Urban Transformations

PERSPECTIVE

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Real-world laboratories in Urban, Rural, and Marine contexts

Christian Wagner-Ahlfs[1*], Maria Busse[2], Markus Egermann[3], Kai de Graaf[1], Marion Glaser[4], Daniela Kempa[5], Artem Korzhenevych[3,6], Heike Schwermer[7], Miriam von Thenen[8] and Claudia Wolff[9]

*Correspondence:
Christian Wagner-Ahlfs
cwagnerahlfs@kms.uni-kiel.de
[1]Center for Ocean and Society, Kiel University, Kiel, Germany
[2]Co-design of Change and Innovation Working Group, Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany
[3]Leibniz Institute of Ecological Urban and Regional Development, Dresden, Germany
[4]Leibniz Centre for Tropical Marine Research, Bremen, Germany
[5]Leibniz University Hannover, Hanover, Germany
[6]Faculty of Business and Economics, TU Dresden, Dresden, Germany
[7]Department of Agricultural Economics, Kiel University, Kiel, Germany
[8]Leibniz Institute for Baltic Sea Research, Warnemünde, Germany
[9]Geography Institute, Kiel University, Kiel, Germany

Abstract

Real-world laboratories (RwLs) have emerged as a scientifically grounded, sustainability-oriented, transdisciplinary approach to support transformative change through the co-production of knowledge via engagement and experimentation. While originally rooted in urban settings, real-world laboratories have increasingly been developed in rural and marine areas. Urban, rural, and marine areas have unique contextual characteristics that remain insufficiently addressed in both research and practice. This paper offers a first comparative view on real-world laboratories in urban, rural, and marine settings by using four different epistemological and ontological perspectives in spatial science: bio-physical, social-constructivist, geographic, and social-materialistic. We highlight key differences and investigate the implications of identified differences for transformative governance.

Keywords Real-world laboratories, Spatial science, Transdisciplinarity, Transformation, Urban governance, Rural governance, Coastal governance, Marine governance

Policy and practice recommendations

Across all RwL, the diverse social constructions of space and time must be explicitly addressed.

In urban RwL, participation should be strengthened at the neighbourhood level, where people feel most connected.

Rural RwL should use local values and narratives as well as ecosystem knowledge as valuable information.

For marine RwL, governance processes need to reflect the multidimensional nature of space.

In rural, urban, and marine areas, diverse identities should be integrated into decision-making.

Science highlights

- This article gives the first systematic comparison of RwL in urban, rural, and marine contexts.
- The analysis is based on different epistemological and ontological perspectives in spatial science.
- The RwL categories have differences that impact governance issues and decision-making structures.
- Space, identity and conflicts are shaped by power relations and local practices.

Introduction

Real-world laboratories (RwLs) are characterised by Parodi et al. (2023) as transdisciplinary research and development settings where researchers and other societal actors collaboratively experiment within a defined real-world context to initiate and support sustainability transformations, promote learning processes, and generate transformative knowledge. While originally rooted in urban settings, RwLs have increasingly been implemented in rural and marine areas. The different contextual characteristics of urban, rural, and marine areas, however, have not yet been sufficiently addressed in the RwL literature and in practice. This is important because RWLs do not take place in neutral spaces. They are shaped by the specific social, material, ecological, and institutional conditions of the places in which they are implemented. This paper investigates how RwL approaches are implemented differently in urban, rural, and marine contexts in Germany. We use four spatial perspectives as a framework to explore the implications of spatial context for the design of RwLs, their experiments, and their role within transformative governance approaches that focus on systemic change to sustainability rather than just on urban, rural or marine development. Based on this, the paper addresses two main questions:

1) How does the implementation of the RwLs differ across urban, rural, and marine contexts in Germany?

2) What implications do these spatial differences have for the design of RwLs and experiments to foster transformative governance approaches in these three spatial settings?

The comparative analysis offered here draws on the experiences of the authors regarding the implementation of RwLs between 2015 and 2025 in Germany. We understand this contribution as a start for a wider discussion rather than a presentation of final results.

Methodological approach

Analytical framework

Even though urban, rural and marine areas appear to be different spaces at a first glance, a systematic analysis of their respective spatial characteristics is important to understand the concept of 'space' on which the analysis is based. Following Egermann et al. (2026) and in accordance with Löw (2001), four different perspectives are employed below to characterise and compare urban, rural, and marine RwL: (1) the biophysical view, (2) the social constructionist perspective, (3) the relational geography approach, and (4) the socio-material perspective. Our intention is not to present the four perspectives as

mutually exclusive categories, but as distinct analytical lenses that foreground different dimensions of spatiality in real-world laboratories (Fig. 1).

