*Systems Research and Behavioral Science*

WILEY

SYSTEMS RESEARCH and BEHAVIORAL SCIENCE

RESEARCH ARTICLE OPEN ACCESS

# Improving Understanding of the Dynamics of Biodiversity Generation in Agricultural Areas Through Participatory Systems Mapping

Wouter Spekkink[1] | William Voorberg[2] | Wiesje Korf[1] | Hedi Westerduin[1]

[1]Erasmus School of Social and Behavioural Sciences, Erasmus University Rotterdam, Rotterdam, Zuid-Holland, the Netherlands | [2]Naturalis Biodiversity Center, Leiden, Zuid-Holland, the Netherlands

**Correspondence:** Wouter Spekkink (spekkink@essb.eur.nl)

**Received:** 25 September 2025 | **Revised:** 12 February 2026 | **Accepted:** 2 April 2026

**Keywords:** agriculture | biodiversity | feedback structures | participatory systems mapping

## ABSTRACT

This paper examines how Participatory System Mapping (PSM), implemented through multiple parallel stakeholder workshops, can uncover interacting factors and feedback structures shaping ditch biodiversity, stimulate systemic learning and generate actionable insights for biodiversity governance. In the Alblasserwaard, a Dutch agricultural area, a living lab that unites diverse actors to develop ecological restoration measures revealed divergent stakeholder perspectives on mechanisms shaping ecological quality of ditches. We applied PSM to foster shared systemic understanding, asking how interacting factors collectively influence ecological quality of ditches. Across six workshops with 25 stakeholders, participants developed system maps that were subsequently integrated into a single, validated map. The synthesis revealed feedback structures and interactions that were not visible in individual maps and broadened stakeholders' appreciation of relevant drivers of ecological quality of ditches. Most importantly, it broadened the focus beyond financial incentives to include community attitudes and knowledge as key motivators for farmers' engagement in ecological management. In addition, it pointed to a potential balancing feedback loop that may reduce the effectiveness of compensation schemes for ecological management. The study demonstrates the methodological value of integrating multiple PSM workshops into a single intersubjective system map and its policy relevance, evidenced by concrete influence on regional biodiversity governance.

## 1 | Introduction

Biodiversity is under threat. We define biodiversity as the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part (IPBES 2019). Agricultural practices are among the largest contributors to biodiversity loss (World Economic Forum 2025). Agriculture contributes heavily to change of habitats and exploitation of organisms (IPBES 2019). It converts natural habitats into intensely managed systems, introducing pollutants and overdoses of fertilizers (McLaughlin and Mineau 1995; Dudley and Alexander 2017). Currently, concepts that may reduce or even break this destructive pattern are becoming more popular in agricultural practices. These concepts include organic farming (Hole et al. 2005), agroforestry (McNeely and Schroth 2006), or—of particular interest in the Dutch context—nature-inclusive agriculture (Runhaar 2017). Hitherto, these concepts are rarely put into practice in agriculture and there is limited understanding of the dynamics that stimulate or discourage their implementation. Although the body of literature on the governance of biodiversity recovery in agricultural fields is growing (e.g., Zinngrebe et al. 2022; Velten et al. 2018; Westerink et al. 2017), how different factors *collectively* and *systemically* affect the adoption of biodiversity measures is underexplored. This systemic understanding is necessary to understand why certain measures are adopted and others are not.

In the Alblasserwaard area of the Netherlands, a living lab focused on regenerating biodiversity in agricultural fields has been in operation since 2021. One of the living lab's focal areas has been the ecological management of the ditches surrounding farmland, which function as critical corridors for biodiversity in this intensively farmed polder landscape. Improving the ecological quality of ditches and their banks can yield substantial benefits for insects, birds and fish populations (STOWA 2009).

In this context, limited understanding of the dynamics that stimulate or discourage ecological ditch management became apparent. Different stakeholders offered explanations rooted in their own worldviews. Policy-makers tended to emphasize the need for economic incentives to motivate farmers to engage in ecological farming. Farmers often expressed worries about potential negative consequences for their business case, and some pointed to community attitudes and consumer preferences as key barriers. Ecologists, by contrast, focused primarily on ecological processes affecting ditch quality. As researchers involved in the living lab, we hypothesized that all of these mechanisms are plausible but incomplete, and that the ecological quality of ditches is most likely the result of interactions between them. These interactions were largely absent from the individual perspectives articulated by stakeholders. Understanding such interactions is crucial, as they have important implications for the design of interventions aimed at stimulating ecological management. For example, policy makers' emphasis on compensation schemes reflects a focus on economic incentives, yet the effectiveness of such schemes is likely to depend on how financial considerations interact with other factors shaping farmers' motivations.

To improve understanding of the interactions influencing ecological quality of ditches, we initiated a participatory process aimed at integrating different stakeholder viewpoints into a systemic understanding of the underlying dynamics. We drew explicitly on systems thinking as a source of inspiration, seeking to help participants recognize the interconnectedness of their seemingly separate concerns. Equally important, the process encouraged stakeholders to anticipate unintended consequences of proposed interventions that might emerge from the complex interrelations between factors. Representatives of farmers, nature organizations, banks, policymakers and civil servants participated in six Participatory System Mapping (PSM) workshops in which we asked (1) what factors determine the ecological quality of ditches in their area and (2) how these different factors influence each other. We combined the results of the six workshops into an integrated system map that captures the intersubjective views of the involved stakeholders. The integrated map was validated in a workshop with a selection of stakeholders from the six original workshops.

In this paper, we present our approach to PSM, the results obtained, and reflections on its policy impact. Our practical aims with this are (1) to explore the diversity of factors influencing ditch biodiversity, (2) to identify feedback structures that may affect the results of attempts to improve ditch biodiversity and (3) to assess the policy implications of these insights. An overarching aim is to show how PSM, implemented through multiple parallel workshops with a broad group of stakeholders, can stimulate a learning process in which participants revise their understanding of biodiversity-related problems. In doing so, we contribute to the further development of an emerging trend in the literature on PSM and Group Model Building (GMB), in which multiple stakeholder groups are engaged in separate workshops rather than involving the same group in an iterative process (Rajah and Kopainsky 2025). We show that integrating the results of these separate workshops can produce a system map that offers concrete and actionable lessons for stakeholders involved in biodiversity restoration, and we demonstrate how these lessons were translated into tangible policy impacts. The paper thereby also offers concrete examples of how participatory, systems-thinking-based approaches can inform the identification and design of policy interventions aimed at improving biodiversity governance.

This paper proceeds as follows. In the next section, we briefly outline the systemic perspective that served as the point of departure for our participatory process. We then outline the setup of the participatory process. This is followed by a presentation of our findings on the types of factors that influence ecological quality of ditches according to the involved stakeholders and the systemic interrelations between these factors. We offer a short reflection on how our insights have influenced policy on this topic. We close our paper with a discussion and a conclusion.

## 2 | Learning About Complexity

### 2.1 | Systemness, Complexity and Interventions in Systems

Systems thinking encompasses a range of schools with different emphases, but most share an understanding of systems as interconnected sets of elements whose interactions produce emergent behaviour (Meadows and Wright 2008). Within this literature, complexity is commonly associated with systems composed of diverse elements linked through multiple, evolving interrelations (Gerrits 2012). These interrelations often form feedback structures that make system behaviour difficult to infer from isolated components (Sterman 1994), helping to explain why reductive analyses tend to overlook key system dynamics (Cairney 2012). Even simple feedback loops can be difficult to analyse in terms of their consequences (Sterman 1994), but complexity becomes most pronounced in systems where multiple, feedback loops are interlinked (Meadows and Wright 2008; Rhee 2000). In such systems, reinforcing and balancing processes interact, giving rise to nonlinearity, path dependence, lock-in (David 1985; Gerrits and Marks 2008) and self-organization (e.g., Rhee 2000; Baugh Littlejohns et al. 2018).

This understanding of complexity has important implications for possibilities to intervene in systems. Under conditions of complexity, the effects of policy interventions are inherently difficult to predict (Gerrits 2012; Cairney 2012; Teisman and Klijn 2008). However, merely emphasizing the risk of unintended consequences of policies has become an exercise in

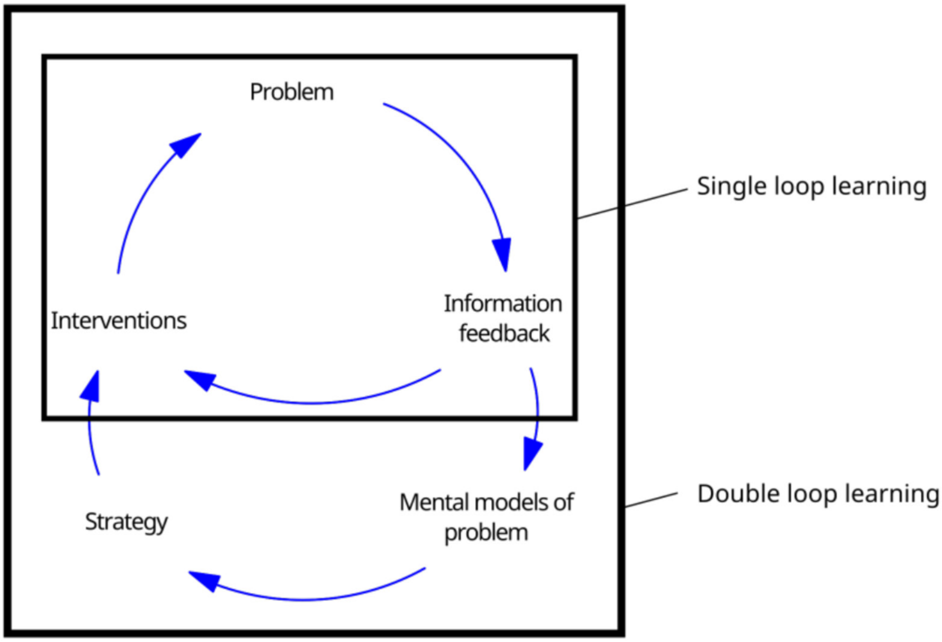


**FIGURE 1** | Double loop learning in the development of interventions in policy systems (adapted from Sterman 1994). [Colour figure can be viewed at wileyonlinelibrary.com]

stating the obvious, offering limited guidance for improving the design of policy interventions. A systems perspective can provide more substantive support by clarifying potential leverage points and anticipating effects of interventions in feedback-rich contexts (Wright 1999). It may thereby help prevent erroneous causal inferences that result from the open-loop views of causality that actors tend to adopt (Sterman 1994; Vennix 1999), overlooking feedback loops and the multiplicity of causal influences (Dyehouse et al. 2009). Policy interventions based on such simplified causal models may trigger feedback dynamics that undermine their objectives, a phenomenon described as policy resistance (Ghaffarzadegan et al. 2011). Evidence of policy resistance can be found, for example, in meadow bird protection policies, which have shown limited effectiveness or benefits concentrated on a narrow range of species (Melman et al. 2008; Grondard et al. 2023).

