas ■ halt overgrazing and restore overgrazed lands ■ define marine protected areas to aid recovery of fish stocks ■ develop a local sustainable water resources management strategy ■ greater use of renewable energy sources on the island, such as thermal springs, hydropower and solar ■ reduce import of non-renewable materials ■ reuse and recycle local waste materials ■ systematic protection of mountain areas for forest regrowth	■ assess island social metabolism by quantifying all resource flows connected to the reproduction of material stocks, livestock and humans ■ estimate goat abundance and movement within *Natura 2000* areas ■ identify and showcase links between environmental protection and eco-tourism ■ assess state of terrestrial ecosystems (e.g., forests, grasslands, agricultural areas) ■ assess freshwater resources' state and develop integrated water resources management plan	■ experiment with sown biodiverse pastures to increase productivity and grazing tolerance ■ tree sampling to 1. reconstruct forest structure, and 2. identify critical priority areas that require immediate protection and regeneration ■ establish Samothraki Nature Observatory (SNO) for continuous water and ecological quality assessments ■ integration of SNO in the LTER-Greece network ■ give recommendations for the implementation of a circular economy ■ prevent construction of large-scale wind park, so as not to threaten the island's freshwater resources
SOCIAL			
■ bad accessibility, infrequent ferry connections ■ inefficient social services: healthcare, education ■ lack of specialised skills and training ■ mistrust in state institutions, lack of cooperation	■ improve connectivity, infrastructure and services ■ enhance information exchange and local communication ■ provide lifelong learning opportunities ■ enhance cooperation culture	■ explore interventions in education and healthcare systems ■ investigate collaboration possibilities in farming, fishing, tourism and services ■ support and create communication channels for dissemination, raising awareness on local sustainability issues	■ support Sustainable Samothraki Association ■ communication channels (local radio, website) ■ environmental education initiatives (e.g., citizen science on forest degradation) ■ regular public presentations of research findings ■ *Islands of Hope* project on fostering a culture of democratic deliberation
ECONOMIC			
■ inadequate and costly waste management ■ short tourist season ■ lack of employment opportunities (esp. for young) ■ unused potential of local resources ■ lack of funding for business start-ups	■ sustainably managed natural resources ■ expanded tourist season ■ enhanced online presence and improved communication ■ economic activities that enhance the character of the island ■ improved supply chains of agriculture, synergies with tourism (local food)	■ reduce waste and cost to the municipality ■ explore new business model of slaughtering house, incl. cooling, packaging and exporting, more effective utilization of goats ■ establish more informed planning for farmers and better marketing, labelling of local produce	■ assist municipal waste management, raise awareness, composting initiative in schools ■ decision support tool *Happy goats*, app for farmers to better plan their animal numbers and their costs ■ labelling for organic products ■ improve tourist infrastructure (e.g., hiking paths)

