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The role of connective interventions in the collective management of public-bad problems: Evidence from a socio-ecological system perspective

Julissa A. Galarza-Villamar[a,b,c], Mariette McCampbell[c], Christopher Agyekumhene[c,d,e], Domina Asingizwe[f,g], Emmanuel M. N. A. N. Attoh[h,i,j,k], Elias Damtew[c,l], Richard Chepkwony[m,n], Katarzyna Cieslik[o], Nyamwaya Munthali[c,d,e], Marilyn M. Murindahabi[g,p,q], Faith Mutavi[f,r], Andy B Nyamekye[h,i,j], Shiferaw Tafesse[l,m], Paul C. Struik[s] and Cees Leeuwis[c]

[a]Soil Physics and Land Management group, Wageningen University and Research, Wageningen, the Netherlands; [b]Escuela Superior Politécnica del Litoral, ESPOL, Polytechnic University, Guayaquil, Ecuador; [c]Knowledge, Technology, and Innovation group, Wageningen University and Research, Wageningen, The Netherlands; [d]International Institute of Tropical Agriculture, Accra, Ghana; [e]Laboratory of Geo-information Science and Remote Sensing, Wageningen University and Research, Wageningen, Netherlands; [f]Strategic Communication group, Wageningen University and Research, Wageningen, The Netherlands; [g]College of Medicine and Health Sciences, University of Rwanda, Kigali, Rwanda; [h]Water Systems and Global Change group, Wageningen University and Research, Wageningen, The Netherlands; [i]Public Administration and Policy group, Wageningen University and Research, Wageningen, The Netherlands; [j]Kumasi Institute of Technology, Energy and Environment, Accra, Ghana; [k]MDF West Africa, Accra, Ghana; [l]International Potato Center, Addis Abeba, Ethiopia; [m]Wildlife Ecology and Conservation group, Wageningen University and Research, Wageningen, Netherlands; [n]Kenya Wildlife Service, Nairobi, Kenya; [o]Global Development Institute, University of Manchester, UK; [p]Laboratory of Entomology, Wageningen University and Research, Wageningen, Netherlands; [q]Environmental Systems Analysis group, Wageningen University and Research, Wageningen, Netherlands; [r]International Livestock Research Institute, Nairobi, Kenya; [s]Centre for Crop Systems Analysis, Wageningen University and Research, Wageningen, Netherlands

ABSTRACT
Managing public-bad problems is difficult and arriving at an effective collective response can be an even bigger challenge. Using a socio-ecological systems framework, we explore the role of communication-focused interventions in the management of public bads in six African case-studies. We analyse case-specific livelihood units, public-bad risk conditions, and threats, and the strategies to prevent and control a public bad. We assess the impact of connective interventions on existing risk governance systems and problem management. Our

CONTACT Cees Leeuwis cees.leeuwis@wur.nl

findings show that connective interventions enable people to define risk boundaries, learn about the costs and benefits of public-bad management, and develop capacity for collective decision-making and problem monitoring. However, connective interventions cannot work in isolation and require complementary strategies, and trust in broader governance and institutional arrangements. Our research demonstrates the value of the social ecological systems framework in synthesizing lessons and insights from diverse interdisciplinary studies.

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KEYWORDS disease; complex problems; livelihood; interdisciplinary research; public bads; collective action

1. Introduction

Rural communities in Africa are confronted with numerous challenges that emerge from the way in which social and biophysical processes interact. These include water scarcity, environmental degradation, and the continued prevalence of a range of human, animal, and crop pests and diseases. Such challenges can be characterized as "complex" along several dimensions (Leeuwis et al., 2018) which makes it difficult to foster collective action and stakeholder coordination that are needed to effectively deal with these challenges. In this paper, we synthesize the results of six case studies from Africa that stem from 11 PhD projects which were implemented under one larger interdisciplinary research programme.[1] The studies explored the role of communication-focused strategies that are based on principles of participatory monitoring, mutual exchange, and citizen science (referred to as "connective interventions" in the remainder of this article, see Damtew et al., 2020) in enabling more effective collective action. In line with the complex nature of the challenges under investigation, we use a socio-ecological systems (SES) perspective to integrate and synthesize the insights generated and lessons learnt. We are specifically interested to find out whether and when connective interventions can help shift the logic and boundaries of collective action and decision-making in socio-ecological contexts that can be characterised in terms of public-bad situations.

This paper follows up on a NJAS special issue (Volume 86–87 in 2018) which included a series of 11 diagnostic papers investigating the same six case studies that are discussed in this contribution. The special issue provided the starting points of the interdisciplinary research programme (Cieslik et al., 2018) and

[1]The Responsible life-sciences innovations for development in the digital age: Environmental Virtual Observatories for Connective Action (EVOCA) was a multi-year project that started in 2016. EVOCA was implemented with funding from the Wageningen University Interdisciplinary Research Fund (INREF). For more information about the project and its outcomes and impact we refer to www.evoca.com.

a range of natural and social science studies that explored the kinds of connective interventions that could potentially be relevant in the complex contexts at hand (Leeuwis et al., 2018). This synthesis paper presents the eventual insights that were obtained through action research that was designed on the basis of the diagnostic work reported in the earlier mentioned special issue.

We start this contribution with a theoretical positioning and justification of our line of inquiry, which ends in the presentation of an operational analytical lens and several sub-research questions. We then proceed with a materials and methods section in which we characterise our six case-studies and discuss methods of data collection and data analysis. The subsequent results section provides a systematic description and analysis of the six cases in terms of (a) the public-bad and collective action problem at hand, (b) the associated risk governance system and the challenges faced by direct users, (c) the effects of the connective intervention, and (d) the lessons learned from the cases. In the analysis and discussion section, we use a comparative analysis to answer the research (sub-)questions, and draw conclusions.

2. Theoretical positioning

Socio-ecological systems (SES) are systems in which interacting societal and ecological subsystems mutually shape each other (Gallopín, 2006). In such systems, human interactions, relations and interdependencies are influenced by biophysical and non-human biological units (Carpenter et al., 2001). SES are complex systems because they are dynamic and adaptive, and their outcomes are emergent and affected by social factors, like different levels of agreement, uncertainty, and flexibility in human subsystems (Leeuwis et al., 2018; Schlüter et al., 2019; Shaw et al., 2014). Consequently, the interactions in SES are characterized by multi-causality, non-linearity and cross-scale effects (Ostrom, 2007).

Studying and exploring suitable solutions to SES problems require the integration of knowledge from multiple disciplines and explicit recognition of (the roles of) various stakeholders (Wang & Grant, 2021). Hence, to develop understanding of a SES problem, it is necessary to become familiar with the driving forces that shape particular processes of social and ecological change, like collective action, resource appropriation, production, communication, organisational behaviour, creation and diffusion of knowledge, cultural traditions, and other human and non-human actors and actions (Cole et al., 2019; Ostrom, 2007).

Traditionally, SES problems have been primarily studied from an institutional economics perspective, particularly as collective action problems that hinder the conservation of a common good (e.g. forest, groundwater) or the production of a public good (e.g. infrastructure, clean air) (Ostrom, 2006). Instead of studying the production of a public good, in this paper, we use conceptual thinking about SES and collective action problems to analyse the prevention of public bads with the help of communication-focused strategies. Public bads are non-rivalrous and non-excludable issues causing loss of social welfare for individuals and communities (Sonnemans et al., 1998), such as infectious diseases.

Ostrom made ground-breaking contributions to collective action research. She found that – in addition to certain external conditions – micro-level dynamics related to trust, reciprocity, and communication were the most critical factors enabling collective action towards sustainable management of common good resources (Ostrom, 2006). In line with Ostrom's findings, Van Asselt and Renn (2011) identified communication and information as two of the pillars of good governance, together with inclusion, integration, and reflection (Van Asselt & Renn, 2011). Our interest in the role of communicative strategies in relation to the prevention of public bads was further informed by the increased availability of information and communication technologies in Africa (see Cieslik et al., 2018; Leeuwis et al., 2018).

Löfstedt (2003; cited in Van Asselt & Renn, 2011) defined communication as meaningful interactions in which knowledge, experiences, interpretations, concerns, and perspectives are exchanged. In addition, communication is a mechanism through which human relationships are managed, negotiated and changed (Leeuwis & Aarts, 2011). Social movement research argues that sustainable and effective collective action to address SES problems requires various levels of organisational resource mobilization, where communication is an organizing principle (Lofstedt, 2003 cited in Van Asselt & Renn, 2011). Resource mobilization is fundamental to sustain human organisation and leadership, and to bridge different interests and develop common-action frames (Bennett & Segerberg, 2012).

Bennett and Segerberg (2012)[2] described the organisational communication mechanism that links individuals and networks to mobilize resources in order to achieve a common goal as "connective action". They describe connective action as a novel organisational mode that relies less on formal organisational coordination, and arises from new spaces of interaction in (digital) media landscapes. As demonstrated by Bennett and Segerberg (2012), connective action can be an influential and powerful complement to more traditional forms of organisation and collective action. Similarly, connective action may or may not give rise to collective action and may co-occur within the same ecology of actions as other forms of human organisation.

Our research synthesizes the influence of interventions that are oriented towards fostering connectivity (i.e. connective interventions), with a focus on

[2]Their research on connective actions emerged in a context of contentious politics, characterized by more individualized and technologically (e.g. social media) mediated processes.

interventions that aim to contribute to the management of public-bad problems through collective action (Leeuwis et al., 2018). We assess the value of communication-focused strategies based on participatory monitoring, mutual exchange, and citizen science in enabling collective action (Ostrom, 2009a; Cieslik et al., 2018; Leeuwis et al., 2018). To do so, we study six cases from the Environmental Virtual Observatories for Connective Action (EVOCAs) programme (Cieslik et al., 2018). The EVOCA programme studied the potential of knowledge sharing platforms (known as Environmental Virtual Observatories (EVOs) to address pressing public-bad problems in rural West and East Africa.[3] Each case was conducted by an interdisciplinary research team that was tailored to the case. Case teams hence varied in disciplinary expertise and choice of conceptual frameworks.

This study enhances our understanding of how connective interventions affect risk governance strategies, and how those strategies in turn contribute to the management of collective action problems. We demonstrate the value of the SES framework for understanding and enhancing collective management of public bads, and synthesising insights and lessons from interdisciplinary case studies. In so doing, we inform the current debates regarding sustainable development (SDGs 2, 6, 7, 13 and 15). For the past 20 years, sustainability has been a leading target of scientific research and policy agenda (Musters et al., 1998) but few empirically driven projects investigated sustainable management of public bads from the SES perspective (Colding & Barthel, 2019). We show how, in the context of governance of public bads, understanding the conditions for sustainable performance of complex socio-environmental systems is key to enabling effective collective action at the grassroots. This is of particular importance for the policy contexts in the Global South where new forms of bottom-up governance, many of them involving sub- and nonstate actors, often supplement the relative scarcity of government action (Hale, 2014).

2.1. Analytical framework and research questions

Ostrom (2007) introduced a multilevel and nested framework, the SES framework, to analyse the sustainability of socio-ecological systems. In the SES framework, resource systems (RS), resource units (RU), governance systems (RGS), and users (U) are the core subsystems interacting and generating outcomes within an SES. The original framework focuses on the sustainable management of common resources. For example, the

[3]For more details about the programme we refer to the programme website: https://www.wur.nl/en/project/responsible-life-science-innovations-for-development-in-the-digital-age-evoca.htm.

trees (RU) within a protected forest in a specified territory (RS), managed by certain formal and informal institutions (GS), and providing livelihood or recreational services to individuals (U). Galarza-Villamar et al. (2021) adapted Ostrom's SES framework to a public-bad risk management situation, when a hazard (e.g. the spread of an infectious and contagious disease) threatens the livelihood system (composed of livelihood units and production assets) on which users rely to generate ecosystem services and make a living (Galarza-Villamar et al., 2021). As our research also focuses on collective action problems related to public bads, we adopt the Galarza-Villamar et al. framework (Figure 1) to synthesize the findings of the six case studies. We analysed the case-specific livelihood units (e.g. the humans, animals or crops affected by the disease or hazard), the public-bad risk conditions (e.g. the disease, causal agent, and infection mechanisms), the threats (e.g. livelihood unit losses or fatalities), and the strategies (based on coordination and cooperation at the level of direct users and the broader risk governance system) to prevent and control the public bads (disease spread).

Following Ostrom (2007), the various arrows in Figure 1 emphasize both the direct and feedback interactions between the users and the

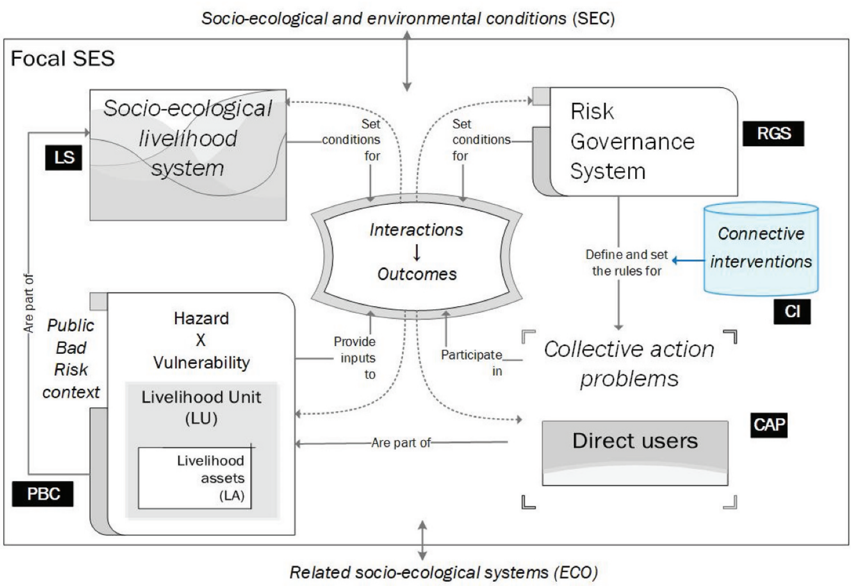

Figure 1. Full framework for analyzing public-bad problems in SES, adapted from Ostrom (2007), as described in Galarza-Villamar et al. (2021). Our primary focus is on the dimensions CI, RGS, and (less) CAP, while the sub-systems PBC and LS are outside the scope of our current study.

system and show how a public bad governance system both affects and is indirectly affected by interactions and resulting outcomes happening at a particular time and within a particular context.