The notion of simplified causal models is closely related to the concept of mental models, which is central in the system dynamics literature. Mental models encompass both boundary judgements (i.e., judgements about what we consider part of a system and what is included; Gerrits 2012) and beliefs about causal dynamics through which systems operate (Sterman 1994). Such mental models are typically far simpler than the underlying system that they seek to represent, and people are generally unable to correctly infer the dynamics of anything but the simplest causal structures (Sterman 1994). Because no single actor can fully grasp the complexity of most policy problems (e.g., Wright 1999; Checkland, 2000), addressing complex issues requires processes through which the mental models can be challenged, revised and partially aligned. Learning about complex causal structures, especially if this occurs in interaction among diverse actors, can contribute to changes in mental models and to the development of more integrated systems representations (Vennix 1999; Rouwette et al. 2016). We argue that such collective learning processes are necessary to address complex problems such as biodiversity decline.

### 2.2 | Changing Mental Models Through Systems Mapping

A key mechanism through which mental models can change is double loop learning (Sterman 1994). Single loop learning occurs when actors adjust their actions in response to observed outcomes without questioning or altering underlying assumptions and causal beliefs. Double loop learning occurs when mismatches between expectations and outcomes are corrected by first interrogating these assumptions and beliefs and only then correcting actions (Tosey et al. 2012). In Sterman's (1994) framework, this interrogation of assumptions and beliefs is described as a change in mental models that actors have of problems (Figure 1).

In the context of our project, it is especially relevant to link learning and changing mental models to the concept of boundary critique (Ulrich 2000; Ulrich and Reynolds 2020). According to this view, actors make boundary judgements that define what aspects are seen as part of a problem situation and what aspects are left out (Ulrich and Reynolds 2020). In this view, mental models of problems are strongly shaped by judgements about what is part of a problem and what is not. Boundary critique involves reflecting on and challenging such boundary judgements in order to encourage actors to explore alternative and potentially revised boundary judgements.

We see the mapping of complex problems as systems as a way of encouraging boundary critique. It allows actors to make (visually) explicit what aspects they consider to be part of a given problem. When constructing such maps together in a well-structured process, the boundary judgements of different actors are confronted with one another, inviting reflection on how the various aspects that actors associate with the complex problem relate. This helps actors to broaden the range of aspects they associate with the complex problem and, at the same time, makes explicit how their understanding of the problem relates to that of others.

Rather than providing definite explanations, systems maps can thus function as devices for collective inquiry, enabling stakeholders to formulate and explore richer theories about the mechanisms that shape a given problem. This, in turn, encourages reflection on existing strategies to deal with the problem: actors may find that these strategies were based on more limited problem framings than those emerging from the mapping process. In this way, systems mapping can support double-loop learning processes, helping actors adapt intervention strategies by revisiting underlying problem framings and assumptions in light of a richer understanding of the problems they are dealing with.

## 3 | Materials and Methods

### 3.1 | Background: Biodiversity of Ditches in the Alblasserwaard Area

As mentioned in the Introduction, our participatory systems mapping process was initiated as part of a living lab research project in the Alblasserwaard area of the Netherlands. The Ablasserwaard area is mostly covered by farmer-owned peat meadowland. The living lab aims to enhance biodiversity in the Alblasserwaard, in close collaboration with involved stakeholders. The project on ecological ditches involves various stakeholders, such as the province of South-Holland, various research institutes, dairy cooperatives, banks and farmers. The focus on ecological ditches is also part of a broader policy effort to ensure that at least 10% of the agricultural land in the area is covered by a network of green-blue elements (Slagboom and Van Dam 2023). Ecological ditches are considered a relatively easy-to-obtain example of these elements. In terms of biodiversity recovery, with its 300.000 km ditches, the Netherlands is one of the richest countries in the world in terms of blue infrastructure. Improving nature quality in ditches (and their banks) is expected to have important benefits for biodiversity including the increase of habitat, connecting habitat and increase of food supply for birds, bats and fish (STOWA 2009).

### 3.2 | System Mapping

Our approach closely resembles PSM (Barbrook-Johnson and Penn 2021) as well as GMB (Vennix 1999; Rouwette et al. 2016; Connolly and Doole 2024), as well as more recent methodological variations such as the Qualitative Systems Exploration Model (Hulme et al. 2026). PSM was originally developed for the participatory evaluation of policies, but has since also been applied for more analytical and design-oriented purposes, including in studies addressing themes adjacent to our own. For example, Lopes and Videira (2017) applied PSM to support the valuation and assessment of ecosystem services. Rich et al. (2018) combine GMB with participatory spatial modelling in a case study of organic urban farming in Christchurch, New Zealand. Blanco et al. (2023) apply Community-Based System Dynamics (a form of GMB) to facilitate farmers' identification of key factors and feedback loops shaping pest dynamics in tomato production. While these studies differ in their specific focus, they illustrate earlier applications of participatory approaches to mapping the system dynamics in complex ecological and agricultural contexts. By directly involving stakeholders, these studies facilitated learning processes through which participants improved their understanding of system dynamics and developed novel ideas for interventions. This learning-oriented objective also underpins our own application of participatory systems mapping.

PSM and GMB typically engage a diverse group of stakeholders in the joint development of a Causal Loop Diagram (CLD) or system map, in which systems are represented as factors and their causal interconnections. Factors can be any elements that can be represented as variables (i.e., they can increase or decrease in value), although they need not be directly measurable or readily quantifiable. Causal connections between factors are represented by arrows that indicate a positive relationship (an increase in one factor leads to an increase in another), a negative relationship (an increase in one factor leads to a decrease in another), or (in the case of PSM) an ambiguous relationship (where a causal link exists but its direction or effect depends on context or other conditions) (see Barbrook-Johnson and Penn 2021). In GMB applications, system maps may also include stocks and flows in addition to causal relationships. Moreover, an explicit aim of GMB is often the development of system dynamics models that can subsequently be quantified and simulated (Vennix 1999; Rouwette et al. 2016).

Indeed, PSM and GMB are not without their limitations. While the maps that they generate can facilitate deeper understanding of complex systems and their dynamics, these maps are inevitably somewhat static snapshots of an evolving system (Hulme et al. 2026). Translating them into quantitative models can be an important step towards a stronger consideration of system dynamics, but this translation is a challenging process (Deutsch et al. 2024), for example, because of the variability and inaccuracy of the identified factors (Woog et al. 2006). In our own study, the main purpose of participatory model building is to facilitate joint exploration, dialogue and learning (by challenging and updating mental models), for which quantification is not a necessity (Hulme et al. 2026). However, that means that the result should be taken as preliminary and temporary maps that serve primarily as learning vehicles. They are means for learning rather than an end in themselves.

PSM and GMB are most frequently conducted with a single multistakeholder group that is involved in the participatory process in one or (often) multiple sessions through which a system map is developed and subsequently refined. Our own approach fits in an emerging trend in which there is not a fixed set of participants, but multiple workshops with different groups of stakeholders, co-producing multiple system maps that describe the same problem and that are subsequently integrated (Rajah and Kopainsky 2025; see Ryan et al. 2021; Rajah et al. 2024 for similar examples). A key aim of our use of PSM was to facilitate a learning process in which stakeholders in our case study areas, from different disciplinary backgrounds, not only exchange their

**TABLE 1** | Overview of workshops and participant backgrounds.

| Workshop | Participant backgrounds |
|---|---|
| Workshop 1: Friday 8 July 2022 | 1 scientist agricultural landscape governance<br>1 representative of a local cheese factory<br>1 representative of the Province<br>1 representative of dairy cooperation |
| Workshop 2: Wednesday 12 October 2022 | 1 representative of province<br>1 representative of bank<br>1 advisor in agricultural sector<br>1 representative of regional water authority |
| Workshop 3: Thursday 20 October 2022 | 1 farmer<br>2 representatives of province<br>1 representative of municipality |
| Workshop 4: Tuesday 1 November 2022 | 2 representatives of province<br>1 representative of bird protection society<br>1 scientist regional development and spatial use<br>1 representative of the ministry of Agriculture |
| Workshop 5: Thursday 3 November 2022 | 1 member of nature and bird watch association<br>1 advisor in agricultural engineering<br>1 farmer/representative farmers' collective<br>1 representative environmental service<br>1 representative of province |
| Workshop 6: Wednesday 14 December 2022 | 1 representative of institute sustainable agriculture<br>1 representative of environmental federation<br>1 representative of bank |

perceptions of the dynamics influencing the ecological quality of ditches, but also begin to understand how these dynamics are ultimately connected and what this means for interventions that can improve ecological quality. We therefore aimed to involve a relatively large and diverse group of stakeholders in the area, which meant that we needed more than one workshop. We compiled a list of 38 relevant stakeholders, representing farmers, local and regional authorities (municipalities, provinces, water authority), banks, nature organizations and independent advisors, and invited these stakeholders to participate in a workshop. We were ultimately able to involve 25 stakeholders across six different workshops of 3–5 participants each, which took place in July–December 2022 (see Table 1). The sample of stakeholders involved is thus the result of a purposive sampling strategy.

The workshops followed the setup described by Barbrook-Johnson and Penn (2021). Given the aims of our workshop, we chose the ecological quality of ditches as our focal factor. In each workshop, we took the following steps:

1. Brainstorm on factors that directly or indirectly influence the ecological quality of ditches
2. Consolidation and categorization of factors to remove duplicates and to develop an overview of the different types of factors that were mentioned
3. Reconstructing the causal connections between the factors, indicating the type of influence (positive, negative or ambiguous) in the process.