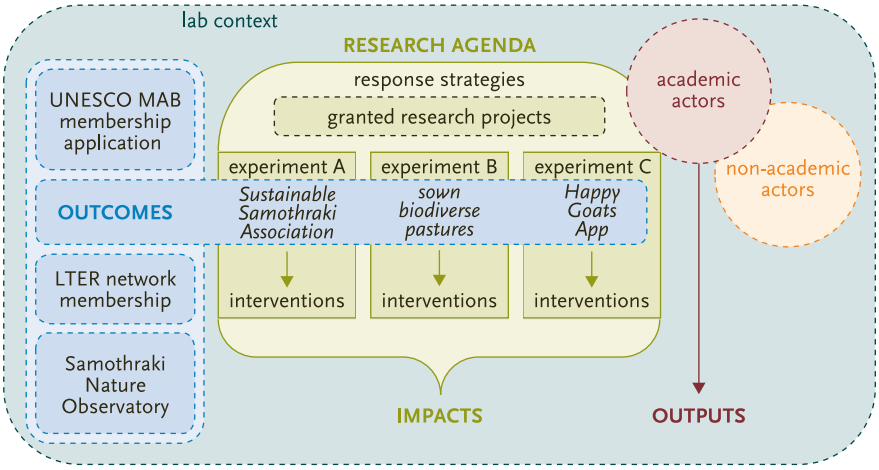

FIGURE 3: The conceptual graph builds on the three-layered depiction of a real-world lab (lab context, experiments, interventions) by Kampfmann et al. (2022, p. 130), advanced by objects of evaluation (impacts, outcomes, outputs) for transdisciplinary (TD) processes by Holzer et al. (2018, p. 812) and elements relevant for the project on Samothraki. Impacts (light green) into the local socioecological system are generated through the implementation of a research agenda, which is the result of TD collaboration between academic and non-academic actors (in circles). The research agenda entails co-developed response strategies to sustainability challenges, enabled through granted research projects and implemented through experiments that represent interventions into the local socioecological system. Outcomes (blue) are represented by institutional arrangements on a local level, such as the Sustainable Samothraki Association (SuSA), application of sown biodiverse pastures (SBP) and the *Happy Goats App*, as well as external institutional arrangements, such as the UNESCO MAB (Man and the Biosphere) membership application, the Long-Term Ecological Research network membership (LTER 2023), and the foundation of the Samothraki Nature Observatory (SNO). Outputs (dark red) are generated by academic actors as empirical results and documentation of the research process in the form of research articles, reports, conference presentations, master's and doctoral theses.

some visions/solutions were common, some evolved in the process. The research agenda was shaped both by academic interests and capacities and by municipal priorities and pressure from activists, and was also constrained by practical issues such as funding opportunities.

Samothraki contextualized as a real-world laboratory

Based on the evaluation framework proposed by Kampfmann et al. (2022, p. 129 f.) we distinguish three components in an RwL: the lab context, experiments, and interventions (figure 3). These components are embedded in one another, as a laboratory entails experiments which generate interventions (Caniglia et al. 2017). This framework has been modified with key elements introduced in table 1 (research agenda and response strategies), three key experiments, and elements representing the lab context for the TD process on Samothraki.

Samothraki is a designated Long-term Socioecological Research (LTSER) platform. LTSER platforms function as hubs for inter- and transdisciplinary research and must ensure continuous data collection and monitoring to provide a knowledge base that helps reorienting socioeconomic trajectories towards more sustainable pathways (Singh et al. 2013). LTSER platforms necessitate the integration of an evaluation framework rooted in the assessment of indicators within the social and biophysical spheres, and in particular in the context of society-nature interactions (Haas et al. 2013). Based on Holzer et al. (2018), we reflect on the TD collaboration on Samothraki, using, as objects of evaluation, the research process, its outputs, outcomes, and impacts, based on indicators selected in accordance with available data at time of writing (figure 3, table 2, p. 40).

Research process

By "research process" we refer to the entire TD process in which challenges and visons are co-defined by academic and non-academic actors. Non-academic actors are represented by motivated locals with various professional backgrounds (mainly female), who were or are directly involved into the research and some of whom founded and lead the Sustainable Samothraki Association (see SuSA below). Academic actors are represented by a group of engaged and regularly returning researchers from various disciplines. Creating the preconditions to facilitate a productive exchange between non-academic and academic actors has always been a priority. This involved regular meetings during our visits to the island, the organization of public events on Samothraki in which latest results were discussed, meetings in Austria to which local key stakeholders were invited, and regular online exchange. The level of involvement of non-academic actors has been mostly voluntary and thus depended on their general availabilities. In a low-income region where most residents work multiple jobs, time has certainly been a limiting factor.

Outputs

The project has created substantial academic output, that means publications, over the years[1]. Several students contributed to our findings with master's and PhD theses. An open access database with detailed information about material input, output, and societal stocks from 1929 to 2019 has been generated (Noll et al. 2022) and has meanwhile been employed in pertinent ecological economics research (Zisopoulos et al. 2023). Stimulated by our activities, a small producer created a one-hour documentary film about the island, its challenges, and the ongoing research, in Greek and English (Kipos 2018).