By applying these four perspectives, we seek to grasp the ontological nature and realities of RwLs in different spatial contexts and settings in order to gain epistemological insights. However, a sharp differentiation between these four ontological and epistemological perspectives (Fig. 2) in spatial science are hard to draw, as they include a variety of social, cultural, economic, ecological and political entities that jointly build complex systems. Therefore, overlaps and interlinkages between these perspectives occur. Nonetheless, this differentiation helps to draw attention to specific aspects that are central to each spatial perspective and in this regard can inform real-world lab settings and related research approaches and methodologies.

The **biophysical perspective** on spaces focuses on physical, biochemical, and ecological properties, processes and functions (Pickett et al. 2011; Schiller and Roscher 2023). In this regard we refer to green (e.g., parks, geology), blue (ocean, rivers), and grey (streets, buildings) infrastructures and the physical space (Tran and Egermann 2022) that conditions and shape RwLs in various domains, including mobility, energy, and agriculture, and play out differently within and across urban, rural, and marine settings.

According to a **social constructionist perspective** (Lefebvre 1974, Löw and Sturm 2005), urban, rural, and marine spaces are socially and culturally co-constructed through human interactions. This "co-construction" is shaped by people's discourses within institutions, social networks, and policies, and integrates actions. Moreover, these social complexities are associated with the negotiation of power-relationships, and can be a source for conflicts and power struggles that take place in RwLs (Foucault 1973; Fienitz

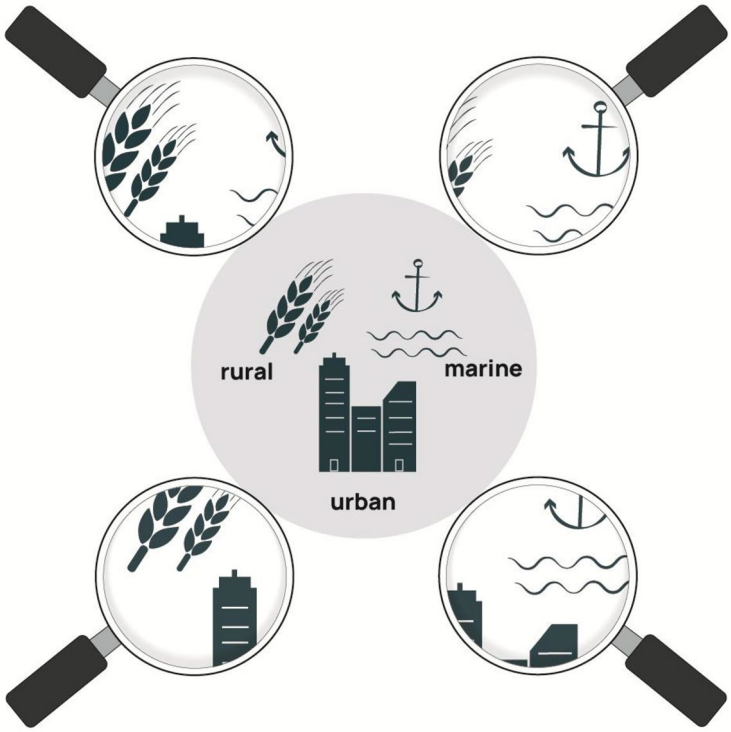

Fig. 1 Our analysis on urban, rural, and marine real-world laboratories looks at the same topic through different ontological and respectively epistemological lenses in order to reveal different insights, overlaps and similarities

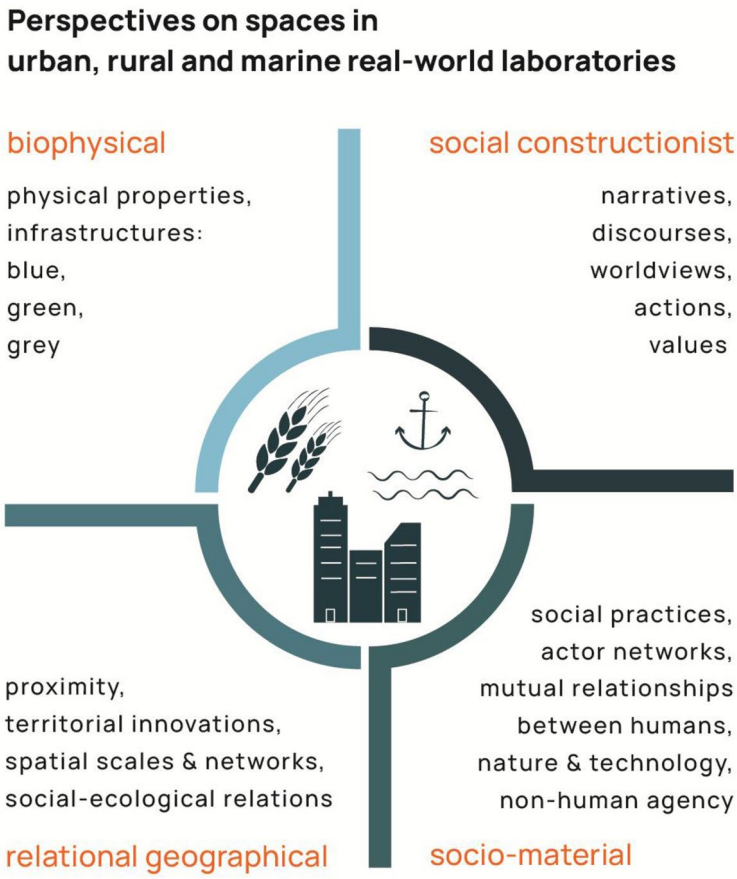

Fig. 2 Perspectives on spaces in urban, rural, and marine real-world laboratories (graphic based on Egermann et al. (2026))