Each of the case studies investigated or introduced an intervention that was oriented to enhancing connectivity and changing the communicative dynamics in the SES. These so-called "connective interventions" were case-specific and ranged from face-to-face and phone-based communication to social media type platforms for learning and exchange, to the set-up of systems to monitor farms and/or disease vectors, and citizen science initiatives. In this setting, the overall research question for our explorative analysis was:

> *Under what conditions can connective interventions change the logic and boundaries of collective action and decision-making to address public bads?*

Following this research question and our operationalization of the theoretical framework to the respective case studies, two specific research questions were identified that match with sub-systems RGS, CI, and CAP-C in the framework:

- [CI to RGS] How do connective interventions influence changes in the existing risk governance system?
- [RGS to CAP] How do such changes in the RGS contribute to managing collective action problems [faced by the direct users of the livelihood unit [LU] in a public-bad risk context [PBC]]?

Where,

CI [Connective interventions], is the intervention that was introduced or studied by the EVOCA researcher(s). These interventions included forms of participatory monitoring and surveillance, citizen science, learning interventions, and provision of digital (social media) platforms for mutual exchange of information (see also Table 5 further below for case-specific details).

RGS [risk governance system], is an adaptation of Ostrom's (1990; cited in Ostrom, 2005) design principles for governing sustainable resources as summarized in Table 1 (Ostrom, 1990 in Ostrom, 2005, p. 259). When these principles are present and operationalized in the RGS, communities are more likely to be able to manage public-bad problems in SES.

Table 1. Public-bad governance design principles, adapted from Ostrom (1990; cited in Ostrom, 2005). Principles 4, 5, 6, and 7, marked with (*), are equal to Ostrom's original definition. All other principles were adapted to represent governance of a public bad.

Design principles for governing sustainable resources	Design principle definition for public-bad governance
(1) Clearly defined boundaries	The boundaries of the public bad (e.g. crop diseases) and the individuals or households threatened by it are clearly defined.
(2) Proportional equivalence between benefits and costs	The rules specifying the desired actions by users for preventing and controlling a public-bad threat are related to local conditions and to rules requiring labour, materials, and/or financial inputs.
(3) Collective-choice arrangements	Many of the individuals affected by the public-bad management rules are included in the group who can modify these rules.
(4) Monitoring (*)	Monitors, who actively audit biophysical conditions and user behaviour, are at least partially accountable to the users and/or are the users themselves.
(5) Graduated sanctions (*)	Users who violate rules-in-use are likely to receive graduated sanctions (depending on the seriousness and context of the offence) from other users, from officials accountable to these users, or from both.
(6) Conflict-resolution mechanisms (*)	Users and their officials have easy access to low-cost local arenas to resolve conflict among users or between users and officials.
(7) Minimal recognition of rights to organize	The rights of users to devise their own institutions are not challenged by external governmental authorities, and users have long-term agency rights to self-organize to prevent and control public-bad threats.
(8) Nested enterprises (*)	For public bads that are a threat for larger systems (e.g. transboundary diseases): Problem definition, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

CAP [collective action problems among direct users of the livelihood unit under focus] are analysed as coordination problems caused by social dilemmas (where there is a tension between self-interested choices and cooperative choices), lack of capacity to cope or respond, and poor recognition of the public-bad problem [risk] (Table 2).

Table 2. Factors hindering coordination among direct users.

Factor	Definition
Social dilemmas	A situation where two or more individuals would be better off if all cooperate, but fail to do so because of self-seeking choices that benefit them individually (Dawes et al., 1988).
Coping capacity	This is determined by limitations in terms of access to, and mobilization of, the resources of a community or a social-ecological system to respond (lessen potential damage, take advantage of opportunities, or cope with the consequences) to an identified hazard, including pre-event, in-time, and post-event response measures (Birkmann et al., 2013; Turner et al., 2003)
Risk perception	Risk perceptions are formed by common-sense reasoning, trust, personal experiences, social communication, and cultural traditions. These are the contextual aspects that individuals consider when deciding whether or not to take a risk, and selecting reduction or prevention measures (Siegrist, 2021; Van Asselt & Renn, 2011; Wachinger et al., 2013).

PBC [public-bad risk context], is determined by vulnerability conditions and characteristics of the hazard that hinders or limits the probability of a public bad (pressure and release model, see Wisner et al., 1994) (Table 3),

Table 3. Components to describe and analyse the public-bad risk context.

Component	Definition
Public bad	The non-excludability and non-rivalry of a public bad is not necessarily the threat itself, which lies in the various direct and indirect potential socio-ecological consequences from its mismanagement (Galarza-Villamar et al., 2021).
Risk	The probability of harmful consequences or losses (physical, social, economic, environmental, cultural, or institutional) resulting from interactions between hazard and vulnerable conditions, in a given area and over a period of time (Birkmann et al., 2013; Thywissen, 2006; UNISDR, 2009).
Hazard/ Hazard potential	A physical event, phenomenon, or human activity that has potential to cause loss of life or injuries, property damage, social and economic disruption, or environmental degradation. Its hazard potential is characterized by its probability (frequency) and intensity (magnitude or severity) (Wisner et al., 1994).
Vulnerability	Vulnerability (of any system) is a function of three elements: exposure to hazard, sensitivity to that hazard, and the capacity of the system to cope, adapt, or recover from the effect of those conditions (Smit & Wandel, 2006).
Exposure	The extent to which a unit of assessment (including its physical and human attributes that are spatially bound to resources and practices that may also be exposed) falls within the geographical range of a hazard event (Birkmann et al., 2013; Turner et al., 2003).
Sensitivity/ Susceptibility	The predisposition of at-risk elements (social and ecological) to suffer harm or modifications (directly or indirectly) by a disturbance (Birkmann et al., 2013; Brooks, 2003; Reed et al., 2013).
Coping capacity/ Societal response capacity	Access to, and mobilization of, the resources of a community or a social-ecological system to respond (lessen potential damage, take advantage of opportunities, or cope with the consequences) to an identified hazard, including pre-event, in-time, and post-event response measures (Birkmann et al., 2013; Turner et al., 2003).

3. Materials and methods

3.1. The cases

We analysed six case studies involving 11 PhD projects in Rwanda, Ghana, Ethiopia, and Kenya (Tables 4 and 5). The case studies have in common that (i) the public-bad problem occurs in a socio-ecological system context, (ii) the interventions had plausible relevance for improving the position of vulnerable groups, (iii) they included an existing or newly introduced connective intervention geared towards fostering collective action that could be studied, and (iv) five out of six cases related to infectious diseases.

Table 4. EVOCA case studies included in the study.

Case study	Doctoral thesis	Leading scientific disciplines
Ticks and tick-borne diseases in Kenya	Connecting divergent worlds: Social and ecological factors influence tick-borne diseases in tropical drylands (Chepkwony, 2021) Tick-borne diseases and livestock-wildlife management in Kenya (Mutavi et al., 2018, 2021).	Communication science; wildlife ecology and conservation
Climate variability in Ghana	Towards a new generation of climate information systems: Information systems and actionable knowledge creation for adaptive decision-making in rice farming systems in Ghana (Nyamekye, 2020). Best of both worlds: Co-producing climate services that integrate scientific and indigenous weather and seasonal climate forecast for water management and food production in Ghana (Nyadzi, 2020).	Earth systems science; public administration and governance; water management
Fall Armyworm in Maize in Ghana	Digitalization of smallholder value chain lending partnerships: An interplay of trust and inclusion (Agyekumhene, 2021). Innovation intermediation in a digital age: Broadening extension service delivery in Ghana (Munthali, 2021).	Communication science; innovation studies; geo-information sciences
Malaria in Rwanda	Citizen science for malaria control in Rwanda: Engagement, motivation, and behaviour change (Asingizwe, 2020). Citizen science for malaria vector surveillance in Rwanda (Murindahabi, 2020).	Communication science; social psychology; entomology; biology
Potato diseases in Ethiopia	Understanding and managing bacterial wilt and late blight of potato in Ethiopia: Combining an innovation systems approach and a collective action perspective (Tafesse, 2020). Social-institutional problem dimensions of late blight and bacterial wilt of potato in Ethiopia: The contribution of social learning and communicative interventions to collective action (Damtew, 2020).	Agronomy/crop ecology; Innovation studies; Development studies; game theory/institutional economics
Banana disease in Rwanda	More than what meets the eye: Factors and processes that shape the design and use of digital agricultural advisory and decision support in Africa (McCampell, 2021).	Innovation studies; crop ecology; game theory; institutional economics

3.2. Methods of data collection

Our approach consisted of collecting and analysing qualitative data through the review of ten published PhD dissertations[4] and peer-reviewed papers (e.g. from a postdoc project e.g. Cieslik et al., 2021), two workshops, and focus group sessions with EVOCA researchers. The latter followed a semi-structured

[4]The dissertation of the 11th PhD project was not yet published when conducting this study, hence we relied on the analysis of individual peer-reviewed papers and interactions with the researcher for this case.

Table 5. Placing selected case studies in a public-bad risk and SES context.

Case study	Livelihood units	Public-bad risk conditions (vulnerability and hazards)			Fatality/Losses	Users risk management	Connective strategy (studied in project sample)
		Public bad	Causal agent	Mechanism of spread			
Ticks and tick-borne diseases in Kenya	Cattle (meat, milk as food or income)	Tick-borne diseases	Different ecto-parasites, bacteria, and protozoans	Different kinds of ticks spread the diseases	Mortality rate of up to 80% in animals susceptible to ECF	Vaccination, acaricides, grass height reduction, resistant breeds, etc.	Mixed communication mechanisms to diagnose/understand/exchange knowledge.
Climate variability in Ghana	Crop production (food and income)	Climate uncertainty and variability	N/A	N/A	Yield losses due to water mismanagement, untimed agricultural decision-making	Indigenous knowledge in weather forecasting. Scientific weather forecasting.	Second-generation climate information system that integrates indigenous and scientific knowledge.
Fall Armyworm in Maize in Ghana	Maize (food and income)	Limited access to production inputs	Insect Fall Armyworm	It produces many eggs, and it can migrate over long distances	Yield losses of 20% to 50%.	Chemical spray	Farm monitoring platform. Self-organized WhatsApp groups.
Malaria control and prevention in Rwanda	A person (labour, knowledge, etc.)	Malaria	Plasmodium parasite	Transmitted through the bite of the infected *Anopheles* mosquito	Over 60 deaths per 1000 cases of children aged <5 years	Removing standing water, spraying insecticide, use of bed nets	Mosquito surveillance programme through citizen science. Information sharing with [non-] volunteers.
Potato diseases in Ethiopia	Potato (ware and seed)	Potato late blight disease	Oomycete *Phytophthora infestans*	Air-borne spores	Yield losses up to 100%	Chemical spray	Face-to-face learning interventions combined with experiential and social learning approaches, and a social media type. Messaging platform.
		Bacterial wilt disease	Bacterium *Ralstonia solanacearum*	Soil-borne, seed-borne, and water-borne	Yield losses up to 100%	Roguing of diseased plants	
Banana disease in Rwanda	Banana (as food or income)	Banana Xanthomonas Wilt (BXW)	Bacterium *Xanthomonas vasicola* pv. *Musacearum*	Infected plant material, cutting tools, long-distance trade, soil, and vectors	Yield losses up to 100% if control is delayed	Male bud removal, tool sterilization, diseased mat uprooting, etc.	Smartphone application to diagnose, register, monitor, and exchange information about BXW.

format, with questions that were designed to explore each element of the adapted SES framework (as outlined in Tables 1, 2, 3 and 5).

3.2.1. Identification of SES framework elements in each case study

We did an explorative quantitative content review of the published dissertations and articles, performing a term frequency calculation to evaluate if the adapted SES framework was suitable for our analysis. We used the software QDA MINER LITEV2.0.8 to code the qualitative data, using pre-determined terms based on main subsystems in the theoretical framework and the principles, components and factors included in those subsystems (e.g. [vulnerability], [threat], [collective action], [perception], [risk], among others (Tables 1–3). The explorative review indicated that all analysed dissertations and affiliated peer-reviewed papers included terms such as [livelihoods], [information], [disease], [management], [system] and [control], with a total frequency above 1000 times. Other terms that link these publications to the SES framework are [decisions], [practices], [predict] and [monitoring]. All these terms relate to strategies to manage a public bad (i.e. the risk governance system), which were in five cases related to diseases. We also found several terms related to collective action problems, such as [trust], [perception], [communication], [participatory], [citizen science], and [learning] (see Figure 2).

Subsequently, we organized the first workshop with EVOCA researchers to discuss the results of the explorative review, and conducted a hands-on exercise where the researchers applied the SES adapted framework to their specific case study themselves. The workshop sessions took place online and served to familiarize the researchers with the framework and to create a basis for in-depth follow-up group discussions. All researchers joined the workshop introduction and provided feedback on the explorative review. The results of the explorative review combined with the outcomes of the first workshop gave us sufficient confidence that the cases selected could be analysed using an adapted version of the SES framework.

3.2.2. In-depth operationalization of theoretical framework per case study

We conducted two focus group sessions with experts from each case study to apply the SES framework. Each session lasted 2 hours and was focused on reconstructing the public-bad context, risk governance system, and collective action problems prior to the connective intervention. Then, we organized another workshop of 2 hours per case study to analyse how the interventions influenced different subsystems of the SES framework. Finally, we organized a discussion and a feedback process that included several EVOCA researchers and project experts.