All factors would be recorded on post-its. In the actual construction of the system map, these post-its are placed on a big sheet of paper with the focal factor already printed in the middle of the sheet. The causal connections were drawn between factors with markers. In the process of reconstructing connections, additional factors would often come up that were then added to the map. See Figure 2 for an example of a resulting system map.

Each session was facilitated by three researchers (members of author team). One facilitator would lead the discussion among the participants and take them through the different steps outlined above. A second facilitator made notes on the discussions that took place on, for example, the nature of the different factors that were mentioned, and provided support in time management. A third facilitator helped in writing post-its on additional factors that would come up during discussions. The facilitators also helped the participants to translate their ideas into factors when necessary: sometimes participants would bring up things that are not clearly factors that can increase or decrease in value, such as existing policies.

### 3.3 | Processing the Results

After each workshop, the facilitators discussed the resulting map among themselves and made further translations of the factors where necessary. At this stage, our focus was solely on ensuring that the ideas of the participants were represented as factors that could increase or decrease in value. We aimed

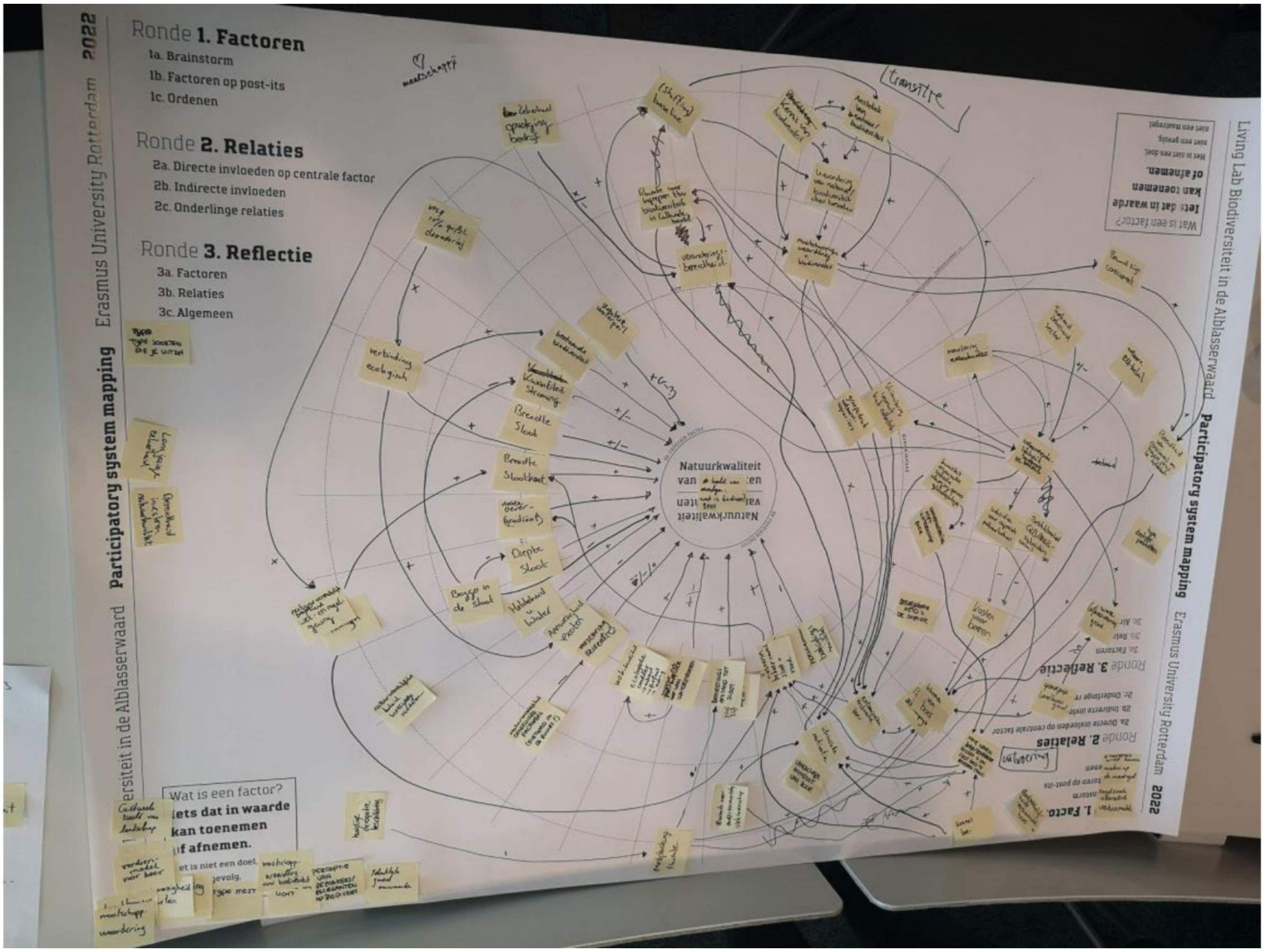


**FIGURE 2** | Example of system map after one of the system mapping sessions. [Colour figure can be viewed at wileyonlinelibrary.com]

to remain as close as possible to the original wording of the participants in order to ensure that the results accurately represented their input. The factors and their relations were then digitized in the form of a node list and an edge list, which we subsequently processed using spreadsheet software and network visualization software (the latter primarily for visual inspection).

After concluding all six workshops, we integrated their results into a single overall map. The approach followed most closely resembles what Ryan et al. (2021) describe as triangulation, followed by different types of recoding of the data. Our approach qualifies as triangulation in that we initially aggregated all factors and their causal connections into a single dataset. This was followed by a recoding process, as many of the factors in the integrated dataset differed slightly in wording while having nearly identical meanings.

The recoding of factors was carried out in spreadsheet software. In one column, we listed the original factors, which were then reordered to group rows containing similar factors. In a second column, one researcher proposed 'harmonized' labels for these factors. In a third column, the same researcher suggested broader categories thereby also engaging in categorical coding (see Table 2 in the Results section for the categories). An additional column was used to provide comments explaining the suggested labels and categories. The other members of the research team reviewed all suggestions and offered counter-suggestions for some cases in additional comments. The final labels and categories were established through consensus among the researchers.

This process reduced the number of factors from 283 (unharmonized) to 158 (harmonized). The harmonization also affected the causal relationships between factors: after harmonization, 350 unique causal connections remained. The research team reviewed all of these multiple times for further refinement. In some cases, both direct and indirect connections between the same factors were present. Where indirect connections represented an elaboration of direct connections, the direct connections were removed from the dataset (see Figure 3 for an example).

We also encountered connections that had become less meaningful after the translation, as well as connections that constituted dead ends, in the sense that they had no clear (indirect) relationship to our focal factor. These connections were removed from the dataset. In addition, we removed connections that the research team agreed were illogical. After processing the dataset in this way, the resulting overall system map had 158 factors and 289 causal connections.

**TABLE 2** | Categories of factors mentioned during our system mapping sessions.

| Category | Description | Number of factors in integrated system map |
|---|---|---|
| Ecological quality of ditches (pale yellow) | Our participants would occasionally bring up factors that can be understood as further specifications of the idea of the ecological quality of ditches. In our integrated system map, we collapsed these factors in the factor 'ecological quality of ditches'. | 1 |
| Water quality (navy blue) | This category is closely related to the first category, but is worth mentioning separately, given the number of times that factors specifically related to water quality were mentioned. | 4 |
| (Ecological) management (raspberry red) | Our participants discussed a variety of activities that fall into the category of management of ditches, including activities specifically related to ecological management. This includes activities such as dredging, mowing, and cleaning of the ditches. We also included the visibility of results of these activities in this category. | 4 |
| Activities on agricultural fields (deep magenta) | The ditches that we focus on surround agricultural fields. Our participants discussed various factors related to activities that occur on the fields themselves, such as the use of pesticides, manure leaching, the amount of space available for farming. | 7 |
| Connections with environment (cobalt blue) | The ecological quality of ditches also partly depends on (ecological) connections of these ditches with the wider environment. Our participants mentioned several factors that capture these connections. | 5 |
| Nature (olive brown) | Our participants discussed several factors related to natural processes, such as developments in the average rainfall and temperature, the amount of vegetation, peat oxidation. | 5 |
| Global developments (dark pink) | Some factors refer to global developments, such as climate change and food scarcity. | 3 |
| Land layout (light pink) | Our participants mentioned factors related to the physical design of ditches that are relevant for ecological quality, such as the angle of inclination of the sides of the ditches, the width of the ditches, and the width of the buffer zone around the ditches. | 3 |
| Motivation (lavender) | Our participants mentioned various factors related to motivations that farmers have to engage in ecological management of ditches. | 6 |
| Costs and incomes (orange) | Our participants mentioned many factors related to costs and incomes for farmers, usually in the context of their motivation to engage in ecological management. | 13 |
| Knowledge (lime green) | Factors related to knowledge, experience and/or education were mentioned frequently. This includes knowledge on biodiversity and ecological management of farmers, but also of water authorities, of farmers' collectives, and of citizens in general. We also included factors related to awareness (of citizens and consumers) here. | 5 |

(Continues)

**TABLE 2** | (Continued)

| Category | Description | Number of factors in integrated system map |
|---|---|---|
| Policy and governance (maroon) | Participants also brought up a variety of factors related to policy and governance at various levels, ranging from EU policies, to local policies. | 15 |
| Monitoring (teal) | Our participants brought up monitoring of ecological quality in multiple forms. | 1 |
| Sentiment (olive) | This category covers a variety of factors related to the sentiment/attitudes towards biodiversity and ecological management. This includes factors related to societal sentiment/attitudes, as well as local sentiment/attitudes. | 9 |
| Pollution (mint green) | This includes various factors related to polluting activities in the area. | 3 |
| Communication (yellow) | This category covers factors related to (the quality of) communication between various actors in the area. Especially the communication between farmers and water authority came up in several sessions. | 2 |

Despite this reduction, the integrated map remained highly complex and therefore still difficult to interpret. We therefore decided to loosen our original ambition to remain as close as possible to the original maps and to further recode the factors in order to generalize them. This process largely follows the steps that Ryan et al. (2021) describe as a grounded theory approach to integrating maps. We examined which broader themes could be distilled from the factors and their causal relationships and used these themes to define more general factors that subsumed the more detailed ones and their connections. We followed the same collaborative procedure as before, with one researcher proposing changes that were subsequently scrutinized by the others. These suggestions primarily focused on removing factors whose meaning was already largely covered by other, similar factors and relationships. Throughout this process, we sought to strike a balance between avoiding excessive abstraction and producing an overview that could still be reasonably interpreted. The resulting map consists of 82 factors and 143 causal relationships.