and Siebert 2023), e.g. regarding the use of space(s) (e.g., for cars or for bikes), the re-interpretation of spaces (e.g., structural weak vs. recreation area), access to spaces (e.g., private vs. common good) and so forth.

The **relational geography perspective** sheds light on the complex interplay between people and spatial entities they are related to. In this regard, e.g. political-geographical territories and related governance aspects (Ehnert et al. 2018) or interdependent spatial scales, and spatial network relations (Coenen et al. 2026) play a major role and point to specific theories and methods, e.g. proximity theory (Reiß 2024) and territorial or regional innovation systems (Trippl and Tödtling 2025). This might become relevant when RwLs have to deal with administrative borders (e.g., cross-border ecosystems or transboundary effects), regulations and laws (e.g., maritime law), or trade relations and telecouplings (e.g., global sustainable food chains). Recent work extends the original focus of the relational analysis into the ecological realm by examining social-ecological relations (Schwenke and Holzkamper 2021).

The **socio-material perspective** shifts the focus from a mere human-centred and individual perspective where biophysical or non-human components are passive to a perspective that highlights the constitutive and active role of objects (as actants) within the systems and networks. It emphasises the continuous and changing relationships of humans, natural and technological systems to overcome dualistic views in RwL settings,

e.g. human vs. nature or social vs. technological (Artmann et al. 2026; Chan et al. 2016; Walsh et al. 2021). These relationships are shaped by processes of becoming and mutual reinforcement, i.e., the co-evolution and relations between things and society in the actors-network or social practice theory (Latour 2007; Löw and Sturm 2005; Shove et al. 2012).

Analysis

We base our analysis on a qualitative and interpretive comparative review of RwLs in three spatial contexts: urban, rural, and maritime settings. The analysis draws on selected practical case studies (for more details on selected RwLs see Supporting information Tab. S1):

a) Urban: Dresden - City of the Future (2015–2022), Climate Neutral Görlitz (2022–2025).

b) Rural: Among the broad variety of rural RwLs, the authors have experiences more specifically with agricultural and biodiversity-oriented RwLs in Germany: FInAL (2018–2028).

c) Marine: Gute Küste Niedersachsen with three RwL sites: Spiekeroog, Neßmersiel, Butjadingen (2020–2024), Reallabor Eckernförder Bucht 2030 (2021–2022), SpaCeParti with two RwL sites: Stein-Wendtorf (2022–2027) and Wismar Bay (2022–2024). The RwLs in a marine context all include the coastal areas with both rural and urban characteristics. As they specifically cover the marine area, we refer to them as marine RwLs.

Insights from all RwL cases regarding similarities and differences were discussed during a workshop at the Real-World Lab Conference "Experimental spaces for pathways to a sustainable society" in Dresden 2024. The analysis follows a qualitative comparative case-oriented logic (Patton 2015). The approach aims to identify analytically relevant similarities and differences between RwL contexts and to derive implications for the design of RwLs and their role in transformative governance.

The analysis was conducted in five steps. First, the selected cases were discussed during a workshop at the Real-world lab conference "Experimental spaces for pathways to a sustainable society" in Dresden 2024. The workshop served to identify initial similarities and differences between urban, rural and marine RwLs. Second, we used four analytical perspectives (bio-physical, social-constructionist, relational-geographic, and socio-material) to guide the comparison. These perspectives guided the analysis of how different understandings of space shape the implementation of RwLs and their role in transformative governance. Third, for each perspective, we identified analytical dimensions in which differences between the three spatial contexts were expected. These dimensions were organised in a comparative matrix. The matrix functioned as an analytical tool for systematically contrasting the three spatial contexts across the four perspectives and for making similarities, differences, and cross-cutting patterns visible. Fourth, the emerging findings were discussed and refined in several online meetings among the co-authors. Through an iterative process, interpretations were compared, contested, and consolidated. Finally, the results from the four perspectives were synthesised in order to derive implications for the design of RwLs, experiments, and governance processes in different spatial contexts.

Results

Biophysical perspective

From a biophysical perspective, spatial differences between urban, rural, and marine real-world laboratories become visible in relation to the material and ecological conditions in which experiments are embedded. This perspective highlights that RwLs are not only shaped by social and institutional arrangements, but also by physical environments, ecosystem dynamics, resource flows, and temporal rhythms. The comparison shows that urban, rural, and marine RwLs differ particularly with regard to their land- or water-based character, spatial extent, ecosystem complexity, land-sea interactions, and seasonality.