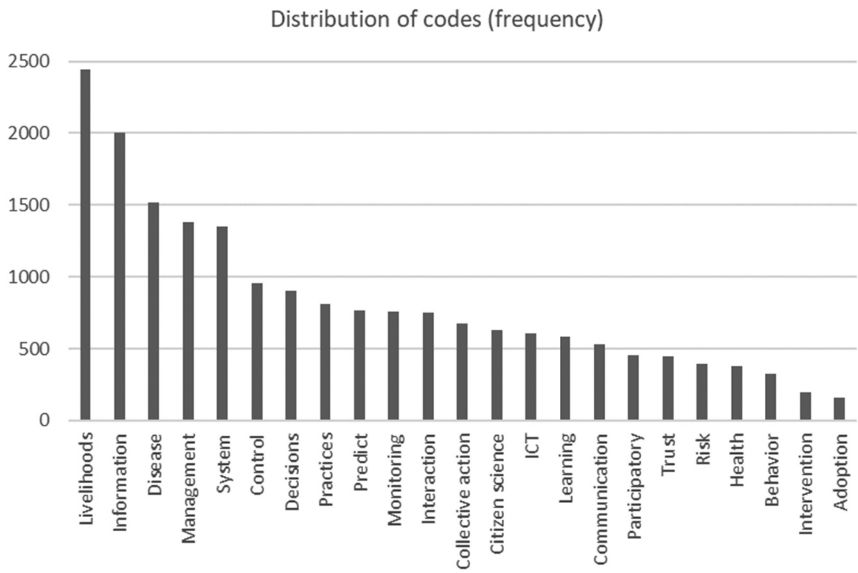

Figure 2. Initial analysis of terms used in EVOCA case studies that align with the adapted SES framework to public bads. Results based on the exploratory coding of eight dissertations and three scientific articles. Two additional dissertations and newly published papers were added to the study at a later point in time.

3.3. *Methods of data analysis*

All cases have been systematically described and analysed according to the framework presented in Figure 1. Interviews were video-recorded and transcribed using Microsoft Teams. Transcriptions were coded and analysed using the variables of each sub-framework. Annex 1 provides an overview of the workshop guidelines and forms used as part of our methodology.

4. Results

In the following sections we present the results from each case study. For each case we first describe the public bad and collective action problem in terms of the SES framework and zoom in on the livelihood units that are at risk. We then assess the existing risk governance system and challenges faced by direct users. After that we discuss how the connective interventions studied influenced the risk governance system, followed by how this influence contributed (or not) to managing the collective action problem.

4.1. Tick-borne diseases and livestock-wildlife management in Kenya

4.1.1. Description of the public-bad and collective action problem

The SES in this case study has animal husbandry as the main livelihood, involving three different land-use practices in Laikipia County, Kenya: mixed agriculture, pastoral grazing, and wildlife conservation. The livelihood unit of interest is cattle, as a provisional service (meat and milk) and as a cultural service (owning many cattle tends to foster respect and social status in the community). Ticks and tick-borne diseases (TTBDs) constitute a risk (a threat) to those whose livelihoods rely on livestock from a human health, food security, and a cultural wellbeing perspective. The incidence of TTBDs in the human-wildlife interface further harms the relationships between livestock owners and conservationists as conservation areas tend to be a critical source of tick infestation to livestock owners' cattle. Therefore, how livestock owners collectively use grazing grounds and individually manage ticks has consequences for all farmers, and TTBDs thus represent a public-bad risk (Figure 3). Current tick management practices are associated with several negative outcomes, including acaricides use malpractices that pose health risks to humans, contamination of water bodies, and tick acaricide resistance.

4.1.2. The existing risk governance system and challenges faced by direct users

The economic inequality among livestock owners, and limited access to pasture and water, are the greatest vulnerability factors for TTBDs control. There is a clear disparity among commercial and small-scale farmers' control of TTBDs, shaped by differential access to information and acaricide application equipment and technique. While pastoral farmers use knapsacks and hand sprayers, which are more affordable but less precise, commercial farmers use more expensive, effective mechanized races. Few extension officers provide advice on appropriate use of acaricides, and they are poorly equipped for that task. Pastoral farmers are more exposed to TTBDs than commercial farmers due to their inconsistency in acaricide treatments, and limited access to pasture that predisposes them to less nutritious and highly tick infested pastures in wildlife inhabited lands. Pastoral farmers need to either compete for "common" grassland or graze their cattle in wildlife conservation areas with high tick infestation, which increases TTBDs risk. Some farmers graze their cattle in leased, tick infested, lands offered by opportunistic commercial farmers. This practice is more common during prolonged dry spells.

Most pastoralists are aware that ticks lead to diseases and livestock mortalities, loss of productivity and poor skin health (Chepkwony et al., 2018). However, they rarely acknowledge or perceive these challenges as a threat to their survival, and often ignore these threats. Consequently, people tend to

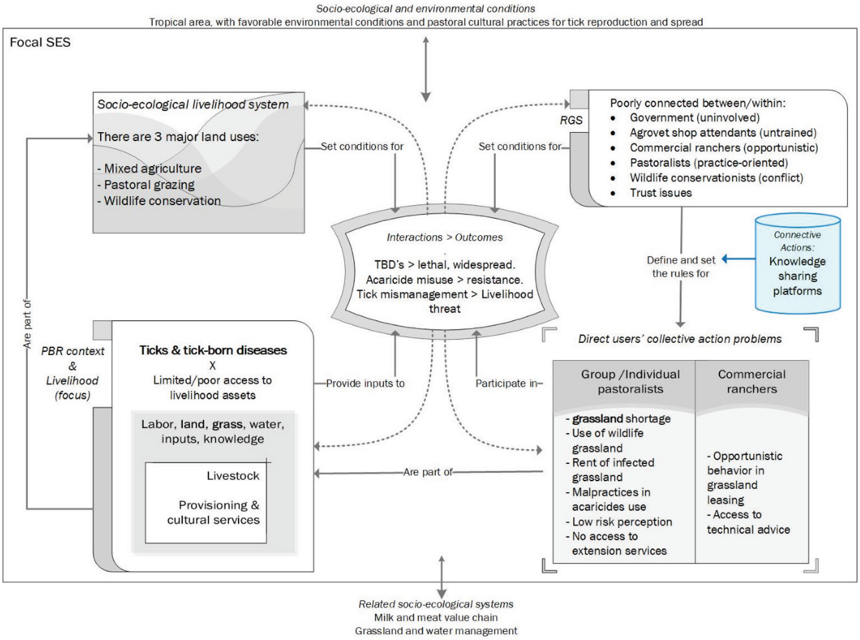

Figure 3. Tick-borne diseases and livestock-wildlife management in Kenya described using the adapted SES framework.

not perceive TTBDs as a collective problem, reducing their motivation to engage in collective TTBDs management. Identification and characterization of ticks is critical to define the risk boundaries of TTBDs, which in turn is essential to defining control strategies. Therefore, local knowledge and skills are valuable assets. Mutavi et al. (2018) found that ranchers, livestock, and wildlife managers could identify and differentiate the different types of ticks and the various stages of their lifecycle, however they could not associate the different tick species with the tickborne diseases they transmitted. Besides, Farmers are not aware of the correct use of acaricides, leading to use over-doses and underdoses while diluting acaricides, admixing with crop pesticides and insecticides, compromising their efficacy. This explains their reluctance to follow strict acaricide application regimes for TTBDs control. Consequently, malpractices with acaricide use lead to quickly evolving acaricide resistance (reducing TTBDs management options and increasing the cost) (Mutavi et al., 2018). Pastoralists mix acaricides, pesticides, fungicides, herbicides, and insecticides to increase (perceived) effectiveness. Contrary to their beliefs, such practices are detrimental to human and animal health, and the environment (Chepkwony, 2021).

The current governance system to manage the TTBDs spread is mostly disjointed among key actors. Responsible public agencies and

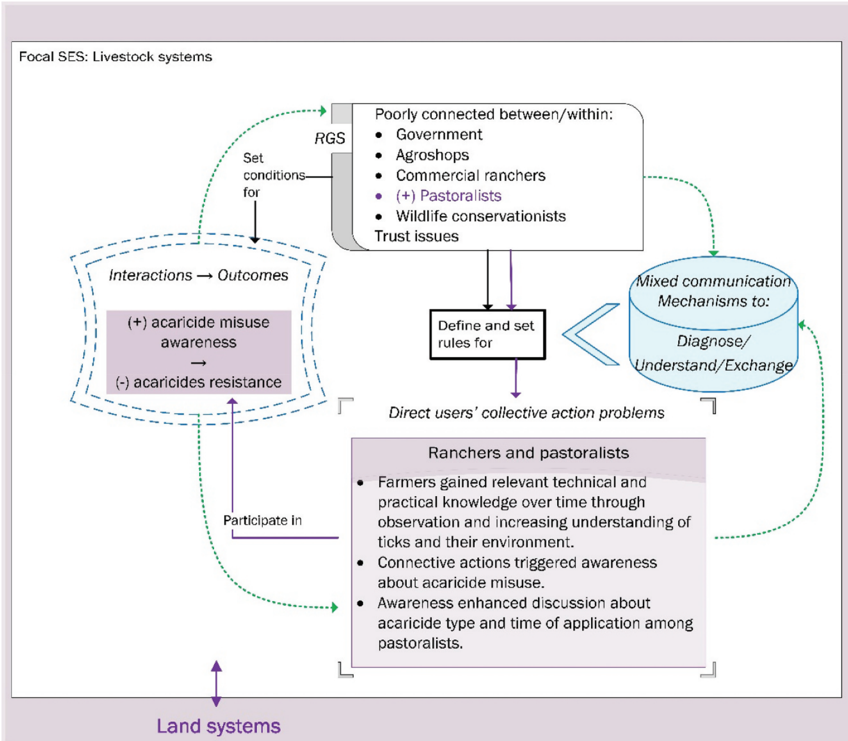

Figure 4. Connective strategies studied in the context of tick-borne diseases in Kenya's case study.

infrastructure, such as cattle dips and extension services, collapsed since 1991 (Mutavi et al., 2021). Nowadays, pastoralists rely on their understanding of the environment and acquired peer knowledge to deal with ticks. There is a poor relationship between pastoralists and the government veterinary officials, often characterized by mistrust. In private conservancies and government ranches, wildlife is either managed in isolation (fenced off) or under an integrated approach (conservation of wildlife in combination with rotational grazing). Private ranches apply pasture management regimes as advised by ecological ranch managers, and tick control practices are executed regularly by trained livestock management staff. Government ranches, though few, host both wildlife and livestock, but are often invaded by pastoral farmers during the dry season because they treat government property as a "reserve"' to cushion them from the uncertainty stemming from changing environmental conditions.

Government ranches apply a less elaborate pasture management system. In community grazing areas, pastoral farmers practise both wildlife and livestock management, following practices (grazing, conservation, and human settlement) delineated by the council of elders, who lead the management committees. During the wet seasons, pastoralists graze their cattle close to home. During the dry seasons they move livestock over large distances, often trespassing other community, private, and government lands. Such transhumance management of livestock often results in intra- or inter-communal conflicts. Communal conflicts negatively impact collaborative efforts, including information or knowledge sharing. Collaborative efforts between community grazing committees and ranchers have allowed some pastoralists access rights during dry seasons, an investment in pasture rehabilitation. However, such investments only pay off if there is no prolonged drought and invasion from pastoralists from neighbouring counties.

4.1.3. The intervention and its effect on the risk governance system and direct users

The increasing dependency of livestock keepers on practical knowledge to tackle emerging issues regarding tick control is creating the conditions (acaricide resistance) that make it more challenging to define the risk boundaries of TBDs. Therefore, Mutavi et al. (2021) recommend mapping the status of tick resistance and identifying connective strategies (Figure 4) to bridge the technical tick information gap: A *"system that monitors treatment failure and conducts lab surveillance, with a joint platform to facilitate discussions between veterinary officers, agrovets, and livestock owners on best treatment practices over time in each region/zone*".

In terms of cost-benefit equivalence, knowledge-sharing platforms can enhance good practices at the direct users' level to prevent socio-economic losses from the risk of acaricide resistance (Chepkwony, 2021; Mutavi et al., 2021). People were not very enthusiastic about using mobile phones to monitor ticks. However, a combination of radio, face-to-face meetings, and other audio-visual tools enhanced connectivity. In a workshop session, Mutavi recalled that:

> Farmers thought something was wrong with the acaricides. We sent samples to the laboratory and showed them that the product was fine but not its application [and] that promotes resistance [. . .]. Pastoralists were shocked to realise that mixing acaricides with pesticides produces weaker tick control.

Mutavi and Chepkwony agreed that connective strategies are essential to facilitate collective choice arrangements. For example, to reach collective agreement on what type and doses of acaricide to apply in shared grazing areas, there is a profound need for actors to collectively evaluate the results together and calibrate agreements when needed. However, the impact of such connective interventions on collective action is likely limited. Other pressing issues (such as (in)security in the area, cattle rustling, human-wildlife conflicts, and the spread of other notifiable zoonotic diseases such as foot and mouth disease (FMD), rabies or brucellosis undermine risk perception on TTBDs (and consequently willingness to engage in disease prevention) and detriment the capacity to cope with the consequences of TTBDs.

Chepkwony asserted that single connective strategies in TTBDs control are insufficient. TTBDs are not an isolated collective-action problem. The two most significant factors influencing TTBDs management are land management (bio-physical) and animal body conditions (host vulnerability state). Land management is critical for TTBDs, because it impacts the availability of pasture and water, and therefore the movement of livestock, especially during the dry season. Therefore, land management is the core collective action problem in the SES and management mechanisms create or hinder the socio-ecological conditions for farmers to manage TTBDs (Chepkwony, 2021).