### 3.4 | Validation

While the aim was to develop a simplified system map that retained the structure of the original as much as possible while conveying the same information at a higher level of abstraction, some loss of detail was inevitable. We therefore decided that validation of the resulting map was required, allowing us to check whether it still sufficiently represented the input provided by the participants, according to their own views.

We conducted the validation through a workshop organized on 9 June 2023, to which all participants from the earlier workshop were invited. Thirteen participants joined the validation workshop. For this session, we further simplified our categorization of factors into six categories: Knowledge, Motivation, Business Models, Climate and Water, Cooperation, and (Landscape) Management and Design. Participants were divided into three subgroups, each of which reviewed the map with a primary focus on two of these categories. Each subgroup was provided with a poster version of the integrated map, as well as post-its and markers. Participants were asked to discuss the map and to highlight anything they considered wrong or missing. They could make corrections directly on the map or by adding post-its (see Figure 4 for an example).

Participants did not remove any factors or relationships from the map, but they did add various comments. Some of these additions consisted of elaborations or examples of ideas already present, rather than fundamentally new elements. Several comments concerned the insufficiency of reimbursements for ecological management, which is a qualification of a dynamic already captured in the systems map, rather than a new dynamic. Another example of such a comment was that different types of motivators carry different weights for different farmers. Other comments offered examples of things captured by the map at a more abstract level. For example, several comments mentioned specific subsidy programs that are in existence, while the map refers to these programs in a more general sense. While such additions were valuable for interpreting the system map and helped participants make sense of it, they did not necessitate changes to the map itself.

Other additions, however, did invite revisions of the map, all of which related in some way to farmers' motivation to engage in ecological management. One straightforward addition was that engaging in ecological management can also generate pleasure, which can increase motivation. Another concerned consumers' willingness to pay higher prices for products from farmers who contribute to biodiversity restoration. This willingness affects farmers' income and thereby their motivation to engage in ecological management. Appreciation from the local community and peer pressure among farmers were also


**FIGURE 3** | Example of factors where we encountered direct (grey) as well as indirect (black) connections. In these cases we would typically remove the direct connections, as the indirect connections provided more precise information about the nature of the relationship between the corresponding factors.

identified as factors influencing motivation. The most consequential addition was that seeing the results of ecological management feeds back into farmers' motivation. In this context, participants emphasized the importance of monitoring ecological outcomes in order to make these results visible. Together, these additions introduced feedback loops between ecological outcomes (ecological quality of ditches) and farmers' motivation that had not previously been included in the map. Moreover, they highlighted monitoring of biodiversity outcomes as an important instrument for stimulating ecological management. Finally, participants added the possibility of tailor-made reimbursements as a factor influencing the attractiveness of business models for ecological management, thereby indirectly affecting motivation. After incorporating these additions, we finalized the system map with 86 factors and 147 causal relationships (see Figure 5).

## 4 | Results

In this section, we present our findings on the diversity of factors identified by the involved stakeholders and the complex dynamics revealed by the system map that results from our participatory process, and we reflect on how these findings have influenced thinking on policy interventions to stimulate ecological management of ditches in the Alblasserwaard area. This is partly supported by an interpretive analysis of our results, for example where it involves the categorization of factors into different types. Our analysis of system dynamics is primarily informed by a reconstruction of feedback loops present in the system. To reconstruct these, we used the Kumu webtool (Kumu 2025).

### 4.1 | The Diversity of Factors Identified by Stakeholders

One of the key motivations for developing the system map was that stakeholders in the Alblasserwaard area tended to focus on only a limited set of factors that they thought were important in stimulating ecological quality of ditches in the area. The most frequently discussed factor was that of reimbursements, based on the idea that such financial incentives would help motivate farmers to engage in ecological management. One simple but valuable idea that the system map can illustrate is that there is actually a broad diversity of factors at play that often interact with each other. Table 2 offers an overview of 16 categories of factors that we identified during the harmonization of the results from our 6 system mapping workshops.

The diversity of categories in the integrated map is revealing, as it shows that the intersubjective image constructed by stakeholders captures a much greater complexity than any single stakeholder typically articulates, particularly with regard to the range of influencing factors. When focusing on our focal factor (ecological quality of ditches), we observe that it is influenced by ecological management, connections with the environment, nature, water quality, global development, land layout, pollution, and agricultural activities on the field (see Figure 6). While none of these factors are unexpected in isolation, their combined presence underscores the importance of not viewing the ecological quality of ditches solely as a matter of ecological management. Rather, it also emerges from other practices that may not prioritize biodiversity or even have attention to it. This underlines the importance of treating biodiversity as an integral challenge that needs to be taken into account in a wider range of policies and practices that affect the area.

Figure 6 also reveals three mechanisms through which ecological management influences the ecological quality of ditches: increasing the width of buffer zones along ditches where no agricultural activities can take place; reducing manure leaching by avoiding manure application near ditches; and reducing pesticide use. The first two mechanisms proved particularly relevant in relation to a feedback loop discussed later, as they involve practices that reduce the surface area of land available for agricultural production or manure placement. This points to a potentially hidden cost of ecological management practices in the form of reduced farm income.

Before turning to feedback loops in more detail, it is worth examining another key factor that emerges from our map: farmers' willingness to engage in ecological management, that is, their motivation (Figure 7). This factor is particularly interesting because it is influenced by a wide range of incoming factors. At the outset of our project, stakeholders (especially policymakers) placed strong emphasis on financial reimbursements as a means of motivating farmers to engage in ecological management. However, the mapping exercises revealed that motivation is shaped by many additional factors alongside reimbursements.

One factor that emerged frequently concerns attitudes towards biodiversity (and related topics) within the communities in

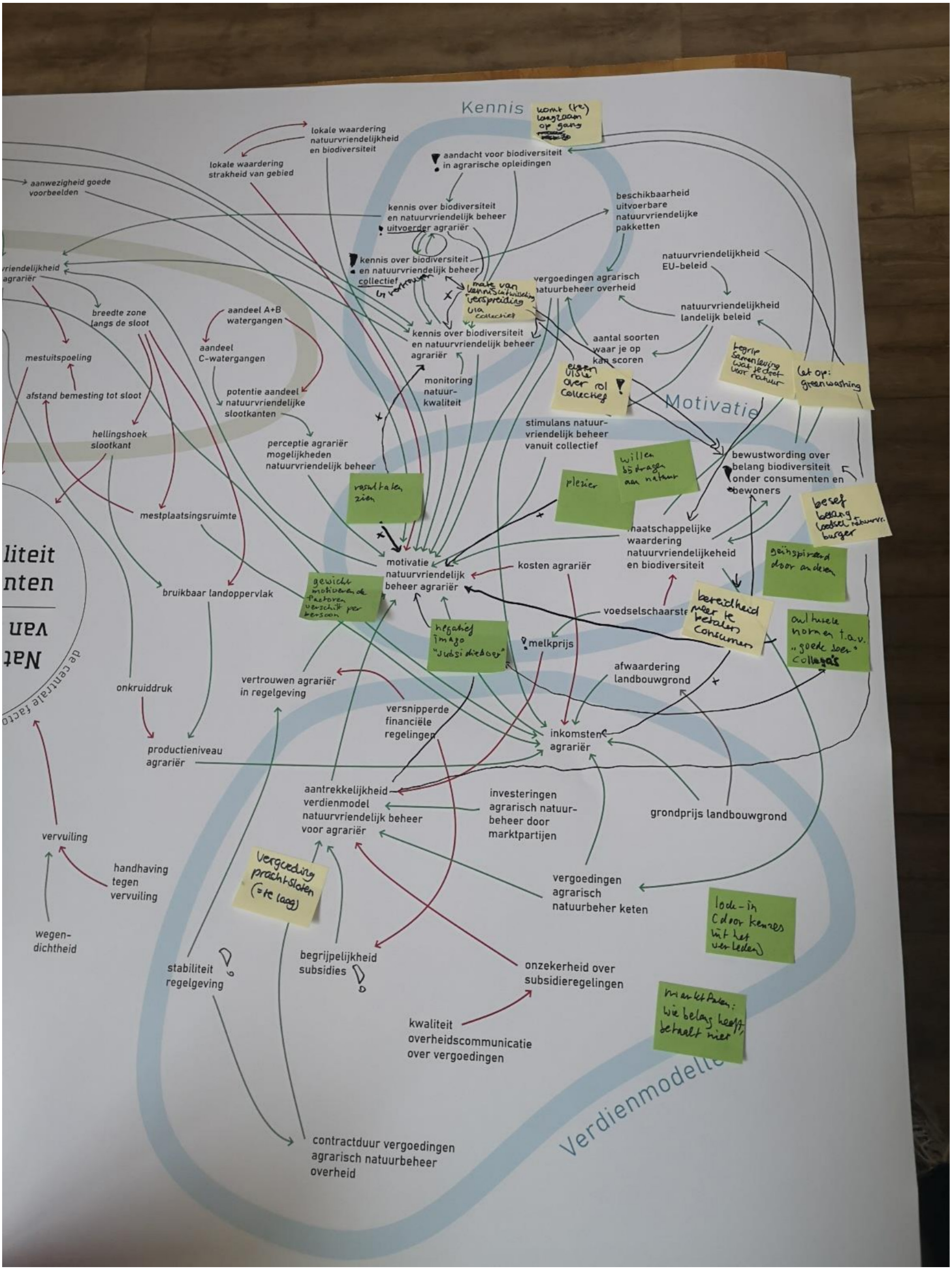


**FIGURE 4** | Example of an annotated system map during the validation session. [Colour figure can be viewed at wileyonlinelibrary.com]