Land vs. water A first relevant difference concerns the distinction between land-based and water-based environments. Urban and rural RwLs are usually located primarily on land, even though they may include water-related elements such as rivers, lakes, or groundwater systems. Marine RwLs, by contrast, are situated in or across sea or coastal environments. They therefore often involve a greater diversity of interconnected ecosystems, including marine, terrestrial, and coastal systems. This increases the complexity of governance, as actors from different sectors and spatial domains need to be considered, including those concerned with coastal management, marine protection, fisheries, tourism, infrastructure, or land-based environmental pressures.

Size Urban RwLs are typically well-defined physical spaces, such as a neighbourhood, a city district, or a city. Rural RwLs often encompass larger geographic areas due to the space-consuming nature of rural activities such as agriculture or renewable energy production. Marine RwL often capture larger scales of marine and coastal dynamics, enabling the derivation of transferable knowledge (Kempa et al. 2023), e.g., coastal protection in different settings. Many components of marine RwLs are characterised by covering long coastlines and large aquatic areas. Some components lack fixed boundaries, e.g., wind or migrating fish populations, while others have fixed boundaries, similar to urban RwLs (e.g., harbours, dykes). This difference in size has implications for accessibility, e.g., ocean areas, and also rural regions are more difficult to access than an urban district.

Ecosystem dimensions and services All types of RwLs are composed of various overlapping ecosystems (Müller and Lange 2022), but in different ways. While urban and rural RwLs are dominated by land-based ecosystems, marine RwLs deal with aquatic ecosystems and their interconnections with coastal land. They are influenced by a range of land-ocean interactions such as nutrient flows from rivers (HELCOM 2023) and interactions of subterranean groundwater with the ocean (Arévalo-Martínez 2023). Rural and marine ecosystems provide more material goods (e.g., food production), having a greater scope of regulating services (e.g., cooling, groundwater recharge, coastal protection) (Marin-Diaz et al. 2023). In urban contexts, regulating and cultural ecosystem services (e.g., recreation) are often very localised.

Fluidity Urban RwLs are dominated by grey infrastructures, fixed in their positions, while rural and marine RwLs are associated with mobile and fluid components that may constantly change their position (e.g., water, aquatic organisms, nutrients).

Seasonality An important temporal dimension for rural and marine RwLs is seasonality. This relates to the availability of natural resources depending on seasonal life cycles, or abiotic aspects such as ice coverage, wind, rain, or dryness. This applies to urban RwLs to a lesser extent.

Social constructionist perspective

We identified several aspects for comparing urban, rural, and marine RwL: conflicting use of space, urban-rural divide and urban-marine divide, identity, time for running activities, time to show effect and connection to the RwL site. The comparison shows that conflicting use of space occurs in all RwLs, but to varying degrees. Identification with the surroundings plays a key role in all RwLs.

Conflicting use of space In urban and rural RwLs, land is often a limited and contested resource, shaped by multiple interests with underlying worldviews, values and narratives that can even result in land use and interest conflicts (Fienitz and Siebert 2023). In marine RwLs, although areas such as the EEZ in the German Bight (BSH 2009) demonstrate considerable potential for competition for marine territories, more space seems available with regard to "the world's ocean". In urban settings, grey infrastructure is dominant and conflicting with other uses that are possible in green and blue infrastructures. Therefore, future grey, green, and blue infrastructures are important transformational experiments. In rural settings, agricultural activities are often competing with energy production or nature conservation (e.g., debates of land sparing and sharing). Divergent objectives regarding the future of rural areas are brought to light in rural RwLs, and efforts are made to negotiate a shared vision and transformation pathways (Busse et al. 2024a, b). Additionally to land use conflicts and agricultural intensification, in some regions, land abandonment has become problematic, e.g. in marginal mountain regions. In marine settings, activities can take place simultaneously in one geographical location, but in different compartments of the environment, e.g. on the seafloor and in the water column. The same is true for the coast - there is only one foreland, but different demands for usage. Salt marshes and mudflats, for example, provide habitats for specialised plants, offer coastal protection and building material for dykes, and they also provide recreational opportunities (Barbier et al. 2011; Baptist et al. 2021).

Urban-rural-divide, urban-marine-divide Urban spaces are seen as a melting pot of diverse identities, cultures, and political orientations. In our exchange of RwL experiences, we contested the hypothesis that urban citizens should be perceived as more progressive (e.g., students, entrepreneurs) and hold potential for change and experimentation, while conservative citizens interested in keeping the status quo are more frequent in rural areas. The economic dimension (booming vs. declining regions) is much more important than the divide between urban and rural (Pinggera 2022). In all RwLs under review, we found powerful urban regimes but also rural and coastal citizens can be progressive and actively engage in transformative experiments.