4.1.4. Lessons from this case

Mutavi's and Chepkwony's diagnosis of TTBD as a public bad and their assessment of the potential benefit of connective strategies to manage suggests that the management of complex problems requires interventions beyond connectivity. On the one hand, TTBDs management relates to the governance principle of nested sub-systems (see Table 1), as it is part of a broader system that involves the entire landscape (water and land use and distribution, cultural practices, etc.). On the other hand, the availability of resources to manage TTBDs is co-dependent on strategies to deal with complex and urgent issues in water and land distribution and use, which are critical resources conditioning good TTBDs management practices.

4.2. Water monitoring and irrigation management for food production in Ghana

4.2.1. Description of the public-bad and collective action problem

Nyamekye's and Nyadzi's case study focuses on farming systems in Northern Ghana, particularly the relationship between rice production and water management in the face of climate change and variability. Their study considers three different groups of rice farmers: those engaging in irrigated or rainfed production, and those using a combination of both. Most farmers do not have access to irrigation systems. Rice is central as a livelihood income source, although farmers have multiple in-farm (poultry and other crops) and off-farm activities. Climate change and variability threaten both rainfed and irrigated rice producers. Rice farmers depend on seasonal weather and climate information for agricultural decision-making, such as seed selection and scheduling of planting, fertilization, irrigation and harvesting (Nyadzi, 2020; Nyadzi et al., 2018; Nyamekye, 2020; Nyamekye et al., 2018).

From a SES perspective, we frame the capacity to resolve the poor availability of appropriate predictions of seasonal rains and water availability as a collective action problem. Sub-optimal predictions hinder community coping capacity and resilience (weakening crops and food systems), aggravate social dilemmas around irrigation and water management, and shape stakeholders' perception of risk around critical farming decisions (when, where, and how to act). This in turn influences productivity and water availability at the individual and collective level. Water scarcity (resulting from weather uncertainty and farming decisions) can be regarded a public bad (Figure 5).

4.2.2. The existing risk governance system and challenges faced by direct users

Farmers producing rainfed crops follow traditional governance arrangements. For example, they must consult the community chiefs about land and water use. In periods of rainwater scarcity these farmers explore alternatives such as using small water pumps to discharge water from tributaries of the Bontansi River onto their farmlands (Nyadzi, 2020, p. 163). At the Bontanga irrigation scheme, the manager engages other stakeholders to agree on schedules for discharging water through canals onto farmlands. Changes in water levels in the Bontanga dam reservoir and increasingly erratic rainfall patterns have increased the vulnerability of farmers, regardless if they produce irrigated or rainfed crops Climate forecasts can help farmers reduce their vulnerability to drought and extreme weather conditions while allowing them to maximize opportunities whenever favourable conditions are predicted (Nyadzi, 2020, p. 48).

There are two sources of weather forecasting to cope with climate uncertainty: indigenous and scientific ones. Indigenous Forecasting (IF) techniques are based on observations regarding (changes in) indigenous ecological indicators (IEIs) deemed relevant to making weather and seasonal climate forecasts. Scientific forecasts are based on intensive data collection and quantitative and predictive modelling approaches. Nyadzi et al. (2021) found that farmers use both. They find their own IF mostly reliable to predict daily events even though IEIs are not clear enough for long-term predictions. However, farmers report difficulties with applying IF due to environmental changes (Nyadzi, 2020, p. 119).

4.2.3. The intervention and its effect on the risk governance system and direct users

Climate accuracy relies upon multiple factors, and knowledge production is one of the pillars (Nyadzi, 2020, p. 175; Nyamekye, 2020, p. 63). Nyamekye and Nyadzi explored farmers' and scientists' knowledge, skills, and techniques to forecast the weather as a critical asset to inform rice cropping decision-making through a co-produced connective

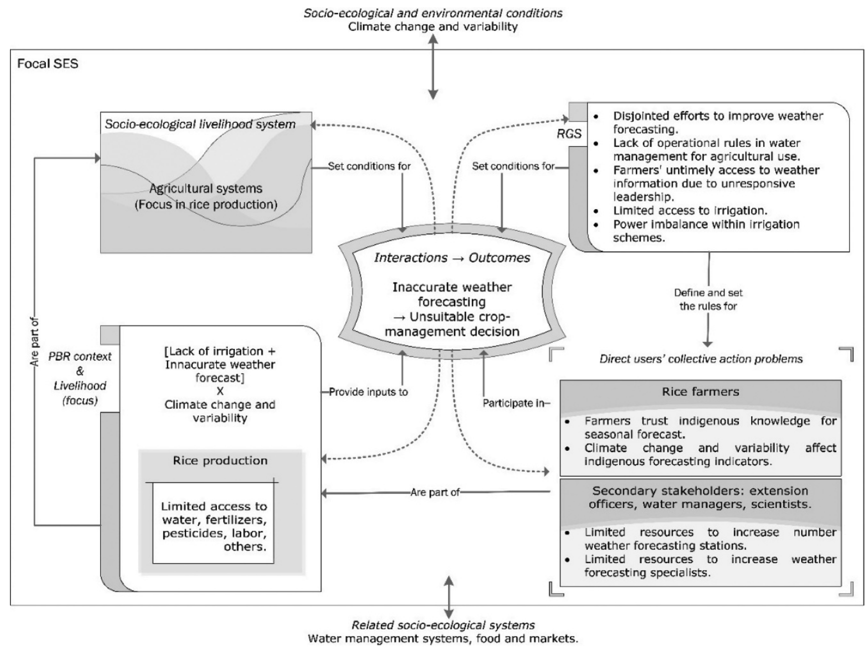

Figure 5. Water monitoring and irrigation management for food production in Ghana described using the adapted SES framework.

intervention. The connective intervention was a second-generation climate information system (Figure 6). It combined both indigenous and scientific forecasts (labelled "integrated probability forecasting" (IPF) for actionable decision-making. The IPF method was developed, and its reliability and acceptability were assessed. The IPF system leveraged a virtual platform for information exchange, collecting data from farmers, and sharing forecast information. Farmers and scientists co-defined the problem and co-created the integrated solution collectively while respecting each other's bodies of knowledge, norms and values (Nyadzi, 2020; Nyadzi et al., 2021).

4.2.4. Lessons from this case

Nyadzi's study shows that it is possible to integrate indigenous and scientific forecasts into reliable forecast information that adds value to each individual forecast (Nyadzi, 2020, Nyadzi et al., 2021). Integrating local and scientific knowledge, data, and practices (into Integrated Probability Forecasts) improved credibility, legitimacy, cognition, and familiarity, and enhanced the adoption of climate services. Communication about weather and climate uncertainties improved farmers' confidence in them, and this trust appeared

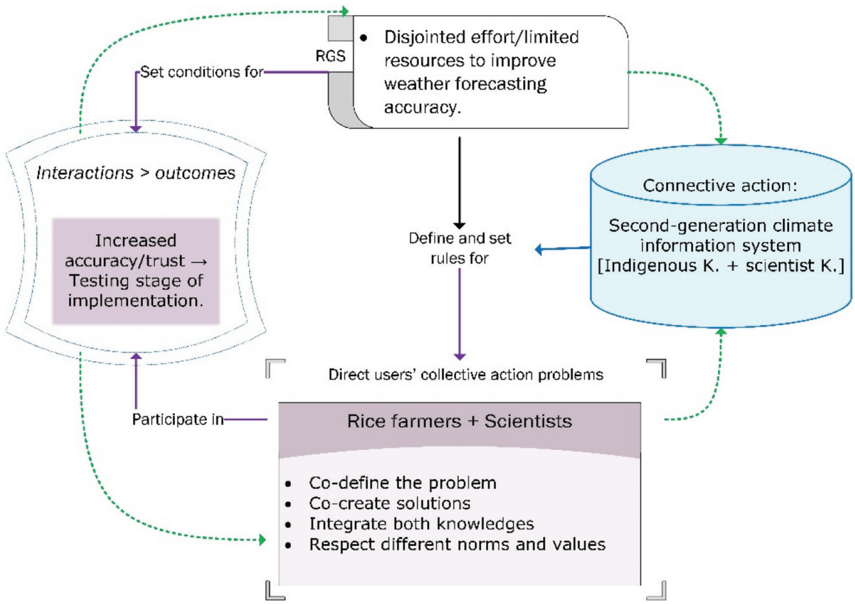

Figure 6. Connective interventions studied in the context of weather forecasting in Kenya's case study.

a significant determinant for adoption of IPF (together with proven reliability of the forecast for decision-making and risk reduction).

Nyamekye's (2020) work furthermore shows that farmers do not interact with just one information system, and that community members need to be engaged in the creation of actionable knowledge. Diverse information systems [e.g. community radio, farmer-to-farmer knowledge exchange, commercial radio, and mobile-based-only platforms] can be synergetic (p.155). In summary, the weather forecasting case shows that integrating indigenous and scientific knowledge in the co-production of climate services [connective intervention] contributes to better risk governance to climate variability. In terms of proportional equivalence between benefits and costs, co-creating climate services with direct users and including indigenous knowledge increases uptake. Furthermore, openness, and transparency during the IPF design process and communication about forecast uncertainties (probabilities of weather event occurrence) increases trust in the service and enables collective-choice arrangements (between farmers as end-users and indigenous and scientific forecasters). These changes in the risk governance system can change farmers' risk perception about weather uncertainty and variability, while the availability of more accurate forecasting allows them to better adapt farm decision-making to climate conditions, thereby decreasing their vulnerability.

4.3. Fall armyworm in maize in Ghana

4.3.1. Description of the public-bad and collective action problem

Munthali and Agyekumhene explored the role of several phone-mediated connective interventions in collective action arrangements in Ghana's maize farming system. Their studies focus on the public-bad problem of fall army-worm in maize, and they approach it from the perspective of different stakeholders. Maize is a critical food crop in Ghana but has a suboptimal productivity of 2 t/ha while the estimated potential yield is 5 t/ha. Reasons for low productivity are environmental and biological threats, but also disabling socio-economic and institutional conditions (Figure 7). The fall armyworm pest, *Spodoptera frugiperda*, was first identified in Ghana in 2016. Fall army-worm isis native to the Americas, but due to intra-continental transportation links and climate change it has fast invaded and spread through Africa (Agyekumhene, 2021; Agyekumhene et al., 2018; Munthali, 2021; Munthali et al., 2018). Within two years, fall armyworm spread throughout sub-Saharan Africa, causing losses of 20–50% in maize yields. Therefore, fall armyworm is a significant threat to people's livelihoods and food security (Early et al., 2018; Prasanna & Renard, 2018).

4.3.2. The existing risk governance system and challenges faced by direct users

The existing risk governance system lacked early warning and timely pest monitoring strategies and was characterized by a slow response and top-down problem-solving approaches. There were limited resources and knowledge exchange opportunities between farmers, extension agents, applied researchers, and other value chain actors, limiting the formulation of appropriate management strategies. As a result, farmers had untimely access to information, knowledge, inputs, and credit to cope with the new pest, and faced significant crop losses.

Munthali found that neither farmers nor extension agents recognized the new pest when it emerged. Farmers' awareness of the pest infestation was limited, leading to underreporting and limited control efforts. Meanwhile, officials in the extension system required certain pest occurrence thresholds to be reached in an area (size of fields infested and damaged) before considering fall armyworm an economic threat. Extensionists did initially not recognize it as a new pest either. Once they did, there were no mechanisms in place that would allow extensionists to collaborate with researchers and vice versa. Reports outside the official reporting channels were mistrusted or not taken seriously by those higher up in the organisational hierarchy,

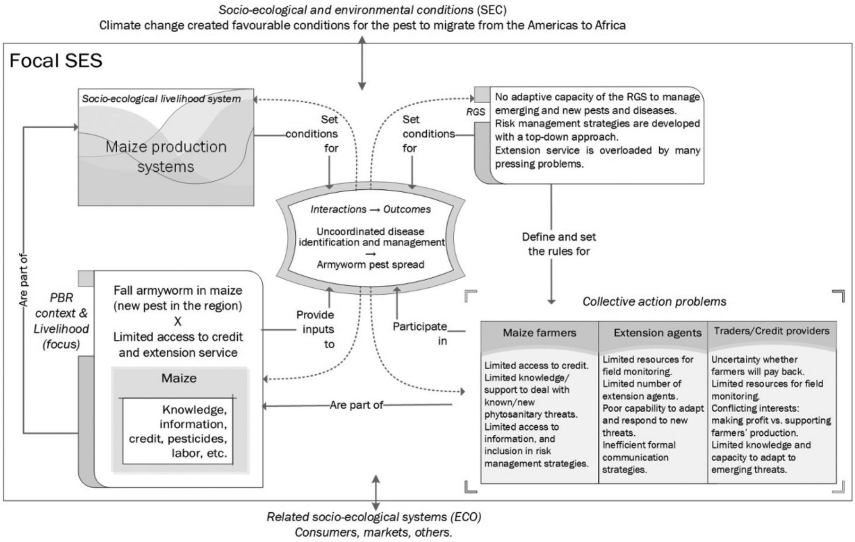

Figure 7. Fall armyworm in maize in Ghana described using the adapted SES framework.

reinforcing the poor availability of resources for farmers, extension agents, and researchers to engage in joint-knowledge sharing and problem-solving efforts (Munthali et al., 2021). In the absence of formal and credible information sources, farmers experienced difficulties with selecting appropriate management options from the multitude of unvetted solutions that circulated in their networks.

Simultaneously, Agyekumhene asserts that poor access to credit hindered farmers in acquiring assets and inputs that could decrease their vulnerability. Investors, traders, insurance companies and others perceived farmers as a high-risk investment, which prevented farmers from engaging in lending agreements. Munthali and Agyekumhene ascertained that stakeholders did not recognize their mutual interdependence, the collective dimensions of the fall armyworm problem, and the need for joint problem-solving.