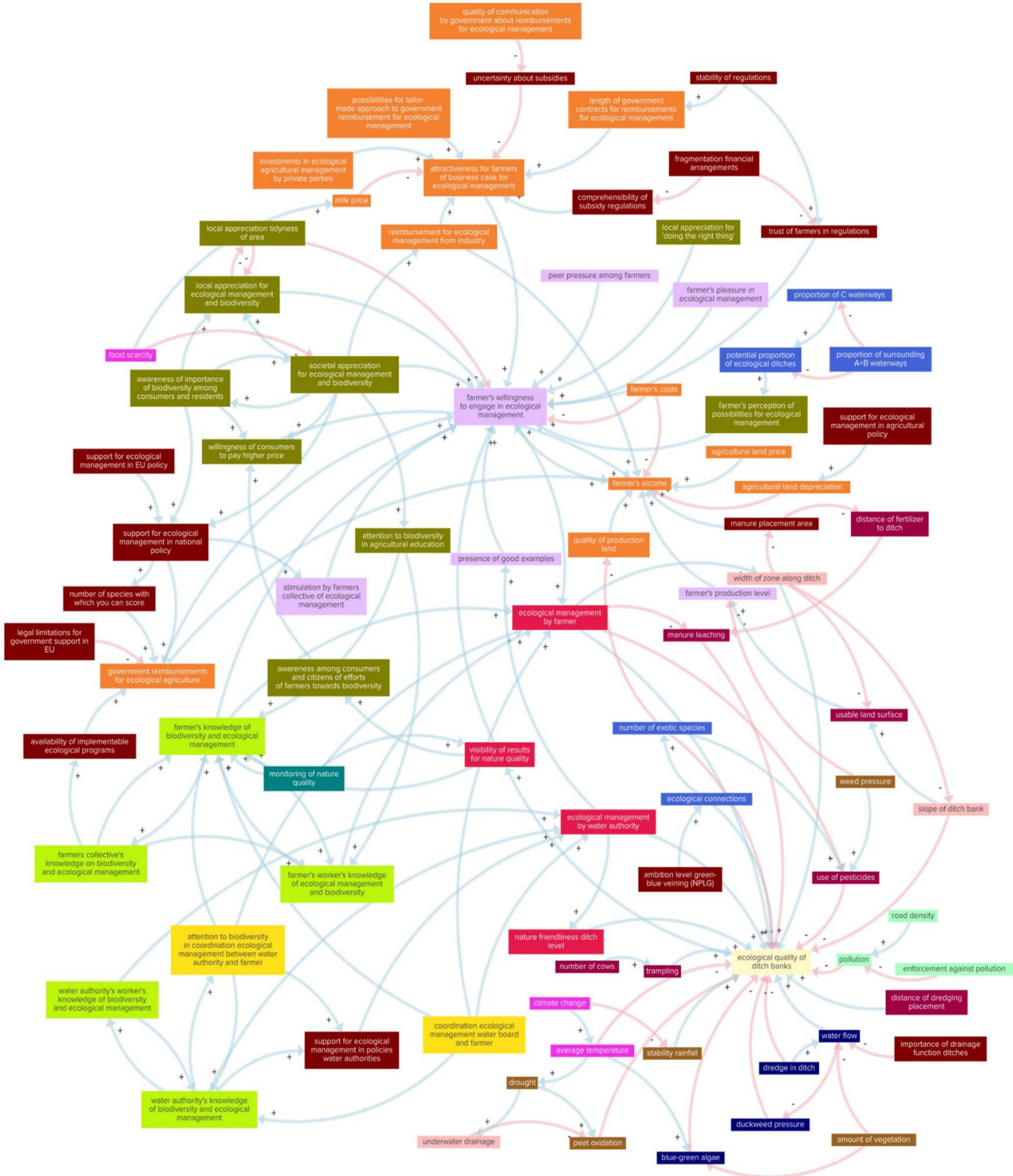


**FIGURE 5** | Plot of integrated system map. The different colours represent different categories of factors (see Table 1). Blue arrows (labelled with a +) represent causal relationships where a change in one factor causes a change in the same direction of another factor. Red arrows (labelled with a -) represent causal relationships where a change in one factor causes a change in the opposite direction of another factor. A PDF version of the complete CLD with a slightly adjusted layout is available in the Supporting Information. [Colour figure can be viewed at wileyonlinelibrary.com]

which farmers are embedded. Farmers noted, for instance, that biodiverse ditches were sometimes perceived by others as messy or as a sign of poor management. Another important motivator is the presence of positive examples. This is closely related to the role of the water authority in ecological management. It emerged repeatedly that the water authority did not always set a good


**FIGURE 6** | Factors directly influencing ecological quality of ditches (ingoing connections to these factors were removed for readability). [Colour figure can be viewed at wileyonlinelibrary.com]

example, leading some farmers to question why they should engage in ecological management if governmental actors do not do so themselves.

Figure 7 also includes a factor related to farmers' knowledge of biodiversity and ecological management. While the figure does not show this explicitly, this factor is part of a broader cluster of interrelated knowledge-related factors involving multiple actors engaged in ecological management. As discussed later, these factors are embedded in feedback loops through which shared knowledge of biodiversity and ecological management develops via exchanges between actors. The relevance of this knowledge for farmers' motivation lies in the fact that greater understanding of biodiversity and of the role of ecological management in preserving and restoring it increases farmers' willingness to engage in such practices.

While the map thus reveals a variety of influences on the motivations of farmers, financial considerations indeed remain important. One of these considerations, the attractiveness of the business case for ecological management, depends on a variety of factors, including reimbursement schemes, milk price, and the clarity and stability of regulations. Considerations of costs and benefits are indeed important influences on farmers' motivation as well. However, we found that these are embedded in multiple feedback loops, which affect how reimbursements should be designed. This moves us from a focus on the diversity of factors to a consideration of the system dynamics that connect them, the central topic of the next section.

### 4.2 | The Systemic Dynamics Revealed by the System Map

A key focus in examining the dynamics visualized in the integrated system map is to study the feedback loops that it reveals. It is also worthwhile reflecting on how feedback loops emerged at various steps of our process (see Table 3). In two of the workshops that we conducted, no feedback loops emerged at all. The feedback loops reconstructed in Sessions 2, 5 and 6 are all relatively short feedback loops that refer to learning processes through which knowledge on ecological management accumulates. The 21 feedback loops in Session 4 include somewhat longer feedback loops, but all 21 feedback loops are variations on a single theme, which is the interaction between motivations of farmers to engage in ecological management and societal attitudes towards ecological management that change as a result of (the outcomes of) ecological management. This is the only feedback loop that was not created intentionally by the participants in the workshops. One of the facilitators noticed the feedback loop, and when it was brought to the attention of the participants, they confirmed its importance. Thus, the general observation is that feedback loops were rarely detected in the individual mapping sessions. To some extent, this supports the observation of Sterman (1994) that people tend to think in simple causal chains and ignore feedback loops.

It also underlines one of the added values of integrating maps from different sessions, as the integrated map reveals many more feedback loops that were not explicated in the individual maps. Before simplification, the integrated system map contained 225

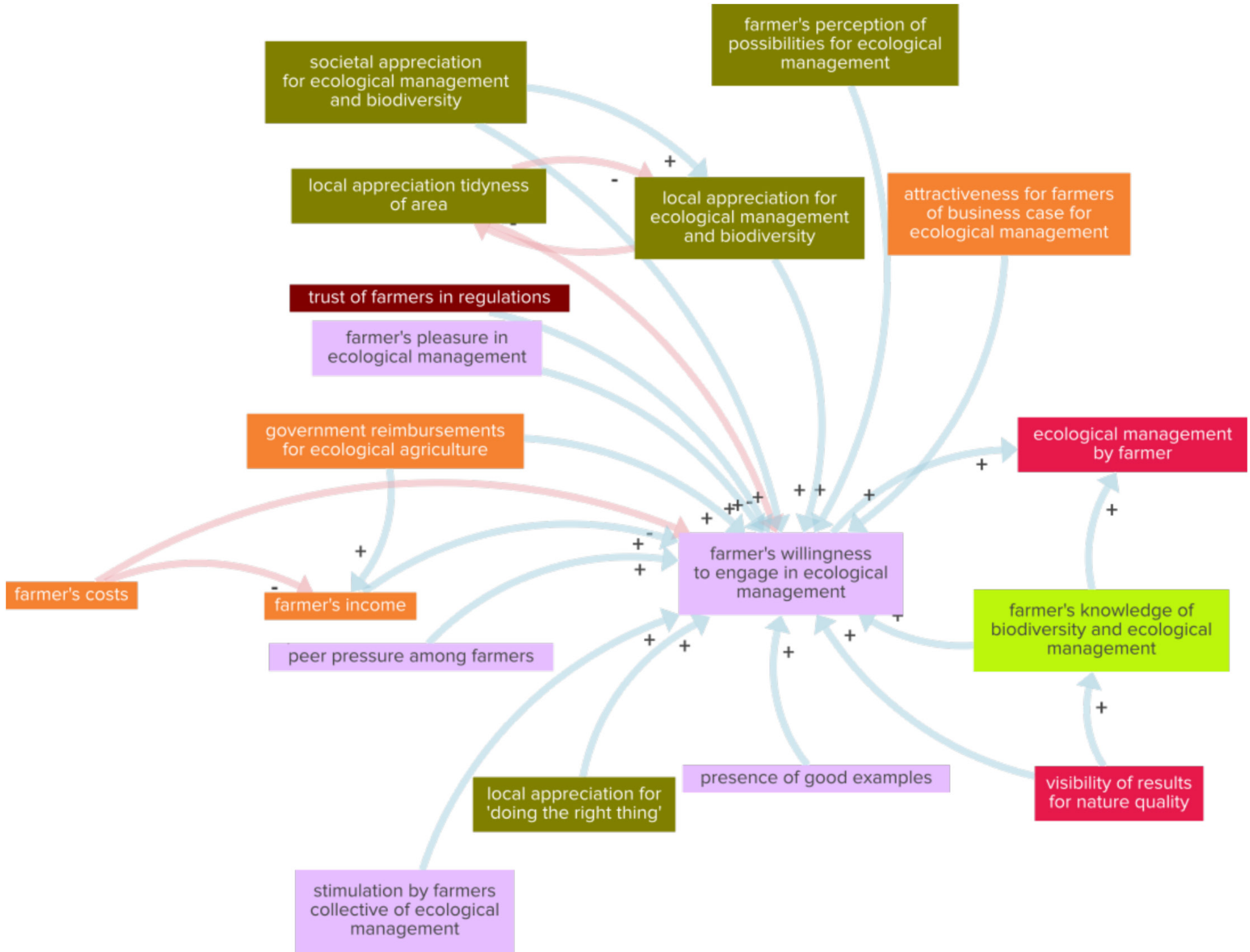


**FIGURE 7** | Factors influencing the willingness of farmers to engage in ecological management (ingoing connections to these factors were removed for readability). [Colour figure can be viewed at wileyonlinelibrary.com]

**TABLE 3** | The number of feedback loops that appear in different system maps.

| Session | Number of feedback loops |
|---|---|
| 1 | 0 |
| 2 | 4 |
| 3 | 0 |
| 4 | 21 |
| 5 | 1 |
| 6 | 4 |
| *Integrated system map before simplification* | *225* |
| *Validated integrated system map* | *58* |

feedback loops. To some extent this exponential increase can be explained by the sheer number of connections included in the integrated map: There are often many highly similar paths between two given factors, and if these factors are connected through feedback loops, all of these paths will be counted as a separate loop, while in reality they are variations of the same loop. In the final system map that we obtained after our validation session, 58 feedback loops exist. These too are mostly variations on a few themes.