Urban residents often have expectations about how rural areas should be used (e.g., for energy production or tourism), how food should be produced, and how nature should be protected. This creates social pressure and resentment among rural actors, which

manifests itself for instance in protests by farmers and might lead to a social divide between neighbouring urban and rural areas or within peri-urban areas (Busse et al. 2021).

The same applies to coastal and marine areas, these are also expected to fulfil the demands mainly from an urban population: fresh fish, wind energy, coastal protection, recreation, and nature protection.

Identity and place attachment: Identification with the surroundings plays a key role in all RwL, e.g., neighbourhood, land- or seascape, or territory. Our analysis showed that there is not one "urban, rural, or marine identity" but a huge diversity in all areas and population groups. In urban RwLs, identification is strongly related to the neighbourhood and to the district rather than to the whole city. In rural RwLs, place attachment is strongly linked to landscapes, but also to village and community structures, traditions, and intangible socio-cultural values (Knaps et al. 2020). However, the relationship between people and nature can be very different also among people in rural areas beyond cultural place-related traditions. Intrinsic values of nature are often cited by regional conservationists or instrumental values are often relevant for farmers (Busse et al. 2021). In marine RwLs, people's identification with the sea is an elementary part of how people perceive the system and what kind of relation they have with the sea and its resources (Schwermer et al. 2021a). Different relational values and social-ecological system ideas drive people's interaction with the sea. Taking a closer look at fishers as one specific stakeholder group, it becomes obvious that place attachment also feeds into self- or role-identity (Twigger-Ross and Uzzell 1996): Fishing is often perceived as a traditional profession practiced within families over generations and thus embedded in the identity of individuals, families, and coastal communities (Döring et al. 2020; de Graaf et al. 2023).

Time for running activities Time is an important factor in transformation. Long-term orientation is key for all types of RwLs with project cycles of experiments and evaluation. We did not find differences between urban, rural, and marine settings here.

Time to show effect In all RwLs, experiments can show effects relatively quickly. Above all, the aspect of usage - whether something is adopted or implemented - can be assessed in the short and medium term. Long-term effects such as effects of climate protection measures in cities, changes in agriculture-related biodiversity or effects of restored salt marshes for coastal protection are often critical to measure. This needs costly long-term monitoring and data collection that is usually not funded within the RwLs.

Connection to RwL site There can be large physical distances between places where stakeholders live, where activities take place and where effects show up in rural and marine RwLs; e.g., activities around a marine protected area might be distant to where people live, but directly interact with the working area of fishers. Urban RwLs are usually more directly related to stakeholders` neighbourhoods.

Relational geography perspective

Taking a relational geography perspective, we identified the following aspects to be compared: complexity of governance, overriding national interests, transboundary effects,

and actor networks. The comparison shows that urban, rural, and marine RwLs differ particularly with regard to complexity of governance and the relevance of overriding national interests.

Complexity of governance Urban RwLs have relatively high freedom to operate on the local level, as many decisions can be made by the local authorities. The situation is more complex in rural and marine RwLs, which are often subject to national or international interests and regulations (e.g., coastal protection, military security, nature protection zones) and characterised by multi-level governance complexity (Burn and Stöhr 2011; Chuenpagdee and Jentoft 2015) as well as lack of fit between areas of institutional responsibility and ecosystem boundaries (Galaz et al. 2008). Key resources such as land or energy sources are located in rural areas and part of national strategies limiting the power of local communities. For example, the German Western Baltic fishery is anchored in local harbours, taking place in a wider marine area, managed under the European Fisheries Policy (EU 2013).

Overriding national interests Many coastal and marine areas are subject to overriding national interests. For Germany's coasts, there is a complex network of national laws and legally enshrined interests that coordinates various competing claims on coastal use (nature conservation, economic interests, safety, etc.). This is limiting the freedom to operate in marine RwLs. In rural RwLs, the focus is on local/ municipal governance, which is overlapped by EU policies (e.g., Natura 2000 as an European mandate). Urban RwLs are characterized by significant local planning authority with a high level of regulatory detail in the various sectoral plans.

Transboundary effects Experiments are small-scale in all RwLs, so it is to be expected that their effects will also be observed primarily in the immediate vicinity. However, many organisms, nutrients, and pollutants have a natural fluidity and do not remain in one place. Ecological and socio-economic transboundary effects outside the experimental site are possible. For example, protected areas can create positive transboundary effects while water pollution creates negative effects.