4.3.3. The interventions and their effect on the risk governance system and direct users

Munthali and Agyekumhene argued that appropriate control of fall armyworm (for which true solutions were unknown at the time of research) required enhanced connectivity to facilitate timely and location-specific (co) creation of new knowledge. The connective interventions studied by Munthali included two social media platforms (one using WhatsApp and one using Telegram) that facilitated information sharing and interaction between researchers and extension staff, and played a role in finding, sharing, and implementing effective responses to fall armyworm (Munthali et al., 2021). Munthali found that the social-media platforms indeed served as a space to connect researchers and extension agents with different knowledge and resources, and that interactions on the platforms served to enhance inter-organisational detection and monitoring of fall armyworm as well as sharing of experiential and science-based knowledge. This helped considerably in developing and disseminating strategies for pest and disease control, and in identifying knowledge gaps relevant to further collaborative problem-solving. However, open communication on social media platforms are constrained by social hierarchies, and platforms cannot usefully operate in isolation from other modes of communication (which corresponds with the findings in our previous case) (Munthali, 2021; Munthali et al., 2021); Figure 8).

Agyekumhene on the other hand, co-designed a (phone-mediated) communication platform to improve trust in lending partnership arrangements with farmers. The main goal of the platform was to make credit provision more inclusive, and thereby enhance farmers' capacity to cope with new threats, such as the timely purchase of pesticides to control fall armyworm. The platform was co-created with stakeholders (e.g. traders, credit providers, and extension agents) and served to exchange digital images. These images became boundary objects for collaborating value chain actors (Agyekumhene et al., 2018, 2020). Those providing credit for pesticides and other inputs demanded assurance that farmers were able to pay back loans and wanted to have insight into farmers' practices and performance. Previously, those credit providers would ask input- and extension service agents to regularly monitor a farmer's fields and register farm(er) data to assess credit worthiness. This system was labour intensive and therefore costly. The assumption was that credit checks could become more cost-effective if farmers sent pictures of their fields and crops to prove that they followed good agricultural practices and to monitor crop development and post-harvest activities. Agyekumhene found that input providers and money lenders could indeed derive information from farm-level images. This helped with assessing farmers' attitudes towards farming and input-use and estimating farm productivity, and served to increase trust in lending arrangements.

4.3.4. Lessons from this case

The fall armyworm case shows that farm imagery was an effective way to ensure farmer accountability and transparency to financers. According to Agyekumhene et al. (2020)this could reduce the risks of defaulting farmers, enhance smallholders' access to credit and inputs, and increase the willingness of credit providers to restructure loans when farmers are confronted with challenges (e.g. low rainfall or disease outbreaks) that result in (partial) crop failure. However, tensions could arise around the fair interpretation and evaluation of pictures since reasons for sub-

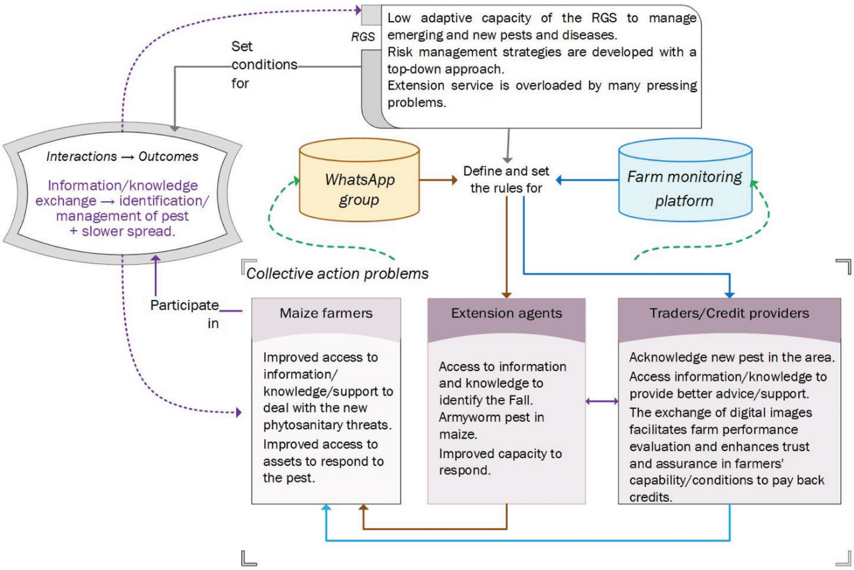

Figure 8. Connective interventions to address Fall armyworm in maize in Ghana described using the adapted SES framework.

optimal performance could often not be determined based on the pictures.

This case study suggests that digital platforms and technologies can be integrated in the co-design of innovative institutional arrangements for addressing challenges such as fall armyworm. In SES terms, such technologies and platforms can contribute to (1) defining the public-bad risk boundaries, (2) securing balance in the distribution of cost and benefits, (3) offering space for collective choice arrangements and accountability, and (4) providing a more accurate perception of risk among different stakeholders across the value chain.

4.4. Control and prevention of malaria: The mosquito radar in Rwanda

4.4.1. Description of the public-bad and collective action problem

The research conducted by Murindahabi and Asingizwe in Rwanda focuses on human capital from a citizen science perspective (Asingizwe, 2020; Asingizwe et al., 2018, 2019; Murindahabi, 2020; Murindahabi et al., 2018). Malaria has a significant impact on the economy and household welfare. In the study area, households commonly rely on farming for their income. Malaria infections among household members, whether it is the principal provider or another member, disrupts farming and other labour activities for several days as the household needs to seek and provide medical care. It may take up to one month for a person to recover from malaria and fully resume work activities, long enough to affect household wealth significantly and make malaria a public bad (Figure 9). Disruptions in seasonal activities like rice farming have productivity and food security consequences. Malaria is also a financial burden for low-income households: despite access to medical insurance (commonly known as community-based health insurance) people still need to cover approximately 10% of the treatment cost.

4.4.2. The existing risk governance system and challenges faced by direct users

Control of vector-borne diseases like malaria has both individual and collective dimensions. Long-lasting insecticide-treated nets (LLINs), indoor residual spraying (IRS), and control of mosquito breeding sites are the primary strategies to control malaria. These strategies are quite effective in preventing indoor transmission; nowadays more than 70% of the infections happen outdoors. Mosquito surveillance is critical to identify how vectors spread the infection to hosts (definition of boundaries) and both the surveillance itself and the subsequent targeted interventions to reduce the risk of infection require investments and collective action. Although forms of mosquito surveillance take place in Rwanda, the current measures to prevent and

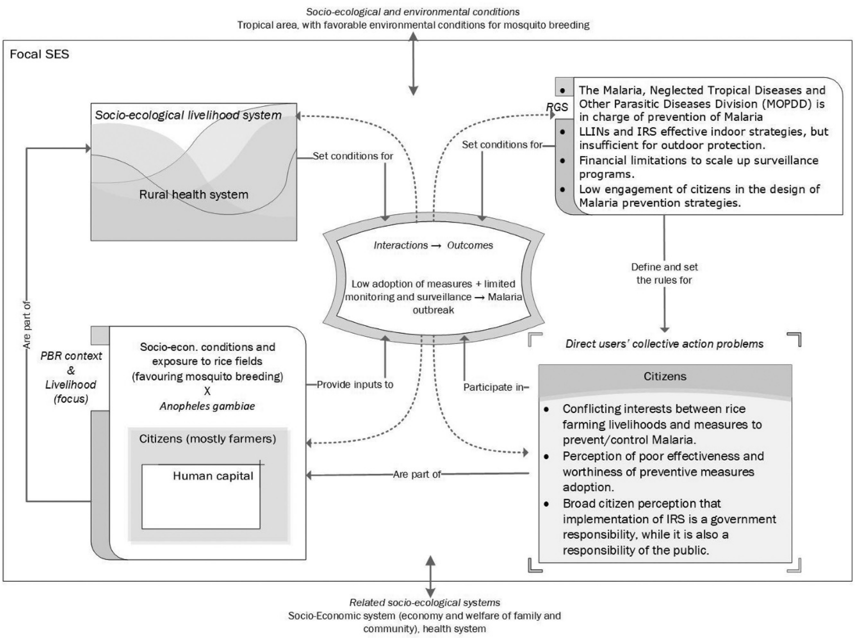

Figure 9. Control and prevention of malaria in Rwanda described using the adapted SES framework.

control Malaria are not enough to eliminate the disease. This has negative socio-economic consequences that range from individual (capacity to work) to national (health system costs) ones. Poverty and other socio-economic factors decrease the uptake of malaria prevention measures, e.g. reflected by the non-use of mosquito nets and the failure to remove potential mosquito breeding sites (like containers with stagnant water). Other factors that increase people's vulnerability include beliefs and habits around the use of bed nets; a weakened immune system due to existing health issues; inopportune access to and inappropriate use of malaria treatments; livelihood conditions that are favourable for mosquito breeding (e.g. rice paddies); mosquito insecticide resistance and change in biting behaviour of malaria mosquitos due to previous spraying campaigns.

4.4.3. The intervention and its effect on the risk governance system and direct users

As part of their study, Murindahabi and Asingizwe designed (Asingizwe et al., 2019), implemented (Asingizwe et al., 2020; Murindahabi et al., 2021, 2021, 2022)and evaluated (Asingizwe et al., 2020) a citizen science programme for malaria control and vector surveillance in Rwanda. The citizen science programme for malaria control and vector surveillance was co-designed with citizen volunteers (direct users) and included low-cost, locally produced mosquito traps, paper-based data collection; monthly feedback on data via SMS; and result validation workshops. Volunteers were involved in the selection process of materials, schedules, reporting methods, feedback processes and communication mechanisms.

Figure 10 illustrates how the citizen science programme influenced the malaria RGS from a SES perspective. The researchers found that citizen science offered opportunities to scale the surveillance and response capacity (a contribution to defining risk boundaries). Malaria and mosquito surveillance proved essential to generate socio-ecological information for decision-making, such as the geographical distribution of confirmed malaria cases, present mosquito species, and experienced mosquito nuisance. For example, a better understanding of the presence of specific mosquito species helped to gain insight into insecticide resistance in the region and supported the selection of suitable insecticides to apply in IRS strategies. In addition, citizens' participation increased awareness, facilitated collective risk sense-making, and supported the adoption of prevention practices. This could decrease host vulnerability, and subsequently reduce the likelihood of risk expression (infections). Furthermore, information about both the vector and the host risk behaviour contributed to defining risk boundaries, e.g. by indicating where and when to implement malaria control interventions. Finally, a change in risk perception was measured, leading to greater adoption of prevention behaviour.

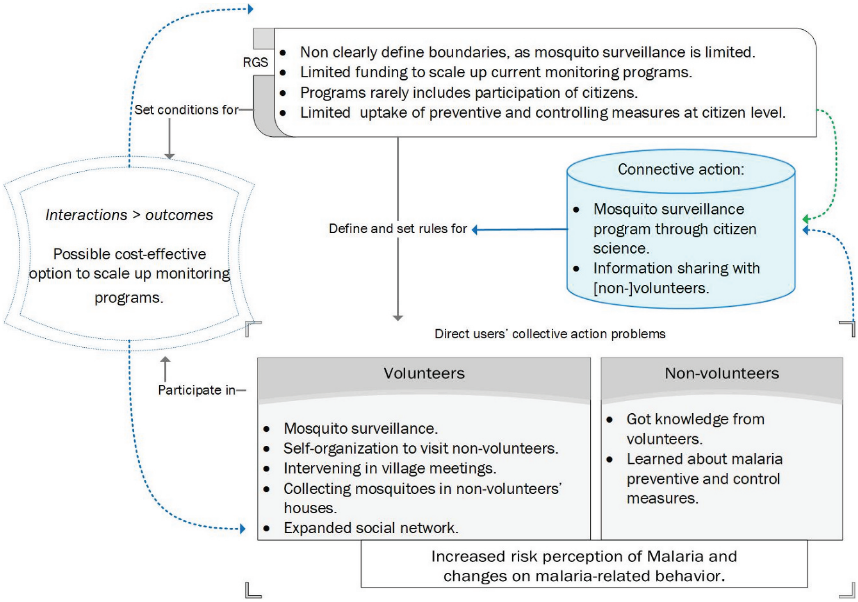

Figure 10. Connective citizen science intervention influencing the RGS for the malaria case in Rwanda.

4.4.4. Lessons from this case

The pilot scale findings by Murindahabi and Asingizwe on the contribution of citizen science are promising, although Asingizwe asserts that "*further studies that involve policymakers are needed to determine their perceptions and acceptance of the programme, and how it can complement the active surveillance of the national malaria control programme*".

The malaria case shows that a connective intervention in form of a citizen science programme can contribute to (1) more cost-efficient strategies to manage risks, and (2) defining appropriate risk boundaries for a public bad. Locally made mosquito traps managed by citizens are a cost-effective option to expand programmes that collect entomological data such as mosquito specimens, mosquito nuisance, and biting intensity, as a proxy for malaria transmission risk (Murindahabi, 2020; Murindahabi et al., 2018). Additionally, citizen science programmes can contribute to determining areas with a higher or lower outbreak risk (definitions of boundaries). However, citizen science programmes are no silver bullet for solving malaria but need to come together with other interventions, require active involvement of decision makers, and suitable renumeration of volunteers.

4.5. Potato late blight and bacterial wilt disease

4.5.1. Description of the public-bad and collective action problem

This case study deepened insight into the contribution of connective interventions to collective choice arrangements for the management of bacterial wilt and late blight in potato farming systems in Ethiopia (Damtew et al., 2018, 2020; Tafesse et al., 2018). Potato production is a critical source of food and income. There are three types of potato producers: seed potato growers, ware potato growers, and farmers who grow both seed and ware potatoes.

Potato farmers suffer from recurrent outbreaks of late blight and bacterial wilt disease, which increase poverty and food insecurity. Late blight is primarily air-borne, and the spores of the oomycete *Phytophthora infestans* causing late blight can travel very far. The disease can also be seed-borne and soil-borne. Weather conditions drive the spread of late blight, which is seasonal (rainy season) and mainly chemically controlled. Farmers' ability to apply appropriate chemicals (in terms of quality and quantity) is critical. Bacterial wilt is not seasonal, is indigenous in many parts of Ethiopia, and is a seed-borne, soil-borne, and water-borne disease, caused by *Ralstonia solanacearum*.