1 *www.sustainable-samothraki.net*

TABLE 2: Objects of evaluation and indicators used to reflect on the socioecological research process on Samothraki (adapted from Holzer et al. 2018, p. 812)

OBJECTS	INDICATORS
research process	productive interactions; level of involvement; degree of inter- or transdisciplinarity of team
outputs	publications; students graduated; databases
outcomes	institutions; education and outreach programs; associations; cooperatives; changes in land management practices
impacts	changes in level of trust, conflicts, legitimacy of an idea, policy, or practice; distribution of ideas; changes in key sociometabolic indicators; size or strength of a social network

Outcomes

Institutional arrangements reshaping the lab context (figure 3) are the Samothraki Nature Observatory, a framework for monitoring, research, and education on the island's freshwater resources (SNO 2023), and the inclusion of the island into the LTER network, which fosters long-term collaboration between researchers and local actors (Singh et al. 2013, Skoulikidis et al. 2021, LTER 2023). The UNESCO MAB (Man and the Biosphere) membership application[2] (Greek National MAB Committee 2013) represents a special element as it defines an activity by academic and non-academic actors that constitutes a potential institutional context in the future. All three elements were supported by the local municipality. Since 2012, we facilitated eight interdisciplinary international summer schools.

The Sustainable Samothraki Association (SuSA) (experiment A) was founded by local citizens with the aim of promoting sustainable development locally, providing an interface between visiting researchers and the local community, and eventually contributing to the future Biosphere Reserve management.[3] The association was formally established in 2016, consisting of a diverse group of 60 local citizens that promoted environmental awareness and was actively engaging with projects and decision-making of the local municipality. The association collaborated with the scientific advisory board it had elected (SuSA 2023).

Sown biodiverse pastures (SBP) are the subject of a five-year experiment (experiment B) with a seed mixture that increases carbon uptake from the atmosphere, pasture biodiversity, and above- and belowground biomass stocks. SBPs were introduced in 2015 to achieve several goals: first, to provide a channel to approach local small ruminant farmers, a particularly reluctant group regarding the adaptation of new practices and ideas, and engage them into the research process. Second, to train a small group of farmers on sustainable pasture management practices by providing seeds for SBPs with the aim of achieving a long-term knowledge transfer to other farmers; and third, to regenerate degraded areas through the direct application of SBPs.

After conducting the first research on the farming system of Samothraki, we started a collaboration with the Greek IT firm Integrated ITDC, the Aristotle University of Thessaloniki, and the Leibniz Centre for Agricultural Landscape Research (ZALF) in order to develop the decision support app *Happy Goats*[4]. *Happy Goats* (experiment C) aimed at providing digital planning support for sheep and goat farmers in Greece and the EU. The initial goal was to use the app as a social learning tool on Samothraki, by encouraging farmers to engage with their farm economy, especially in regard to small ruminant numbers and available pastures.

Impacts

The interventions carried out as part of the research agenda on Samothraki had multiple impacts on socioecological dynamics on the island. Until 2019, nine farmers had applied SBPs on 13 parcels, which led to a continuous engagement with them. However, lack of will and trust into these new practices and logistical barriers resulted in discontinuation in almost half of the experimental plots. The long-term success of such an experiment requires a local partner who is willing to facilitate the continuation of the process. On a positive note, we did manage to create networks and trust between farmers, researchers and activists, creating an important precondition for future activities (Jongen et al. 2023 submitted).

Our work with local small ruminant farmers has helped prepare for the foundation of a farmers' cooperative in 2018, upon the initiative of the former (female) vice-mayor of the island. It established a trading contract with a company guaranteeing to buy all meat and milk from the island at a superior price. This opens a chance for active farmers to improve their income without increasing the number of animals. There is hope that under the umbrella of the new cooperative, and improved communication among the farmers, the SBP initiative might be resumed.

Since 2001 the local small ruminant population declined by 30 %, as a result of behavioral changes among local farmers, triggered by a combination of factors such as the reduction of available grazing biomass, the economic crisis, rising feed prices, and changes in the subsidy schemes (Noll et al. 2019). For preserving local soils, a much stronger reduction is still needed (Panagopoulos et al. 2019) but our achievement certainly was to make this necessity widely known and accepted. The *Happy Goats App* was one of the tools developed for this purpose, even if its initial goals were not achieved. During the development phase it turned out that the app required many more input pa-

2 The UNESCO MAB membership application has been submitted in 2011 and resubmitted in 2013. Due to the lack of the legal and managerial preconditions at state level for the *Natura 2000* area on Samothraki, the application was deferred by UNESCO. In the meantime, the Greek government has initiated the legalization of the *Natura 2000* area. The application now needs to be updated and resubmitted.

3 Guittard et al. (2024, in this issue) discuss comparable problems and efforts in the coastal region of South-West Messinia, Greece.