Actor networks In all partnerships that act in RwLs, different actors take on specific roles, e.g., change agents or intermediary actors and are embedded in their regional setting (Ehnert et al. 2022). They can be very different in their character (individual persons, informal groups, formal organisations), role, function, and transformative knowledge and are influenced by spatial proximity or distance. The following examples show the huge variety of possible actor networks, but shall not be seen as a comprehensive list.For example, rural RwLs can be located in areas with innovative regional clusters or remote areas lacking an innovative environment. This regional embeddedness influences which transformation pathways are taken, which innovations are developed and implemented or who can actively shape both (Rock et al. 2026). In a marine RwL, different actor constellations are possible, for example this can be a single fisher or a FLAG (fishery local action group) (Salmi et al. 2022). Important rural actors are, e.g., the LEADER local action groups. In

urban RwLs, we can observe that global networks focusing on sustainability are actors of change, e.g., ICLEI[1]

This can be explained by the fact that urban RwLs have a longer history, enabling the creation of visible, pioneering urban networks driving transformative change.

Socio-material perspective

The key aspects we identify for comparison from the socio-material perspective include the human interaction with the built environment, the human-nature-interaction and the human-wildlife co-existence. The comparison shows that human-technology-nature relation is important in all RwLs, but the differences are very specific for each RwL.

Interaction with the built environment There are several key topics in urban RwLs, such as testing mobility concepts and temporarily calming streets to test different uses. From a socio-material perspective, mobility experiments in social spaces (neighbourhood, district) cover different social classes and are connected with technical solutions. One focus is on changing places and testing the potential for different types of social interaction and usage of places.

In rural RwLs with a focus on agroecology and agrifood systems, one often discussed claim is the reconnection of growers and eaters through social innovations, such as Community Supported Agriculture or Food Hubs. Processing infrastructures, dietary habits, human-nature relationships, and logistics can be seen as assemblages that foster or hinder such a reconnection (Zerbian et al. 2026). Another example is the development of new ways of production and cultivation such as vertical farming (e.g., Specht et al. 2014), which includes the development of new technologies. Here, future narratives (e.g., techno-fixes, Stone et al. 2025) and the non-human agency of artefacts can play a role.

In marine RwLs, the interaction between fisheries and harbour infrastructure can be cited as an example, including cold storage, locksmith, gas station etc. Cold storage facilities are important to fishers to preserve fresh fish. Changes in the fisheries sector have a direct impact on the built environment. For example, if the number of fishers in a port falls below a certain threshold, fishing cooperatives that operate cooling facilities may be forced to close.

Relationship and interactions between humans and nature In urban RwLs, a topic is re-connecting urban populations with nature using resonance, place attachment, and similar concepts. This is also reflected in participatory experiments in marine settings, graphically interweaving humans and nature by visual mapping of interdependencies (Gaiagraphy) treating all actants (human and non-human) equally (Kreis and Prominski 2025).

Another major topic is **human-wildlife co-existence**, seen as a conflict in rural, coastal, and marine areas (e.g., increasing seal abundance in the Baltic Sea creating conflicts with fishery (Svels et al. 2025), or the increased spread of wolves creating conflicts with livestock farming).

[1] ICLEI is a global network of more than 2500 local and regional governments committed to sustainable urban development. https://iclei.org/.

Discussion: Spatial context matters, but to different degrees

Discussion from a biophysical perspective

In our analysis from a biophysical perspective, we identified several aspects as significant: land- or water-based character, spatial extent, ecosystem complexity, land-sea interactions, and seasonality.

1) Complexity: There is a clear progression from simple to intermediate and complex environmental influences across the different types of RwLs. In urban contexts, the focus is primarily on well-defined, locally confined ecosystems that are significantly shaped by human activity and typically cover smaller areas. Rural and marine RwLs involve ecosystems of greater complexity, encompassing larger natural areas and exhibiting strong seasonal variability.

2) Interaction city/land/sea: Our analysis shows that urban districts primarily consume ecosystem services provided by rural and marine areas (e.g., food). On the one hand, how rural and marine areas are used is in part dependent on the demand of urban areas. Any trade-off analysis (e.g., which use to prioritise in rural and marine areas) would need to consider such demands. On the other hand, marine RwLs are strongly affected by activities in urban and rural areas through nutrients and pollutants entering the sea via rivers and diffusive run-off (Heidecke et al. 2011). This land-sea nexus entails that marine RwLs have to deal with an increased number of external biophysical factors, uncontrollable in the confined spatial design of a RwL.

3) Fluidity: In relation to governance issues, physical fluidity can be considered as significant for two topics: (a) **land-sea nexus** - marine habitats in marine RwLs are strongly determined by factors originating from lands beyond the RwL territory. All water bodies on land (lakes, rivers, groundwater) are affected by land use, and their waters enter the ocean at some point, and may cause eutrophication through nutrients and poisoning of marine organisms through pollutants (Thorsøe et al. 2022). Urban and rural areas, therefore, may influence the state of marine areas. (b) **marine transboundary effects** - marine environment components, such as sediments, nutrients or algae, possess natural fluidity. Thus, decisions in one location can have transboundary effects, e.g. sediment redistribution (Gourgue et al. 2022).

Discussion from a social-constructivist perspective

In our analysis, we identified conflicting use of space, urban-rural divide and urban-marine divide and identity as relevant aspects.