We collapsed these different variations into seven main feedback loops, as visualized in Figure 8 and summarized in Table 4. Loops L1 and L2 are closely related to community attitudes, which also featured prominently in our discussion of the diverse factors influencing farmers' willingness to engage in ecological management. L1 captures the tension participants identified between two possible community attitudes: one characterized by appreciation for biodiversity and ecological management, and another emphasizing tidiness in the landscape. From the latter perspective, biodiverse ditches are often perceived as messy. The main relevance of this loop lies in highlighting the need to stimulate a shift towards greater appreciation of biodiversity, which in turn requires closer involvement of the local community in biodiversity-related efforts. L2 addresses societal appreciation at a more abstract level, namely appreciation from wider society. It highlights that such appreciation increases with a better understanding of the importance of ecological management for

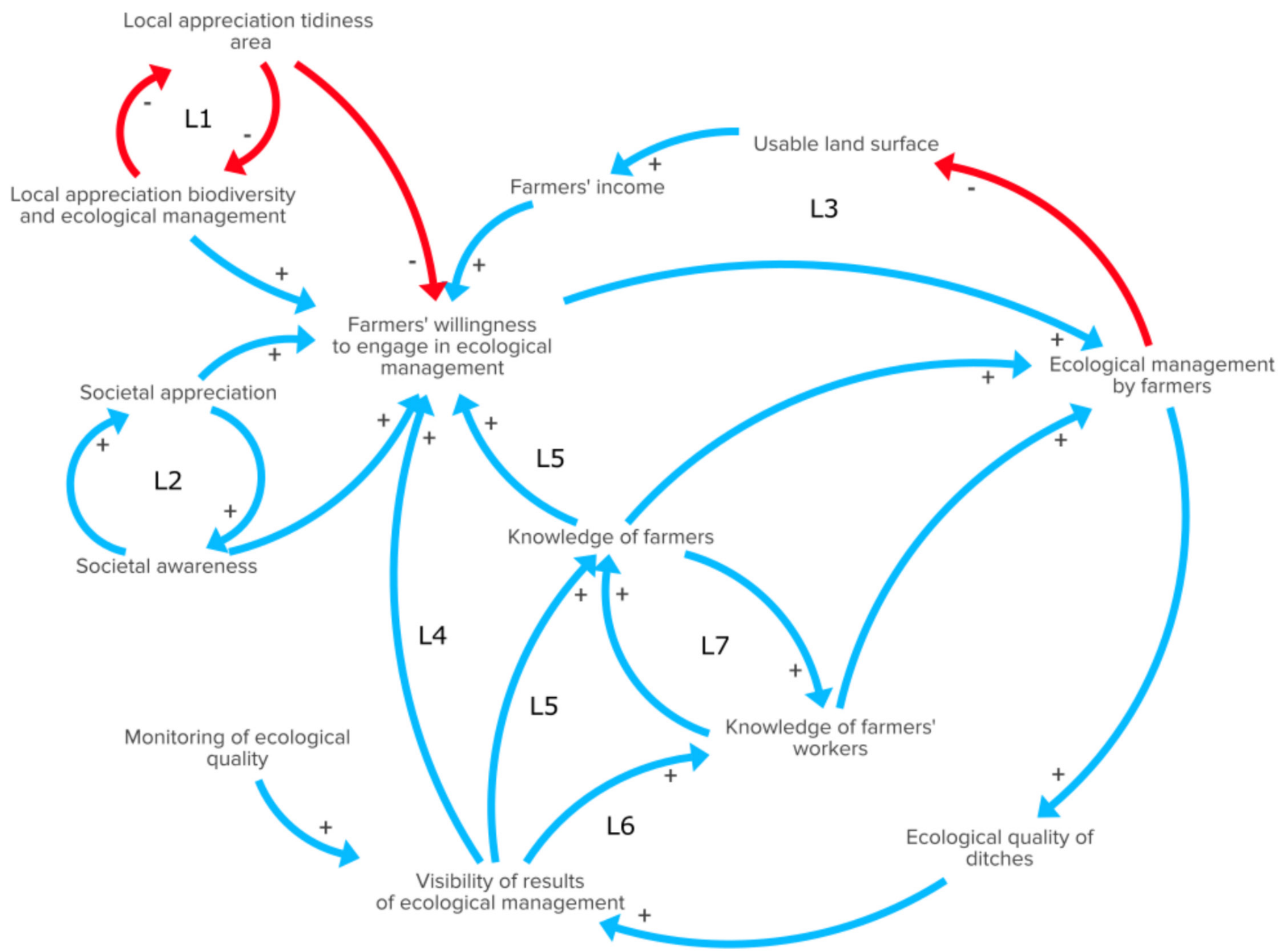


**FIGURE 8** | Simplified view of feedback structure embedded in the integrated system map. Blue arrows (labelled with a +) represent causal relationships where a change in one factor causes a change in the same direction of another factor. Red arrows (labelled with a -) represent causal relationships where a change in one factor causes a change in the opposite direction in another factor. The labelled loops are explained further in Table 3. [Colour figure can be viewed at wileyonlinelibrary.com]

biodiversity. This loop thus also provides a basis for considering awareness-raising as a potential intervention.

L3 captures feedback dynamics that embed ecological management and farmers' willingness to engage in it within self-dampening loops, which we alluded to earlier. The dampening effect arises from income losses associated with ecological management, due to reduced land availability for production and manure placement. A key implication of this loop is that reimbursement schemes must adequately account for these additional costs if they are to effectively support ecological management.

Loops L4, L5 and L6 capture self-reinforcing dynamics associated with observing the results of ecological management. Part of this reinforcing effect stems from the fact that seeing positive outcomes can itself act as a motivator (L4). In addition, farmers and their workers can learn from these outcomes (L5 and L6). Participants indicated that increased knowledge and understanding of how to implement ecological management effectively can strengthen farmers' willingness to engage in such practices. Discussions of these dynamics repeatedly emphasized that biodiversity monitoring by ecologists can increase the visibility of results. Such monitoring therefore constitutes an important leverage point for stimulating ecological management. L7 captures a closely related loop concerning knowledge exchange between different actors. This dynamic was also linked to the importance of educating the various actors who can engage in ecological management. Education was consequently identified as another key leverage point.

In summary, most of the identified loops reinforce earlier observations regarding factors such as community attitudes and knowledge, and they point to leverage points that can be used to stimulate ecological management. Loop L3, however, highlights a distinct risk associated with compensation schemes: if hidden or indirect costs are not adequately addressed, such schemes may fail to achieve their intended effect on farmers' willingness to engage in ecological farming.

### 4.3 | Policy Impact

The integrated system map was developed at a time when multiple stakeholders in the region were preparing an action plan

TABLE 4 | Main feedback loops as shown in Figure 8.

| Feedback loop | Type | Description and importance |
|---|---|---|
| L1: Trade-off between different community attitudes (summarize) | Positive feedback loop | Captures the conflict that participants saw between community attitudes that appreciate biodiversity and ecological management and attitudes that prioritize how tidy the area looks. If this conflict balances more to tidyness, this negatively affects the willingness of farmers to engage in ecological farming. Increasing community appreciation for biodiversity and ecological management is therefore a leverage point. |
| L2: Awareness generates appreciation | Positive feedback loop | Similar in spirit to L1, but at a higher level. It captures how increased societal awareness (about biodiversity) will also positively influence appreciation for biodiversity and ecological management, which can be a stimulant for farmers to engage in ecological management. Creating awareness is therefore a leverage point. |
| L3: Hidden income loss after ecological management | Negative feedback loop | Captures a self-dampening effect in ecological management, caused by (extra) loss of income for farmers who engage in ecological management. This is due to loss of land available for production purposes. The main implication of this loop is that financial compensation for farmers also needs to take into account these indirect losses. |
| L4: Visibility of results as a motivator | Positive feedback loop | Captures that seeing the results of ecological management (in which monitoring can play a role) can increase further increase motivation of farmers to engage in ecological management. Making results of ecological management visible (through monitoring) is thus a leverage point. |
| L5: Increased knowledge as a motivator (A) | Positive feedback loop | Similar to L4, but this loop emphasizes that farmers can also gain knowledge from the results of their work, which can also further affect motivation. This is a second reason why making results visible is a leverage point. |
| L6: Increased knowledge as a motivator (B) | Positive feedback loop | Nearly identical to L6, but emphasizing that not only knowledge development among farmers is important, but also knowledge development among their workers. |
| L7: Knowledge exchange | Positive feedback loop | Captures how knowledge exchange can mutually strengthen the knowledge of different relevant actors. Education is identified as a leverage point here. |

for the green-blue veining of the Alblasserwaard area (Slagboom and Van Dam 2023). Green-blue veining refers to the connection of linear landscape elements (e.g., tree lines and ditches) to strengthen ecological connectivity and thereby enhance biodiversity. Concretely, the action plan aims to increase the share of green-blue veining in the area to 10% by 2050, whereas it is currently estimated by local stakeholders to be well below 5%. The plan was developed through cooperation between the regional farmers' collective, several municipalities, two provinces, the regional water authority, and in collaboration with Naturalis. Through this plan, the involved stakeholders seek to make a substantial contribution to the Netherlands' ability to meet European legal requirements for biodiversity, climate goals as set out in the Paris Agreement, and statutory requirements for water quality. The plan forms part of the broader National Program for Rural Areas.