4 *www.happygoats.eu*

rameters than initially planned for. Therefore, it became too complex to be used by local farmers.

The Sustainable Samothraki Association (SuSA) represents a core element of the TD process. SuSA undertook numerous activities, such as a successful composting initiative in collaboration with schools, several environmental education activities, a "local food" project in childcare institutions, and actions to support sustainable fishing funded by the European Sea and Fisheries Fund (SustainSea 2021). At the same time, it provided advice and local contacts to various research efforts. This two-way interaction greatly benefited research by improving outcomes, providing "plausibility checks" for scientific interpretations and widening the scope of scientific research, as well as achieving a better dissemination of results. SuSA, while not formally represented in the municipal council, frequently raised issues there and supplied arguments for sustainable solutions (as, for example, opposing to mountain-top wind parks that researchers had exposed as threats to freshwater resources). Upon invitation from UNESCO, members of SuSA participated in regional meetings and thus came into contact with other Biosphere Reserves.

However, many of our local collaborators, including the first president of the association, were "newcomers" (expatriates, migrants, or returning migrants) who often remained more or less "outsiders". Similar patterns of foreigners and returning emigrants engaging in environmental conservation have been observed in island contexts, such as the Dutch Caribbean (Mac Donald 2022). The departure of some key collaborators after several years of involvement, in combination with conflicts in relation to the planned SuSA board change (and also coinciding with the emergence of the Covid-19 pandemic) led to a longer period of dissatisfaction, resignation, and inactivity, almost causing the end of SuSA. Guimarães et al. (2024) emphasize the pivotal role of commitment, continuity, and regular interaction in shaping the attainment of transdisciplinarity objectives. The challenge arose when perceived success was lacking, compounded by the limited involvement of us researchers during this period. In 2022, after sustained and engaged support from members of the research team via the *Islands of Hope* project (Varvarousis and Petridis 2023)[5], a new board was elected, which already demonstrated significant activity and engagement. It remains to be seen whether a new momentum will be created to build up on the vision and achievements of the past.

A lesson from all this so far is that, in relation to TD processes, a team needs both innovative thinking and local acceptance, and this is sometimes translated into finding a good balance between more established locals and "newcomers", and requires maintaining a certain flexibility in adapting roles and maintaining porous borders for new members.

Conclusions

Our research aimed to close knowledge gaps about the socioecological system of the island, and to trigger a broader transformative learning process and empowerment among local citizens that could turn the current socioecological crisis into a success story of sustainability. Overall, we were lucky that the original idea, namely to take a pathway towards sustainability rather than towards economic growth and "modernization", survived and might now even find institutional support from UNESCO, reinforced by local, regional, and national policy measures.

Successes and setbacks cannot be as clearly attributed to our research as the term "real-world laboratory" might insinuate. Actual changes in socio-environmental relations take much longer to unfold than scientific insights.

The RwL setting helped to formalize elements that need to be in place for ensuring a continuation of the TD process beyond the relatively short period of funded research projects. What makes this RwL stand out is the fact that it attempts to facilitate a sustainability transition of a whole island and thus needs to engage with all components of the system. In this context, our insights have the potential to serve as showcases for facilitating sustainability transitions on larger scales.

The island setting undoubtedly played a role in shaping this process. The way the local community organizes their social metabolism is intricately linked to the specific conditions island communities face, necessitating solutions tailored to these circumstances. At the same time, the initiators of the TD process developed a personal and collective bonding with the island – a fact that motivated them to seek solutions to perceived threats that jeopardized the pursuit of their idea of a fulfilling life on Samothraki. The unique island context shaped the experiences of all involved, presenting them with complex and demanding real-world dynamics that, in some instances, even contributed to the decision to leave the island.

Over the time, some of the key problems we addressed scientifically have started to be taken up by local policy makers. Nevertheless, successes and setbacks cannot be as clearly attributed to our research as the term "real-world laboratory" might >

5 *https://islandsofhope.gr/english*. The project targeted, among others, improving participation and communication processes as well as mapping institutional pathways. See also Jung and Wentland (2024, in this issue) who see citizen engagement and institutional embedding as two elements of perceived RwL success.

insinuate. Actual changes in socio-environmental relations take much longer to unfold than scientific insights. But, as scientists, we are happy that they started moving.

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