The distinction in terms of **identity** is often oversimplified: urban populations are frequently perceived as more progressive, while rural and marine communities are seen as more traditional - though such classifications do not reflect the diversity of local identities or self-perceptions. Our analysis showed a huge diversity in all areas and in all population groups. It also became clear that place attachment is an important issue: interventions should take place where people feel connected finding solutions for local problems may increase stakeholders` acceptance of e.g. management decisions (Schwermer et al. 2021b). For example, urban residents often identify with their neighbourhoods, while rural and marine participants connect with local landscapes and ecosystems. Self-identity (e.g., as a farmer) is a key factor in social relations, which needs to be considered in communication with stakeholders within a RwL setting.

Urban/rural/marine divide While urban RwLs face high demand for limited space, rural and marine RwLs contend with increasing pressures on vast but contested areas, offering both challenges and opportunities for negotiating innovative, sustainable solutions. This can be seen as an **urban-rural divide** and **urban-marine divide**. However, using the same space for different purposes at the same time creates a high potential for transformational experiments in negotiating compromises and trying out new uses. In addition, conflicting interests are not necessarily related directly to the living space and the working area of participants of a RwL, which is most obvious for rural and marine RwLs. This might imply a higher complexity for governance and higher challenges for transformational experiments in rural and marine RwLs.

No differences in **time for running activities** and **time until effects become visible** could be detected between urban, rural, and marine RwLs. As a general principle: the smaller an infrastructure, the quicker change can be detected. Because ecosystems are large, long-term monitoring of systems is absolutely necessary. These dynamics highlight the importance of inclusive, context-sensitive approaches to governance and transformation.

Discussion from a relational geographical perspective

In our analysis we identified complexity of governance, overriding national interests, transboundary effects, and actor networks as relevant for comparison.

The **complexity of governance** increases from urban to rural to marine RwLs. Urban RwLs generally benefit from greater operational freedom at the local level, as many decisions can be implemented directly through local administrations which have sufficient legal authority for this. In contrast, rural and marine RwL face multi-level governance challenges, and are more often influenced by **national or international interests** (Burns and Stöhr 2011). These overlapping regulatory and political layers can slow down or prevent the implementation of needed management measures due to e.g. multi-layered and complex legal requirements.

Transboundary effects show the complexity of RwL experiments and illustrate how important multilevel- and multiactor-governance is. This is most significant in rural and marine RwLs, because of the *fluidity* of ecosystems, geological dynamics, as well as the complexity of governance mentioned above. Even if experiments in all RwLs are typically small-scale, with primarily local effects, the transboundary effects underscore the need for multilevel governance.

In terms of actor networks, **change agents** play a crucial role in all RwLs. Success depends on identifying and engaging with local social networks, especially with gatekeepers, and key stakeholders. There is no fundamental difference in this regard between urban, rural, and marine settings. However, the specific ways in which participants take on the role of change agents vary according to the unique context and structure of each RwL.

Discussion from a socio-material perspective

In our analysis, we identified three aspects as relevant for comparison: the human interaction with the built environment, the human-nature-interaction and the human-wildlife co-existence.

All RwL categories embody a complex socio-material assemblage between humans, nature, and technology. The interaction between humans, nature, and technology creates dynamics that shape life in urban, rural, and marine RwLs. These places of interaction are co-shaped by their material conditions, including ecosystems and social practices. Across all contexts, the **human-technology-nature relationship** is characterised by feedback loops: technologies shape how humans engage with nature, while natural systems and social values and norms influence livelihood, technological development, and adoption. In marine and rural RwLs, humans are more directly influenced and affected by nature (its components, interactions, and dynamics) than in urban areas.

In **urban RwLs**, nature is usually a place of recreation, contrasting with the grey infrastructure of the city. The focus here is on experiencing nature either to deepen or to bridge the divide between urban residents and their natural surroundings.

In **rural RwLs**, technology intersects with traditional and modern practices, altering how nature is utilised and managed. Precision agriculture, renewable energy systems, and digital monitoring tools redefine the material realities of farming, forestry, and resource extraction. These technologies can enhance productivity and sustainability, but they also introduce new dependencies, risks, and power dynamics that influence local socio-material relationships.

In **marine RwLs**, the sea is a space transformed by human-made infrastructures such as ports or aquaculture systems or by socio-technical complexes such as fishing regimes. How communities and other user groups (e.g., multi-national fishing enterprises) interact with and perceive the sea influences ecological outcomes, livelihoods, and profits and can either enable sustainable practices or exacerbate environmental pressures.

However, the boundaries between urban and non-urban nature appear to be blurring. The debate surrounding the return of wild animals as predators in the food chain is no longer confined to seals in the sea and wolves in the countryside - now that wild animals are also venturing into towns and cities.

Conclusions for the design of RwL in urban, rural, and marine spaces and their wider governance context

Drawing on experiences from various RwLs, this paper compares their implementation in urban, rural, and marine contexts. Using four perspectives, we examine (1) differences in RwL implementation impacting governance issues and decision-making structures, and (2) their implications for the design of RwLs and experiments within these.