The Alblasserwaard area has one of the highest densities of ditches in the world, making ditches a potentially crucial component in increasing green-blue veining. The insights generated by our system map regarding the factors influencing the ecological quality of ditches are therefore highly relevant to the action plan. We presented the integrated system map during a meeting of the stakeholder group involved in the plan's development, highlighting our key findings concerning both the diversity of factors involved and the feedback loops in which compensation schemes for farmers are embedded.

In particular, insights related to the diversity of influencing factors shaped the discussion that followed the presentation. A key conclusion drawn by the stakeholders was that the plan should more explicitly address how local communities can be more closely involved in efforts to increase green-blue veining, and that education should play a central role in this process. These ideas were subsequently incorporated into revised versions of the plan. For example, the following excerpt from the plan illustrates this shift (translated from the original):

> "Communication is an important tool for scaling up the GBDA. How do you involve and motivate the various parties involved? Local authorities and the Farmers' Collective have an important role to play in this. In addition to motivation, education is also important. We will do this by offering workshops (Nature Building Blocks) and providing further training for contractors (ecological management). Ecological management will also be included in the curricula of secondary vocational education (MBO) and higher professional education (HBO). In addition, we will inform and educate rural residents about ecological management and the application of GBDA on their own land."
>
> (Slagboom and Van Dam 2023, 6)

The plan also addresses several other elements that are represented in our system map, such as the importance of compensation schemes, attractive business models and biodiversity monitoring. However, these aspects were already prominent in earlier versions of the plan, prior to our system mapping efforts. The plan does not explicitly address the feedback loops in which compensation mechanisms are embedded. During the stakeholder meeting, a representative of the farmers' collective noted that 'additional losses' resulting from ecological management are already being taken into account within existing compensation schemes, for which the collective is responsible for implementation.

The most significant impact of our work on the action plan is reflected in the explicit inclusion of communication and education as key focal points. This provides concrete evidence that PSM and the integrated system map it produced prompted stakeholders to reconsider the boundaries of the problems they were addressing and to adapt their strategies accordingly. As such, this constitutes evidence of double-loop learning resulting from this work.

## 5 | Discussion

Our research findings generate multiple interesting results. First, mapping the (shared) mental models of stakeholders involved in a particular issue (in our case, the ecological quality of ditches) helped to unravel the systemic challenge of an induced policy challenge. By connecting the different factors that participants mentioned and displaying the feedback loops among them, we were able to create an overview of the system surrounding the policy challenge that no single actor can oversee. Thereby, our work helps make the interrelations between diverse elements of a system (Byrne 1998; Gerrits 2012) accessible to a lay audience.

The integrated system map should be understood primarily as a learning-oriented heuristic rather than a definitive representation of an objectively existing system. It is an intersubjective construct, developed with 25 stakeholders to support reflection on boundary judgements and to stimulate reconsideration of strategies for improving the ecological quality of ditches. While context-specific in its empirical grounding, we argue that the mechanisms it reveals are of broader relevance for biodiversity governance in agricultural landscapes.

A central lesson concerns the role of community attitudes and knowledge in shaping farmers' willingness to engage in ecological management. In the Alblasserwaard area, policy-makers initially focused on financial compensation as the primary motivational instrument. Our analysis suggests that this represents only one component of a broader motivational landscape, consistent with earlier findings (e.g., Haggblade et al. 2004; Bell et al. 2023). Several feedback loops in our system map also highlight the importance of community attitudes and knowledge development for farmer motivation. Feedback loops related to community attitudes point to a tension between two dominant evaluative frames: appreciation of biodiversity and ecological management versus appreciation of landscape tidiness. Where the latter prevails, visible outcomes of ecological management may be misinterpreted as signs of poor landscape management. This reduces community support, which can discourage farmers. Conversely, increased understanding of biodiversity processes and management practices can strengthen appreciation for ecological management. Knowledge development and community attitudes are thus mutually reinforcing. In the Alblasserwaard area, these were also the lessons that had the most visible impact in policy processes: In the development of an action plan for green-blue veining of the area, these lessons were used as a basis for including activities specifically aimed at improving community involvement and education in biodiversity and ecological management. These impacts on policy are evidence that double loop learning as a result of our mapping exercises did indeed take place: Stakeholders updated their mental maps of the problem at hand and adjusted their strategies accordingly.

Biodiversity monitoring also emerges as a critical leverage point within these dynamics. By making ecological outcomes visible, monitoring can enhance local understanding, provide tangible feedback to farmers, and strengthen motivation through recognition of results. Approaches such as citizen science (Conrad and Hilchey 2011) may therefore serve a dual function: generating ecological data as a basis for knowledge development while simultaneously fostering community engagement, knowledge and appreciation of biodiversity restoration efforts.

A further theme with broader relevance concerns the potentially hidden costs of ecological management. Beyond the direct investments required, ecological management may reduce the area available for production and for manure application, thereby generating indirect economic costs for farmers. In our system map, these effects are embedded in a balancing feedback loop that can erode the economic attractiveness of ecological management. If compensation schemes fail to account for these opportunity costs, they risk undermining rather than reinforcing farmers' willingness to participate.

We believe these themes are worth exploring further in future research on biodiversity governance in agriculture. While we do not believe that our integrated system map is immediately amenable to quantification and simulation, we suggest that development of quantitative models of the key dynamics summarized above would be valuable. This may include the development of formal models of motivational dynamics in biodiversity restoration in agricultural areas, for example through agent-based modelling or system dynamics modelling. Such models may focus on further exploring how community attitudes, knowledge diffusion and visible outcomes of ecological management co-evolve over time. Another avenue for research of this nature is to attempt to quantify the opportunity costs and hidden economic effects related to ecological management in agricultural areas. The results of this type of modelling may contribute to better-informed compensation schemes.

Our work constitutes a contribution to an emerging trend in literature on PSM and GMB in which multiple groups of stakeholders are involved in parallel workshops (Rajah and Kopainsky 2025). Our approach offers a concrete illustration of an approach to integrating the results of parallel workshops through a combination of triangulation and coding. However, our approach also illustrates how this approach may produce maps that become unwieldy due to their complexity (also see Hulme et al. 2026). We dealt with this by creating a simplified version of the integrated map that we subsequently validated with our stakeholders. However, in future research of this type, it is also useful to take inspiration from recently developed approaches such as the Qualitative Systems Exploration Model (QSEM), which deals with this by facilitating a gradual layering of complexity in system maps.

## 6 | Conclusion

In this paper, we aimed to demonstrate how a systems thinking approach can help to inform thinking about the complex dynamics that influence ecological quality of ditches on Dutch farmland and the role of ecological management therein. We demonstrate how such an approach helps to understand how reversing biodiversity loss in farmland is the result of many complex and indirect relationships. In doing so, we have shown that addressing biodiversity loss may require measures that at first might not be obvious. These include acknowledging the role of farmers in landscape management, addressing cultural ideas about what is 'neat', and local attitudes.

Using a system mapping approach, we supported 25 stakeholders from various backgrounds in the development of an intersubjective picture of these dynamics. Our findings confirm earlier observations of system dynamics literature that people tend to ignore feedback loops that occur in complex systems. We also demonstrate how these feedback loops can yet be reconstructed by integrating the insights from different system mapping sessions. This integrative step reveals one of the added values of an emerging strand within PSM and GMB literature that emphasizes the construction of composite maps from multiple workshops (Rajah and Kopainsky 2025).

Building on the themes emerging from the integrated system map, we were able to broaden and deepen stakeholders' understandings of how ecological management of ditches might be stimulated. This, in turn, informed and enriched local plans aimed at promoting biodiversity restoration through green-blue veining. The observed policy uptake suggests that the approach did more than refine existing strategies; it facilitated reflection on underlying assumptions and problem framings. In that sense, the process provides empirical support for the claim that PSM can enable meaningful double-loop learning.

**Funding**

The research presented in this publication was funded by the Dutch Research Council (NWO) through the NWO-NWA project Living Lab Alblasserwaard: Naar een biodiverse, productieve, leefbare waard (NWA.1331.19.001).

**Data Availability Statement**

The data that support the findings of this study are available from the corresponding author upon reasonable request.

**References**

Barbrook-Johnson, P., and A. Penn. 2021. "Participatory Systems Mapping for Complex Energy Policy Evaluation." *Evaluation* 27, no. 1: 57–79.

Baugh Littlejohns, L., F. Baum, A. Lawless, and T. Freeman. 2018. "The Value of a Causal Loop Diagram in Exploring the Complex Interplay of Factors That Influence Health Promotion in a Multisectoral Health System in Australia." *Health Research Policy and Systems* 16, no. 1: 126. https://doi.org/10.1186/s12961-018-0394-x.

Bell, A. R., O. S. Rakotonarivo, A. Bhargava, et al. 2023. "Financial Incentives Often Fail to Reconcile Agricultural Productivity and Pro-Conservation Behavior." *Communications Earth & Environment* 4, no. 1: 27.

Blanco, M., F. Montes, F. Borrero-Echeverry, et al. 2023. "A Participative System Methodology to Model Pest Dynamics in an Agricultural Setting." *Kybernetes* 52, no. 9: 3550–3565. https://doi.org/10.1108/K-08-2021-0663.

Byrne, D. 1998. *Complexity Theory and the Social Sciences: An Introduction*. Routledge.

Cairney, P. 2012. "Complexity Theory in Political Science and Public Policy." *Political Studies Review* 10, no. 3: 346–358. https://doi.org/10.1111/j.1478-9302.2012.00270.x.

Checkland, P. 2000. "Soft Systems Methodology: A Thirty Year Retrospective." *Systems Research and Behavioral Science* 17, no. s1: s11–s58.