Host resistance to bacterial wilt is non-existent. Prevention measures include keeping farmers' soils, tools, and seeds free from bacteria. Crop rotation is

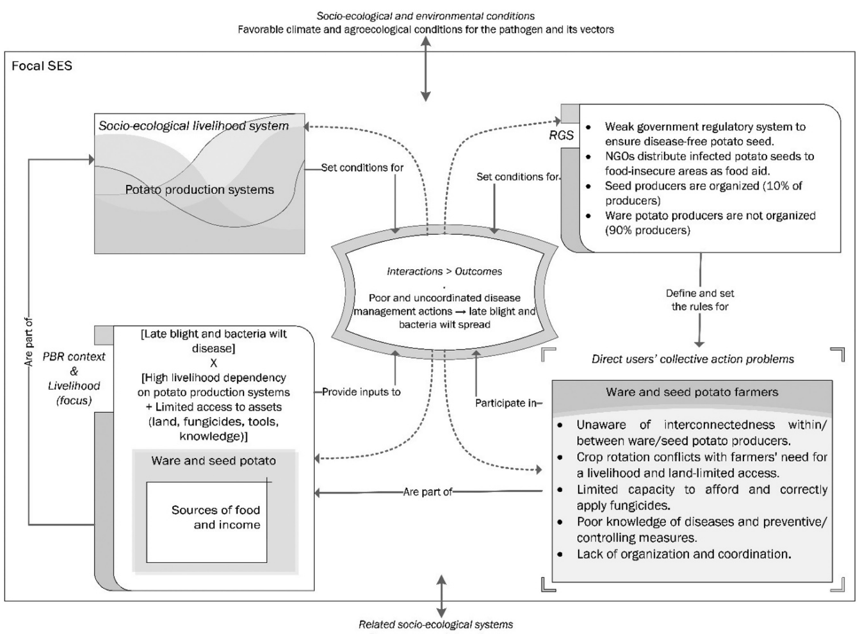

Figure 11. Potato late blight and bacterial wilt disease in Ethiopia described using the adapted SES framework.

crucial to avoid that bacterial wilt stays in the ground. Five to seven years of crop rotation with non-host plants is recommended for the effective elimination of the bacteria from infested soils (Figure 11). Potato crop fields, either for seed or ware, are adjacent to each other and diseases can easily spread from one field to another. Thus, collective and coordinated actions among farmers and other stakeholders are required to manage both diseases.

4.5.2. The existing risk governance system and challenges faced by direct users

Farmers rely on each other for labour and production equipment, and tools and boots can easily transfer the disease when they are not disinfected. Moreover, farms and farmers are cross affected by their respective disease control practices and outcomes. Both diseases are transgenerational, transboundary, and transmittable from ware to ware, ware to seed, seed to ware, and seed to seed. Therefore, the lack of control on any farmland imposes costs or losses on others (Damtew and Tafesse, interview).

Ethiopia has a weak government regulatory system for disease-free potato seed production and marketing, meaning that 90% of disease management regulations for both ware and seed production exist only at the farmers' level. Seed producers represent 10% of potato producers and they are often organized in farmer cooperatives in which quality monitoring committees play an important role. These committees can reject members' seeds that are of poor quality (e.g. infected with bacterial wilt) to be sold through the cooperative. However, in practice the committees face challenges with reinforcing the rules. In addition to these committees, there exist public and private laboratories which occasionally send inspectors to identify the disease in the field and provide advice on control measures. The other 90% of the potato producers are ware producers for whom there are no regulatory procedures. Ware producers tend to individually apply plot level disease management strategies outside formal frameworks. Damtew (2020) and Tafesse (2020) found that collective action is further undermined by limited farmer knowledge and awareness of spreading mechanisms and mutual interdependencies, resulting in a poorly developed collective risk perception.

Other factors affecting farmers' coping capacity include low affordability of chemicals to control late blight; the trade-offs that come with a farmer's chosen risk mitigation strategy; sharing of farming equipment; the looming poverty and food insecurity that force farmers to take unfavourable decisions; high cost of disease-free, certified, potato seeds; handing out of infected potato-seed by NGOs in food-insecure regions; and lack of knowledge among farmers to recognize disease symptoms (especially in potato seed); unwillingness of farmers to rotate potatoes with other crops when land is scarce.

4.5.3. The intervention and its effect on the risk governance system and direct users

Damtew and Tafesse designed and applied face-to-face learning interventions combined with experiential and social learning approaches. These approaches were geared towards arriving at collective agreement on strategies to control the spread of both diseases and developing community-based organisational mechanisms to monitor and enhance adherence to those strategies. The connective interventions included: (1) discussion of transmission and spreading mechanisms, (2) field-based observation and identification of disease symptoms, (3) experimentation with alternative measures in a community managed-plot, and (4) discussion and reflection on seed selection, interdependencies among farmers and prevention measures (Damtew et al., 2020b; Tafesse et al., 2020a, 2020b).

Damtew et al. (2020b) found that the learning interventions enhanced farmers' awareness of late blight as a collective problem and provided participants with a new perspective on farmer-to-farmer relationships in disease management. Farmers discovered the importance of cooperation, and few of them (endorsed by all) proposed to involve other farmers in the community (not participating in the intervention) too. The learning interventions organized for bacterial wilt disease yielded similar results (Tafesse et al.,

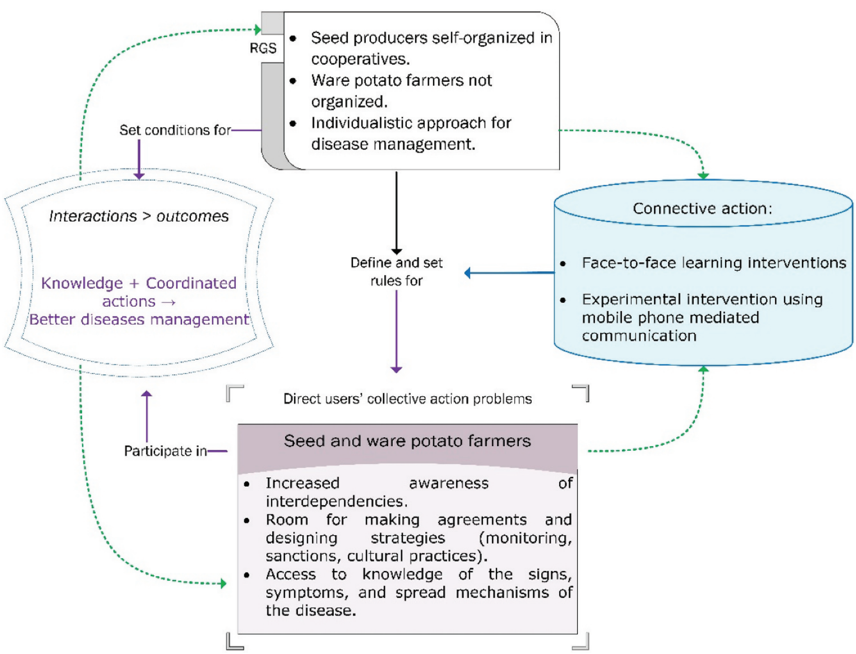

Figure 12. Connective strategy influence in the RGS for the potato late blight and bacterial wilt disease in Ethiopia.

2020, 2020). Seed and ware potato farmers expressed the importance of concerted and collective actions and proposed to work together by developing community-based bylaws and monitoring systems (Figure 12).

In addition, Damtew et al. (2020a) and Cieslik et al. (2021) explored the role of ICT-mediated chatgroups in individual and collective decision-making regarding late blight control through an experimental approach. Damtew et al. studied how the provision of information and ICT- communication (smartphone chatgroups) influenced farmers' individual choices, while Cieslik et al. investigated how ICT communication influenced farmers' decisions to reach a collective target (Cieslik et al., 2021; Damtew, 2020; Damtew et al., 2020a). Both studies were carried out collaboratively and used a framed economic experiment combined with a qualitative content analysis of all the recorded text and voice chats in the various treatment groups. Farmers received an endowment and, over a period of three days, needed to decide several times whether to invest in pesticide spraying on their hypothetical potato field under several experimental treatment conditions. In the study by Cieslik et al. (2021), there was an immunity threshold to be reached by a group of five farmers, determined by the number of farmers deciding to invest in spraying pesticides. If a group reached the threshold, all members received an extra endowment (representing a successful disease-free harvest). Otherwise, group members were affected by the disease and experienced economic losses. Treatment groups could again communicate through a smartphone with a voice-based group chat application.

Damtew et al. (2020a) found that technical information about the interdependence among farmers alone did not trigger farmers to invest in disease control by means of spraying. Provision of information about the decisions of other groups members together with technical information even worsened spraying performance. Contrary, information about group members' decisions alone improved spraying performance. The best collective performance was however achieved when farmers were both provided with technical and monitoring information and could communicate via a chat group on a smartphone. The chatgroup allowed farmers to reach agreements and set up sanctioning systems.

Cieslik et al. (2021) also found that farmers assigned to the ICT treatment group (i.e. with access to the chatgroup) were more likely to contribute to collective prevention of the public bad and to reach the immunity threshold. The chatgroup resulted in higher returns across the group, and farmers used the chatgroup to facilitate complex coordination, establish collective norms, identify and pressure free riders, and increase trust. Most farmers honoured the verbal commitments made in the chatgroup, which appeared to trigger others to commit too.

4.5.4. Lessons from this case

The findings show that connective interventions can support collective responses. The results highlighted that connective interventions need to consider and enable social capital (trust, reciprocity, social cohesion), technical understanding of interdependencies, and coordinated and inclusive design of regulatory processes (monitoring, sanctions). In addition, the communication strategy must allow for deliberation and collective sense-making, either face-to-face or ICT mediated. The studies provide evidence that; connective interventions can trigger changes in the cost-effectiveness of practices (e.g. spraying to reach collective immunity), can shift public-bad risk boundaries to more relevant units; and help overcome collective action problems by enhancing feelings of interdependence. However, the findings also indicate that connective interventions alone do not suffice to overcome collective action problems, and that direct users' (appropriate, sufficient, affordable, and timely) access to resources is equally critical.

4.6. Banana Xanthomonas Wilt disease

4.6.1. Description of the public-bad and collective action problem

This case study focused on smallholder banana production in Rwanda, where the banana mat is the livelihood unit. Banana is the most important staple food crop in the country, covering 23% of the land, grown by 90% of households, and with a significant dietary component ranging from 20 to 80% of daily total food intake (Blomme et al., 2017; McCampbell et al., 2018). Therefore, reduced banana productivity affects households' socio-economic and cultural wellbeing, and food and nutrition security. Banana Xanthomonas Wilt disease is one of the greatest threats to banana production because its infection (caused by the bacterium *Xanthomonas vasicola pv. musacearum*, formerly known as *Xanthomonas campestris pv. musacearum*) can result in up to 100% yield losses (Blomme et al., 2017). BXW is highly and rapidly transmissible through multiple mechanisms such as infected soils, plant material, cutting tools, long-distance trade, and vectors such as birds, bats, and insects (Tinzaara et al., 2016). Unfortunately, no cure exists for BXW. Although eradication of BXW is considered technically unfeasible, good preventative agricultural practices and early response to disease outbreaks can reduce its rapid spread and hazardous socio-economic consequences. However, this is only possible through collective and coordinated actions because farmers' production activities and outcomes are interconnected (Galarza-Villamar et al., 2021; McCampbell et al., 2018) Figure 13).

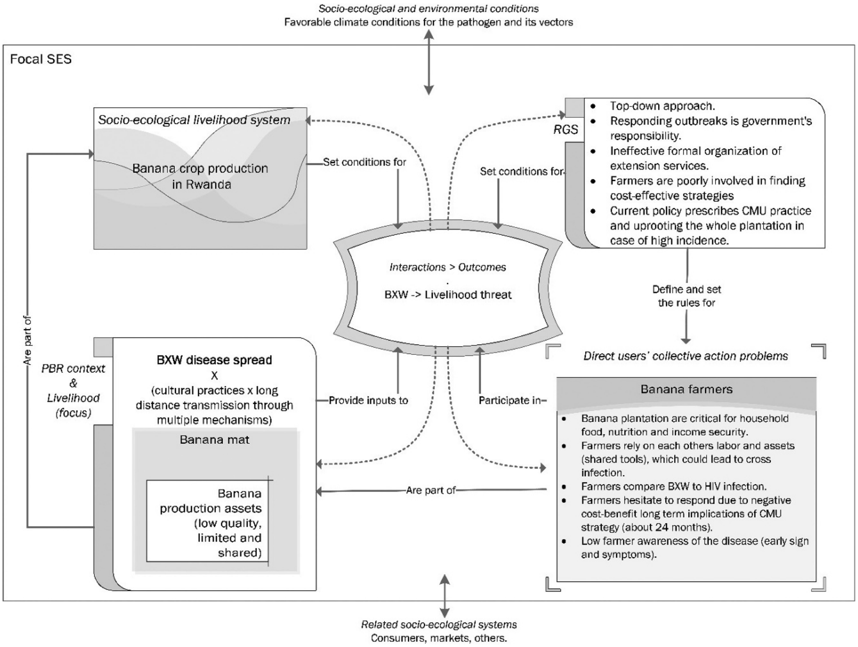

Figure 13. BXW disease in Rwanda described using the adapted SES framework.