The analysis revealed that urban, rural and marine RwL differ in some respects but not in others (Fig. 3). Depending on the perspective taken, these differences are more or less pronounced.

Conclusions for practice

The social-constructivist analysis reveals that space, identity, and conflict are not objective realities but are shaped by discourses, power relations, and local practices. For RwL to succeed, this insight calls for tailored approaches in each context.

In urban RwLs, participation should be strengthened at the neighbourhood level, where people feel most connected. Rural RwL should leverage local narratives and ecosystem knowledge as valuable resources for transformation. At the same time, external demands - such as urban needs for food or energy - must be negotiated transparently

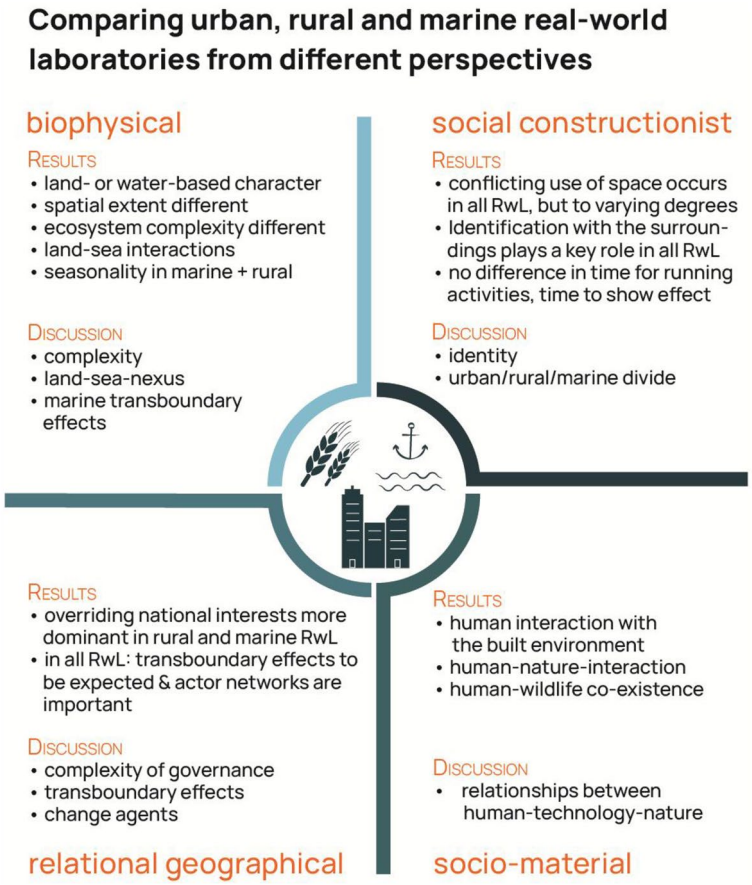

Fig. 3 The graphic summarises results and discussions. The overview highlights overlaps, parallels, contrasts and differences between urban, rural and marine real-world laboratories – it does not claim to be fully comprehensive, but aims to provide an overview

to prevent the use of rural areas as mere service providers, which can undermine local agency and cooperation. For marine RwLs, in particular the ecosystem knowledge of fishers and associated narratives are also important. Governance processes here also need to reflect the multidimensional nature of space, encompassing land, coast, and open water, as well as local and global scales. This requires integrating multiple identities into decision-making. It is essential to recognise the fluid and contested nature of marine spaces when designing adaptive and inclusive governance structures.

Across all RwLs, the diverse social constructions of space and time - including notions of scarcity, seasonality, or boundaries must be explicitly addressed. RwL can only unlock their full potential for sustainable transformation by making these constructions visible and negotiable. This should include reflection of the human-technology-nature relationship, as identified from the socio-material perspective.

As seen from a biophysical perspective, the land-sea nexus and marine transboundary effects should be considered in all RwLs. Relational geographical perspective shows the complexity of governance, that might be even higher in rural and marine RwLs.

Conclusions for further research

This article is based on the experience from various RwLs in Germany and two examples from the global tropical South. This analysis represents a first step in framing the

discussion about different categories of RwLs providing a basis for future research. This should deal with a larger evidence base and systematic research work with RwLs represented in national and international networks, including a more diverse and comprehensive global South perspective.

Abbreviations

EEZ	Exclusive Economic Zone
FLAG	fishery local action group
ICLEI	International Council for Local Environmental Initiatives. Now "ICLEI Local Governments for Sustainability"
RwL	Real-world laboratory

Supplementary Information

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Supplementary Material 1

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Author contributions

CWA and KdG organized the first workshop on the topic in Dresden (2024). All authors jointly collected the characteristics for the different perspectives on RwLs and developed an analytical matrix. CWA drafted the first manuscript with all authors contributing to the development of the manuscript. Graphics by KdG.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

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