Connolly, J. D., and G. J. Doole. 2024. "An Analysis of Participants' Introductory Experience With Causal Loop Diagrams (CLDs) Using Group Model Building (GMB) Scripts." *System Dynamics Review* 40, no. 4: e1785. https://doi.org/10.1002/sdr.1785.

Conrad, C. C., and K. G. Hilchey. 2011. "A Review of Citizen Science and Community-Based Environmental Monitoring: Issues and Opportunities." *Environmental Monitoring and Assessment* 176, no. 1–4: 273–291. https://doi.org/10.1007/s10661-010-1582-5.

David, P. A. 1985. "Clio and the Economics of QWERTY." *American Economic Review* 75, no. 2: 332–337.

Deutsch, A. R., L. Frerichs, M. Perry, and M. S. Jalali. 2024. "Participatory Modeling for High Complexity, Multi-System Issues: Challenges and Recommendations for Balancing Qualitative Understanding and Quantitative Questions." *System Dynamics Review* 40, no. 4: e1765. https://doi.org/10.1002/sdr.1765.

Dudley, N., and S. Alexander. 2017. "Agriculture and Biodiversity: A Review." *Biodiversity* 18, no. 2–3: 45–49.

Dyehouse, M., D. Bennett, J. Harbor, A. Childress, and M. Dark. 2009. "A Comparison of Linear and Systems Thinking Approaches for Program Evaluation Illustrated Using the Indiana Interdisciplinary GK-12." *Evaluation and Program Planning* 32, no. 3: 187–196. https://doi.org/10.1016/j.evalprogplan.2009.03.001.

Gerrits, L. 2012. *Punching Clouds: An Introduction to the Complexity of Public Decision-Making*. Emergent Publications.

Gerrits, L., and P. Marks. 2008. "Complex Bounded Rationality in Dyke Construction." *Land Use Policy* 25, no. 3: 330–337. https://doi.org/10.1016/j.landusepol.2007.09.001.

Ghaffarzadegan, N., J. Lyneis, and G. P. Richardson. 2011. "How Small System Dynamics Models Can Help the Public Policy Process: N. Ghaffarzadegan et al.: Small System Dynamics Models." *System Dynamics Review* 27, no. 1: 22–44. https://doi.org/10.1002/sdr.442.

Grondard, N., E. Kleyheeg, L. Hein, and L. G. J. Van Bussel. 2023. "Effects of Dutch Agri-Environmental Field Margins and Bird Plots on Cropland Birds." *Agriculture, Ecosystems & Environment* 349: 108430. https://doi.org/10.1016/j.agee.2023.108430.

Haggblade, S., G. Tembo, and C. Donovan. 2004. "Household Level Financial Incentives to Adoption of Conservation Agricultural Technologies in Africa."

Hole, D. G., A. J. Perkins, J. D. Wilson, I. H. Alexander, P. V. Grice, and A. D. Evans. 2005. "Does Organic Farming Benefit Biodiversity?" *Biological Conservation* 122, no. 1: 113–130.

Hulme, A., D. Radley, A. D. Brown, et al. 2026. "The Qualitative Systems Exploration Model (QSEM): A New Framework to Support the Structural Analysis of Causal Loop Diagrams Within Participatory System Dynamics." *System Dynamics Review* 42, no. 1: e70015. https://doi.org/10.1002/sdr.70015.

IPBES. 2019. "Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services." In *IPBES Secretariat*, edited by E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo, 1148. https://doi.org/10.5281/zenodo.3831673.

Kumu [Relationship mapping software]. 2025. "Retrieved from" https://kumu.io.

Lopes, R., and N. Videira. 2017. "Modelling Feedback Processes Underpinning Management of Ecosystem Services: The Role of Participatory Systems Mapping." *Ecosystem Services* 28: 28–42. https://doi.org/10.1016/j.ecoser.2017.09.012.

McLaughlin, A., and P. Mineau. 1995. "The Impact of Agricultural Practices on Biodiversity." *Agriculture, Ecosystems & Environment* 55, no. 3: 201–212.

McNeely, J. A., and G. Schroth. 2006. "Agroforestry and Biodiversity Conservation–Traditional Practices, Present Dynamics, and Lessons for the Future." *Biodiversity and Conservation* 15: 549–554.

Meadows, D. H., and D. Wright. 2008. *Thinking in Systems: A Primer*. Chelsea Green Pub.

Melman, T. C. P., A. G. M. Schotman, S. Hunink, and G. R. De Snoo. 2008. "Evaluation of Meadow Bird Management, Especially Black-Tailed Godwit (Limosa limosa L.), in the Netherlands." *Journal for Nature Conservation* 16, no. 2: 88–95. https://doi.org/10.1016/j.jnc.2008.01.002.

Rajah, J. K., A. E. P. Atkins, C. Tang, et al. 2024. "Understanding Hydrologic, Human, and Climate System Feedback Loops: Results of a Participatory Modeling Workshop." *Water* 16, no. 3: 396. https://doi.org/10.3390/w16030396.

Rajah, J. K., and B. Kopainsky. 2025. "A Systematic Method to Integrate Co-Produced Causal Loop Diagrams Based on Feedback Stories." *System Dynamics Review* 41, no. 1: e1794. https://doi.org/10.1002/sdr.1794.

Rhee, Y. P. 2000. "Complex Systems Approach to the Study of Politics." *Systems Research and Behavioral Science* 17: 487–491.

Rich, K. M., M. Rich, and K. Dizyee. 2018. "Participatory Systems Approaches for Urban and Peri-Urban Agriculture Planning: The Role of System Dynamics and Spatial Group Model Building." *Agricultural Systems* 160: 110–123. https://doi.org/10.1016/j.agsy.2016.09.022.

Rouwette, E., I. Bleijenbergh, and J. Vennix. 2016. "Group Model-Building to Support Public Policy: Addressing a Conflicted Situation in a Problem Neighbourhood: Group Model-Building to Support Public Policy." *Systems Research and Behavioral Science* 33, no. 1: 64–78. https://doi.org/10.1002/sres.2301.

Runhaar, H. 2017. "Governing the Transformation Towards 'Nature-Inclusive'agriculture: Insights From the Netherlands." *International Journal of Agricultural Sustainability* 15, no. 4: 340–349.

Ryan, E., M. Pepper, and A. Munoz. 2021. "Causal Loop Diagram Aggregation Towards Model Completeness." *Systemic Practice and Action Research* 34, no. 1: 37–51. https://doi.org/10.1007/s11213-019-09507-7.

Slagboom, R. and J. Van Dam. 2023. "Verkenning Groenblauwe Dooradering Alblasserwaard: Landelijke Pilot Gebiedsgerichte Uitwerking Aanvalsplan Landschap en MooiNL [Exploration of Green–Blue Landscape Connectivity in the Alblasserwaard: Area-Based Pilot of the Landscape Action Plan and MooiNL] (Concept Version, April 25, 2023)." https://www.vwnatuurenlandschap.nl/wp-content/uploads/2023/07/Verkenning-GBDA-Alblasserwaard-concept-26-4-2023-gecomprimeerd.pdf.

Sterman, J. D. 1994. "Learning In and About Complex Systems." *System Dynamics Review* 10, no. 2–3: 291–330. https://doi.org/10.1002/sdr.4260100214.

Stichting Toegepast Onderzoek Waterbeheer (STOWA). 2009. *Handreiking Natuurvriendelijke Oevers: Een Hulpmiddel bij het Proces Van Ontwerp tot Aanleg Van Een Natuurvriendelijke Oever [Guidelines for Nature-Friendly Riverbanks: A Tool for the Process From Design to Construction of a Nature-Friendly Riverbank]*. STOWA.

Teisman, G., and E. H. Klijn. 2008. "Complexity Theory and Public Management." *Public Management Review* 10, no. 3: 287–297. https://doi.org/10.1080/14719030802002451.

Tosey, P., M. Visser, and M. N. Saunders. 2012. "The Origins and Conceptualizations of 'Triple-Loop' Learning: A Critical Review." *Management Learning* 43, no. 3: 291–307. https://doi.org/10.1177/1350507611426239.

Ulrich, W. 2000. "Reflective Practice in the Civil Society: The Contribution of Critically Systemic Thinking." *Reflective Practice* 1, no. 2: 247–268. https://doi.org/10.1080/713693151.

Ulrich, W., and M. Reynolds. 2020. "Critical Systems Heuristics: The Idea and Practice of Boundary Critique." In *Systems Approaches to Making Change: A Practical Guide*, edited by M. Reynolds and S. Holwell (Retired), 255–306. Springer London.

Velten, S., T. Schaal, J. Leventon, J. Hanspach, J. Fischer, and J. Newig. 2018. "Rethinking Biodiversity Governance in European Agricultural

Landscapes: Acceptability of Alternative Governance Scenarios." *Land Use Policy* 77: 84–93.

Vennix, J. 1999. "Group Model-Building: Tackling Messy Problems." *System Dynamics Review* 15, no. 4: 379–401.

Westerink, J., R. Jongeneel, N. Polman, et al. 2017. "Collaborative Governance Arrangements to Deliver Spatially Coordinated Agri-Environmental Management." *Land Use Policy* 69: 176–192.

Woog, R., R. Y. Cavana, R. Roberts, and R. Packham. 2006. "Working at the Interface Between Systems and Complexity Thinking: Insights From a Market Access Design Project for Poor Livestock Producers." *Systems Research and Behavioral Science* 23, no. 6: 727–741. https://doi.org/10.1002/sres.685.

World Economic Forum. 2025. "What Is Your Business's Nature Footprint? World Economic Forum." https://www.weforum.org/stories/2025/01/what-is-your-business-nature-footprint/.

Wright, T. 1999. "Systems Thinking and Systems Practice: Working in the Fifth Dimension." *Systemic Practice and Action Research* 12, no. 6: 607–631.

Zinngrebe, Y., F. Kinniburgh, M. J. Vijge, S. J. Khan, and H. Runhaar. 2022. "Transformative Biodiversity Governance in Agricultural Landscapes: Taking Stock and Looking Forward." In *Transforming Biodiversity Governance*, 264–292. Cambridge University Press.

## Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Supplementary Information.