4.6.2. The existing risk governance system and challenges faced by direct users

Until recently, Rwanda's primary policy for BXW disease outbreaks prescribed a practice called Complete Mat Uprooting (CMU). This involves uprooting the diseased stem and all lateral stems and shoots (i.e. the entire banana mat) regardless of their infection status.[5] In high incidence cases (>70% of the banana mats showing symptoms), the whole plantation must be uprooted (Hakizamungu et al., 2020). In cost-benefits terms, between uprooting a diseased banana mat and harvesting from a new mat requires up to 24 months. Although CMU is effective, it is also labour intensive, time-consuming, and (socially) costly. Therefore, it has a significant negative impact on farmers' livelihoods in the short-medium term, making them hesitant to comply with good BXW management practices.

Collective and coordinated actions among stakeholders are a challenge, given the nature of the disease, the crop, and its users. Socio-ecological risk conditions include farmers' lack of knowledge about the disease, low purchasing capacity (or availability) of good quality planting material, and

[5]More recently, a less invasive practice called Single Diseased Stem Removal, which primary practice involves continuous removal of diseased stems only, started to become accepted as an alternative to CMU.

disease transmission through shared labour and tools across farms. The capacity to cope, adapt, and recover from an outbreak is limited and mostly depends on the wealth of the farmers and their ability to access off-farm income opportunities. More wealthy farmers have more access to information, allowing them to prevent and respond better. Female farmers are the most vulnerable as they are more isolated from information, advice, and resources.

Prevailing risk perceptions contribute to the challenge of BXW management. Farmers compare BXW to HIV or the apocalypse and therefore believe that management practices are unworthy. For example, farmers consider that if they uproot an infected mat and re-plant it, it will get infected and be lost again, especially if neighbours do not manage the disease. Risk perceptions related to the governance system also influence their practices. Farmers try to hide infected plants by cutting down symptomatic stems or leaves to prevent forced uprooting.

4.6.3. The intervention and its effect on the risk governance system and direct users

McCampbell studied a digital intervention (BXW-App) for the management of BXW disease from its development to its implementation, and then explored experimentally the potential impact of digital communication on collective action (McCampbell et al., 2018; McCampell, 2021). BXW-App allowed for a diagnostic procedure, the registration and control of infected plots, and the exchange of information and knowledge about BXW. The application relies on extension agents, who first visit individual farms to run a diagnostic procedure together with a farmer. Depending on the diagnostic result, this is followed by the provision of advice about BXW disease management. The extension agent sends the collected information regarding the health status to a central database. The database is accessible to scientists and government agents and allows geospatial analysis of disease presence. Farmers cannot access this information (Figure 14).

McCampell (2021) argued that digital services could support collective action towards preventing or containing a public-bad problem like BXW disease by making interactions and interdependencies (human-human and human-non-human) more tangible to farmers. However, she also signalled that many of the digital advisory or decision-support services (including the BXW-App) tend to target farmers individually and provide no or limited opportunities for two- or multi-way interaction. Thus, the digital service provided by the BXW-App does not prepare farmers for collective action towards managing the threat, since it does not allow for deliberation, collective sense-making, and managing the risk synergically. McCampbell (*idem)* suggests the need for an intermediary (e.g. farmer promoter) who not only keeps track of all diagnoses in the different individual farms but then also

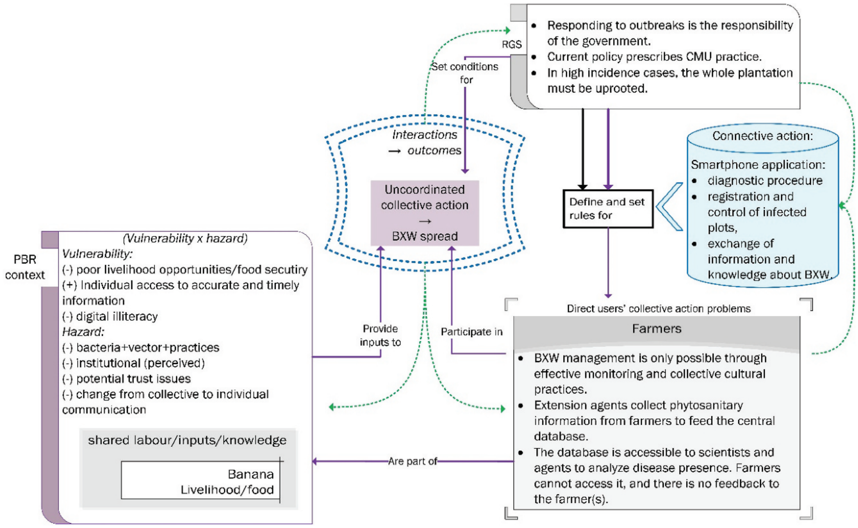

Figure 14. Connective intervention influence in the RGS, direct users' collective action problems, and public-bad risk context for the BXW disease management in Rwanda.

brings these farmers together to build a collective disease management strategy. Other factors hampering a positive effect of BXW-App were that the intervention may reinforce hierarchical power structures through the access and use of farmers' data, and that the intervention can reproduce distrust in the risk governance system and trigger fear-based BXW management practices.

In addition to studying the design and implementation process of BXW-App, McCampell (2021) analysed the impact of different communication strategies on farmers' performance (individual and collective) through an experimental game (simulation). She found that farmers are aware that they are interconnected but are poorly motivated to do something individually or collectively to control BXW since they have a negative perception about the costs and benefits associated with the use of CMU.

4.6.4. Lessons from this case

During a workshop, McCampbell argued that:

> Connective strategies change the boundaries of collective action because there are no boundaries anymore when you talk about digital. The walking distance within the community from the house or farm is no longer a restriction. You can connect everybody in a way. But the question is whether that is always useful? [...] they might go back to their old forms of connectivity such as their community meetings since these allow two-way communication.

McCampbell concluded that a digitalized monitoring strategy is potentially a powerful tool in the prevention stage of risk management, but likely insufficient in supporting other phases in the risk management cycle (mitigation, response, and recovery) since the BXW-App did not facilitate the kind of collective and coordinated action required once the threat is in place. Like in our previous cases, it is shown that if a connective intervention (in this case the BXW-App) is not embedded in a broader system that is conducive to addressing the various challenges identified, it may be counterproductive (e.g. reinforcing hierarchical structures and distrust in the risk governance system).

5. Analysis and discussion

Our analysis of six African cases revealed that both the nature of the SES problem and the characteristics of interventions geared towards fostering connectivity varied considerably across cases. In this section we discuss cross-case insights. We structure our discussion according to our research questions.

5.1. How do connective interventions influence changes in the existing risk governance system?

Connective interventions have the potential to influence the risk governance system. The case studies provide evidence that connective interventions have

Table 6. Summary of cases study findings in terms of the contribution of connective interventions to enabling design principles for public-bad governance.

		Tick-borne diseases	Climate variability and weather forecasting	Fall Armyworm in Maize	Malaria control/ prevention	Potato blight and bacterial wilt	BXW disease
1	Clearly defined boundaries	√		√	√	√	√
2	Proportional equivalence between benefits and costs	√	√	√	√	√	√
3	Collective-choice arrangements	√	√	√	√	√	√
4	Monitoring		√	√	√	√	√
5	Graduated sanctions					√	
6	Conflict-resolution mechanisms		√	√			
7	Minimal recognition of rights to organize						
8	Nested enterprises	√	√	√			

Table 7. Summary of cases study findings regarding the contributions of connective interventions on factors hindering collective action problems among direct users.

		Tick-borne diseases	Climate variability and weather forecasting	Fall Armyworm in Maize	Malaria control/ prevention	Potato blight and bacterial wilt	BXW disease
1	Coping capacity		√	√	√		
2	Social dilemmas			√	√	√	
3	Risk perception	√	√	√	√	√	√

indeed the potential to enable the development and implementation of the governance design principles identified by Ostrom (1990; cited in Ostrom, 2005) and thus influence the RGS (see Table 6 for an overview). The implemented connective interventions differed per case and mostly included platforms for learning and exchange (face-to-face or mediated through mobile phones or social media) and/or the set-up of systems for the monitoring of farms and/or disease vectors, sometimes in combination with citizen science. Notwithstanding this diversity, we found that connective interventions enable different stakeholders (mainly those more directly benefitting from managing the public bad or direct users) to achieve the first four principles outlined by Ostrom (clearly defined risk boundaries; proportional equivalence between benefits and costs, collective-choice arrangements, and monitoring).

In almost all cases, connective interventions contributed to defining the boundaries of the public bad, as they provided opportunities to reinforce monitoring and surveillance within and between stakeholder groups (Principles 1 and 4). In addition, the social networks, knowledge, and information that were co-created through the various connective interventions served as input to designing and implementing more cost-effective managerial interventions (Principle 2), and enabled stakeholders to participate as active decision-makers and public-bad managers (Principle 3). The cases provide few examples where the connective interventions supported design Principles 5, 6, 7 and 8. The design principle demanding minimal recognition of users' rights to self-organise and devise their own institutions (Principle 7) was not represented at all, while some (fall-army worm, weather forecasting, potato disease cases) connective interventions supported the design Principles 5, 6, and 8 (graduated sanctions, conflict-resolution mechanisms, and nested enterprises). Arguably, these three design principles were more difficult to operationalize considering the limited time span and (financial) resources of the projects, and their focus on end-users. Neverthess, the potato case suggests that graduated sanctions may emerge in response to a connective intervention. The cases of weather forecasting and fall armyworm offer early contributions to Principles 6 and 8, as both studies operationalised multi-stakeholder interactions that fostered connections between several system levels and spheres, and made progress in addressing tensions between different epistemic communities (weather forecasting case) or different parties in the value chain and knowledge system (fall armyworm case). Thus, specific features of the connective interventions did, to some degree, shape the way in which they impinged the RGS.

5.2. How do changes in the risk governance system contribute to managing collective action problems [faced by the direct users of the livelihood unit under focus]?

As is summarized in Table 7, all case studies provide evidence that connective interventions have the potential to trigger a change in risk perception. The two cases that used gamification and experimental approaches (BXW disease case and potato diseases case) demonstrated that awareness of co-dependencies plus technical knowledge to understand the underlying causes of such dependencies are essential to increase risk awareness among stakeholders. Changes in risk perception and awareness, in turn, can trigger a change in behaviour towards existing social dilemmas. This was demonstrated in several of the cases both in real life (cases of malaria prevention and potato diseases) and in experimental or game settings (cases of potato diseases and BXW disease). In addition, more accurate risk perceptions and cooperative behaviours also contribute to coping capacity, as they add to human and social capital. This can, for example, be seen in the case of fall armyworm in maize, where the emergence of a new pest triggered self-organized cooperation, and exchange and mobilization of resources facilitated by connective interventions. However, the cases also suggest that creating and sharing socio-technical and ecological knowledge to increase awareness is critical, yet not enough.

Access to resources is equally essential to address public bads, such as access to land (tick-borne diseases), credit to buy necessary inputs (fall armyworm and potato diseases) and (digital) decision-support services and tools (weather forecasting, potato disease, BXW). Finally, it appeared that connective interventions simultaneously supported the emergence of RGS conditions that are favourable for collective action and helped with overcoming typical hindrances to the perception of risks and social dilemmas. This contrasts with the research question's inferred causal direction [RGS to CAP] that assumed a more indirect effect of connective interventions.

5.3. When and how can new (digital) forms of connectivity change the logic and boundaries of collective action and decision-making?

What have the six cases taught us about our overarching research question? The case findings demonstrate that framing socio-ecological system problems as public bads opens new pathways of critical inquiry and inspires innovative approaches to development practice.

The cases provide compelling evidence that improving the communication capacity of groups increases the likelihood of effective collective organizing. All cases dealt with complex interdependencies, involving relations and interactions between diverse stakeholders, which are also co-dependent on interactions with biophysical and biological processes across time and space. In these dynamic settings, complexity can be further aggravated by tension and conflict (e.g. in the tick-borne diseases case), by a high degree of uncertainty regarding the appropriate technical management response (e.g. in the cases of climate variability and bacterial wilt in potato), and – in almost all cases – by limited malleability in existing system configurations (e.g. characterized by poverty, inflexible set-ups, infrastructures or policies, hierarchical governance arrangements, etc.) (see also Leeuwis et al., 2018). In such settings, multiple strategies need to be in place to tackle a public bad problem. In line with this, our findings across the six case studies suggest that connective interventions cannot work in isolation to influence the logic and boundaries of collective action. However, our analysis shows that connective interventions can play roles in operationalizing and supporting RGS conditions that are favourable for collective action. These interventions can also help overcome typical hindrances regarding the way in which risks and dilemmas are perceived. We found that this potential depends on several transversal factors: (i) availability of resources, (ii) co-production and inclusion, (iii) collective sense-making and space for deliberation, and (vi) trust in governance systems and institutions.

The cases demonstrate that effective collective action by smallholder farmers or other unprivileged groups requires access to specific resources and cost-efficient prevention strategies. Our cases make plausible that connective interventions can contribute to developing such strategies and/or enhance conditions to access them. Nevertheless, resource constraints continued to play an important role and hence remain a point of attention. The cases also suggest that inclusive monitoring and surveillance are essential to improve the definition of public bad boundaries, and can contribute to designing more accurate and timely strategies to prevent, control, and respond to public bads (i.e. cost-benefit equivalence improvement). In order to be useful, monitoring systems, prevention strategies, and decision-support tools are best co-produced together with those who are expected to use the tools and benefit from them.

Furthermore, we have seen that connective interventions need to include spaces for collective sense-making, deliberation, and learning to create conducive conditions for collective action. Such spaces can (1) enhance awareness of co-dependence between users, (2) serve to integrate knowledge from different actors or epistemic communities, (3) provide room to co-design and test prevention or control strategies, (4) offer a platform in which community members can encourage each other to contribute to the common good, and/or (5) provide an environment where learning can contribute to more constructive negotiations in case of tensions and conflicts. Several cases suggest that ICT and social media platforms can play meaningful roles in providing such spaces. Yet, at the same time, we see that forms of face-to-face communication remain critically important. Hence, digital forms of connectivity need to be embedded in broader frameworks for interaction.

Our analysis demonstrates that the SES framework can be used to meaningfully integrate insights and synthesize lessons about the collective management of public bads that were obtained from case-studies that varied in terms of the public bads under study, the research context, and the scientific disciplines used to gain understanding about the case's complex problem. The SES framework provides ample entry-points to incorporate insights from various natural and social science disciplines. However, arriving at an integration and synthesis of a variety of cases requires a dedicated analytical process and methodology in which research teams re-examine their work in interaction with scholars who are knowledgeable about the SES framework. Such synthesis can add value to the individual cases conducted as part of large multi-case, interdisciplinary research programmes.

6. Conclusion

This paper emphasised the continued relevance of studying public bads in Africa from the perspective of social ecological systems and in consideration of interactions within SES. Through the case studies, we showed how connective interventions may change risk governance system, thereby affecting interactions in a SES and the outcomes of those interactions. In all cases, connective interventions affected people's risk awareness, in some cases also impacting their coping capacity and social dilemma perception.

In terms of the management of the public bad, we see that the connective interventions in the case studies induced collective action that addressed different management phases or strategies, with an emphasis on collective prevention of the public-bad risk and/or fostering a collective response once the risk had manifested. Often these strategies were intertwined.

This paper synthesized six case studies from a recent research programme. While it was our ambition to bring together lessons from the individual cases and derive overarching lessons from them, integrating knowledge and insights proved a challenge. Although the cases started from a shared interest in the potential of connective interventions in addressing socio-ecological development challenges (Cieslik et al., 2018), one limitation was that, as separate PhD projects, the case studies were time and place restricted, each operating in their own context and with their own objectives, disciplines, conceptual frameworks, and interventions. Yet, the research presented in this paper demonstrates the value of the social ecological systems framework in synthesizing lessons and insights from such diverse interdisciplinary studies. The comparative approach is of particular importance in the light of Ostrom's later work on polycentric governance, where she stresses the importance of developing methods and frameworks that can help to assess and compare the efficacy of particular strategies and interventions across different ecosystems and socio-ecological challenges (Ostrom 2009b).

The time-horizon and set-up of the connective interventions in a project setting for the purpose of research furthermore challenged long-term assessment of impact on vulnerability and exposure to public-bad risks because of connective interventions, or the sustainability and scalability of such outcomes. Thus, based on this study we cannot say if the interventions have had permanent effects. It has, however, become clear that public-bad problems are complex, and that multiple synergistic actions are needed to prevent, respond to, and recover from them such that the vulnerability in livelihood systems decreases. We recommend that similar studies are conducted after interventions have been introduced for a longer period to gather evidence of how connective interventions influence people's capacity for public-bad risk management and collective action over time.

Finally, we see that the way in which farmers and citizens perceive risks, their readiness to engage in open communication about public bads, and their willingness to engage in collective action, may be influenced by their degree of trust in broader governance arrangements and institutions. These institutions are also relevant because public-bad challenges can often not be (fully) resolved by communities themselves. This is in line with Ostrom (2009b) who argues that sustainable management of common good resources can benefit from conducive interaction between governmental bodies and communities, resulting in policies that can rely on community support and complementary forms of collective action. However, most of the connective interventions explored in this paper did not address such alignment with broader governance arrangements but focussed only on localised communities. Thus, we recommend further research to explore how additional connective interventions or complementary strategies could better anticipate the nestedness of governing public bads in complex socio-ecological systems.

In all, the cases provide compelling evidence that improving the communication capacity of groups with help of connective interventions increases the likelihood of effective collective organizing in the face of complex public bad situations. However, connective interventions cannot work in isolation and require complementary strategies, and trust in broader governance and institutional arrangements. Although almost all cases centred around public bad situations that involved infectious diseases in Africa, our conclusions may be relevant to other socio-ecological and sustainability challenges as well. One of the cases studied focused directly on challenges related to climate change, and -as demonstrated by the fall armyworm case- there can be clear linkages between climate change and the emergence of pests and diseases. Eventually, many socio-ecological and sustainability challenges in Africa and elsewhere are somehow connected to the management of commons, public goods or public bads, and this merits broad attention to addressing collective action problems and the use of socio-ecological systems thinking.

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ORCID

Paul C. Struik http://orcid.org/0000-0003-2196-547X

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The ethics approval of all case-studies was arranged through the research committee of the Wageningen School of Social Sciences.

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Annex 1

Theoretical and methodological guidelines for second phase of EVOCA synthesis work: questions and answers

1. Theoretical framework

Q. Which theoretical framework are we going to use to synthesize lessons learnt from EVOCA projects?
A. We will use a framework for analysing a public-bad risk (e.g. the spread of an infectious disease) threatening agricultural livelihoods based on banana production in a socio-ecological systems context from a risk and collective action problem perspective. Adapted from Ostrom (2009a). This framework (see Figure A1) integrates the livelihood unit (e.g. the host of the disease), the public-bad risk conditions (e.g. the disease, agent, and infection mechanisms), the threat (livelihood unit losses or fatality), and the strategies (based on coordination and cooperation at the level of direct users and the broader risk governance system) to prevent and control a public bad (disease spread) into the analysis (Galarza-Villamar et al., 2021b).

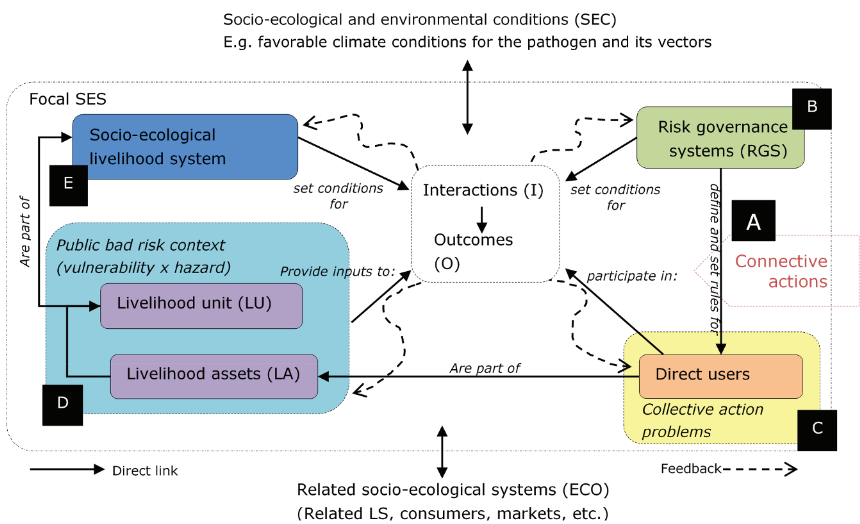


Figure A1. The core subsystems in a framework for analyzing a public-bad risk (e.g. BXW disease spread) threatening agricultural livelihoods based on banana production in a socio-ecological systems context from a risk and collective action problem perspective. Adapted from Ostrom (2009a). Chosen analytical path: a [connective actions]->B [risk governance system]->C [collective action problems among direct users]->D [public-bad risk context within a specific livelihood unit and assets under research]->E [socio-ecological livelihood system].

2. Overall research question

Under what conditions can connective interventions change the collective action and decision-making to address public bads?

3. Analytical path: pre-conditions in terms of information

E [socio-ecological livelihood system]

Q. Which components do we use for rapid characterization of the livelihood system?
A. Adapted SES framework from Ostrom (2009a)

Components	Description and example
SE livelihood system (ALS)	This is represented by a specific territory where diverse livelihood activities take place, involving crops, animal husbandry, and related activities and assets that provide ecosystem services to farmers and consumers.
Livelihood unit (LU)	This is a specific activity providing ecosystems services needed to make a living, e.g. cattle for milk and meat, rice production for human consumption, maize production for human or animal feed.
Livelihood assets	Human: peoples' health and ability to work, knowledge, skills, experience; Natural: land, water, the forest, livestock; Social: trust, mutual support, reciprocity, ties of social obligations; Physical: tools and equipment, infrastructure, market facilities, water supply, health facilities; Financial: conversion of production into cash, formal or informal credit.

D [public- bad risk context]

Q. Which indicators do we use to characterize the risk context?
A. Risk = hazard x vulnerability; Pressure and release model (PAR model)

Public-bad risk context component	Definition
Public bad	The non-excludability and non-rivalry of a public bad is not necessarily the threat itself, which lies in the various direct and indirect potential socio-ecological consequences from its mismanagement (Galarza-Villamar et al., 2021)
Risk	The probability of harmful consequences or losses (physical, social, economic, environmental, cultural, or institutional) resulting from interactions between hazard and vulnerable conditions, in a given area and over a period of time (Birkmann et al., 2013; Thywissen, 2006; UNISDR, 2009).
Hazard/ Hazard potential	A physical event, phenomenon, or human activity that has potential to cause loss of life or injuries, property damage, social and economic disruption, or environmental degradation. It potential is characterized by its probability (frequency) and intensity (magnitude or severity) (Wisner et al., 1994).
Vulnerability	Vulnerability (of any system) is in function of three elements: exposure to hazard, sensitivity to that hazard, and the capacity of the system to cope, adapt, or recover from the effect of those conditions (Smit & Wandel, 2006).

(*Continued*)

Public-bad risk context component	Definition
Exposure	The extent to which a unit of assessment (including its physical and human attributes that are spatially bounded to resources and practices that may also be exposed) falls within the geographical range of a hazard event (Birkmann et al., 2013; Turner et al., 2003).
Sensitivity/ Susceptibility	This describes the predisposition of at-risk elements (social and ecological) to suffer harm or modifications (directly or indirectly) by a disturbance (Birkmann et al., 2013; Brooks, 2003; Reed et al., 2013).
Coping capacity/ Societal response capacity	This is determined by limitations in terms of access to, and mobilization of, the resources of a community or a social-ecological system to respond (lessen potential damage, take advantage of opportunities, or cope with the consequences) to an identified hazard, including pre-event, in-time, and post-event response measures (Birkmann et al., 2013; Turner et al., 2003).

B [risk governance system]

Q. In terms of which components do we describe a risk governance system?
A. We will use an adaptation of Ostrom's (2005) design principles for governing sustainable resources.

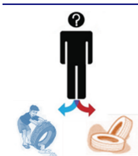
Design principles derived from studies of long-enduring institutions for governing sustainable resources:			Adapted public-bad governance design principles:
1	Clearly defined boundaries	The boundaries of the resource system (e.g. irrigation system or fishery) and the individuals or households with rights to harvest resource units are clearly defined.	The boundaries of the public bad (e.g. crop diseases) and the individuals or households threatened by it are clearly defined.
2	Proportional equivalence between benefits and costs	Rules specifying the amount of resource products that a user is allocated are related to local conditions and to rules requiring labour, materials, and/or money inputs.	The rules specifying the actions for preventing and controlling a public-bad threat that a user is allocated are related to local conditions and to rules requiring labour, materials, and/or money inputs.
3	Collective-choice arrangements	Many of the individuals affected by harvesting and protection rules are included in the group who can modify these rules.	Many of the individuals affected by the public-bad management rules are included in the group who can modify these rules.
4	Monitoring (*)	Monitors, who actively audit biophysical conditions and user behaviour, are at least partially accountable to the users and/or are the users themselves.	Monitors, who actively audit biophysical conditions and user behaviour, are at least partially accountable to the users and/or are the users themselves.
5	Graduated sanctions (*)	Users who violate rules-in-use are likely to receive graduated sanctions (depending on the seriousness and context of the offence) from other users, from officials accountable to these users, or from both.	Users who violate rules-in-use are likely to receive graduated sanctions (depending on the seriousness and context of the offence) from other users, from officials accountable to these users, or from both.
6	Conflict-resolution mechanisms (*)	Users and their officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials.	Users and their officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials.

(*Continued*)

Design principles derived from studies of long-enduring institutions for governing sustainable resources:			Adapted public-bad governance design principles:
7	Minimal recognition of rights to organize	The rights of users to devise their own institutions are not challenged by external governmental authorities, and users have long-term tenure rights to the resource.	The rights of users to devise their own institutions are not challenged by external governmental authorities, and users have long-term agency rights to self-organize to prevent and control public-bad threats.
8	*Nestled enterprises* (*)	For resources that are part of larger systems: Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.	For public bads that are a threat for larger systems (e.g. transboundary diseases): Problem definition, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

C [collective action problems among direct users of the livelihood unit under focus]

Q. In terms of which components do we describe a direct users' collective action problems concerning the specific "public-bad risk"?
A. Collective action problem are seen as a coordination problem due to social dilemmas (self-interested choices, what are those?), capacity to cope/respond, and perception of the problem [risk].

Social dilemmas	Coping capacity	Risk perception
 Social dilemmas define a situation where two or more individuals would be better off if all cooperate but fail to do so because of self-seeking choices that benefit them individually (Dawes et al., 1988).	 Coping capacity is related to the household/community's need for external intervention to repair any damage. See also definition in the public-bad risk context.	 Risk perception is one of the leading factors in disaster risk management because it influences people's response to threats (Shaw et al., 2014).

4. Analytical path: specific questions to guide data collection and analysis

From	To	Questions	Purpose
A [connective action]	B [risk governance system]	How do [the EVOCA proposed] connective actions influence changes in the risk governance system in place?	To answer main research question: Under what conditions can connective interventions change the collective action and decision-making to address public bads?
B [risk governance system]	C [direct users' collective action problems]	How do such changes in the RGS contribute to solving collective action problems [faced by the direct users of the livelihood unit under focus]?	
C [direct users' collective action problems]	D [public-bad risk context-focused on a livelihood unit]	How do such changes in direct users' capability to undertake collective actions influence their capability to manage public-bad risk [in terms of prevention, mitigation, responding, or recovering]?	
D [public-bad risk context-focused on a livelihood unit]	E [livelihood system]	Reflections on how direct users' capabilityto manage a public-bad risk through collective action [elicited by connective actions] might influence the broader livelihood system?	Discussion and further research

5. Data collection method

Focus group sessions with semi structured interviews.