

Article

Adding Emergence and Spatiality to a Public Bad Game for Studying Dynamics in Socio-Ecological Systems (Part I): The Design of Musa-Game for Integrative Analysis of Collective Action in Banana Disease Management

Julissa Alexandra Galarza-Villamar ^{1,2,*}, Mariette McCampbell ¹ , Cees Leeuwis ¹ and Francesco Cecchi ³

¹ Knowledge, Technology and Innovation Group, Wageningen University & Research, Hollandseweg 1, 6706 KN Wageningen, The Netherlands; mariette.mccampbell@wur.nl (M.M.); cees.leeuwis@wur.nl (C.L.)

² Escuela Superior Politécnica del Litoral, ESPOL Polytechnic University, Guayaquil 090150, Ecuador

³ Development Economics Group, Wageningen University & Research, Hollandseweg 1, 6706 KN Wageningen, The Netherlands; francesco.cecchi@wur.nl

* Correspondence: julissa.galarzavillamar@wur.nl



Citation: Galarza-Villamar, J.A.; McCampbell, M.; Leeuwis, C.; Cecchi, F. Adding Emergence and Spatiality to a Public Bad Game for Studying Dynamics in Socio-Ecological Systems (Part I): The Design of Musa-Game for Integrative Analysis of Collective Action in Banana Disease Management. *Sustainability* **2021**, *13*, 9370. <https://doi.org/10.3390/su13169370>

Academic Editors:

Isabel Banos-González and
Julia Martínez-Fernández

Received: 23 June 2021

Accepted: 6 August 2021

Published: 20 August 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract: Human decision-making plays a critical and challenging role in the prevention and control of public bads within socio-ecological systems. Farmers daily confront dilemmas regarding public bad management, such as infectious diseases in their crops. Their decisions interplay with multiple factors and may create the risk conditions in which a public bad can occur (e.g., a disease outbreak). This article presents an experimental board game method (DySE) and its contextualized version (Musa-game) to study the effect of individual and collective human actions on creating or preventing a public bad. The DySE method and the Musa-game add emergence and spatiality (both attributes of SES) to the study of public bads and collective action problems. This methodological proposal allows us to build a contextual understanding of how individual and collective actions of various entities lead to typical system outcomes, i.e., conditions that are (un)favourable to pathogens, and individual decisions about infectious disease management. To conceptualize our method, we used the case of Banana Xanthomonas Wilt disease in Rwanda. This research is published as a diptych. Part I (this article) covers the conceptualization and design of Musa-game. Part II presents empirical findings from testing Musa-game with farmers in Rwanda and recommendations for using the method.

Keywords: socio-ecological systems; livelihood resilience; emergence; public bad; infectious diseases; games

1. Introduction

A collective action problem occurs when the uncoordinated actions of individuals result in sub-optimal and less beneficial outcomes than coordinated actions would. In rational choice-based approaches, this problem occurs when self-interest-driven individuals fail to choose beneficial coordinated actions [1]. Individuals' decision-making toward a good or resource that benefits everyone is influenced by social dilemmas. These are situations in which every person is better off if everyone cooperates, yet this cooperation fails due to conflicting individual interests [2]. In other words, it is a situation in which individual rationality leads to collective irrationality [3].

Public goods (PG), such as public infrastructure or the environment, are non-excludable and non-rivalrous. Common goods (CG), such as a community forest or groundwater, are non-excludable and rivalrous. The difference is that, while the use of a public good by one individual does not affect the availability for another, the use of a common good does. The production or maintenance of a public good, or the use of a common good, is related to the prevention of a public bad [4]. In 1832, Lloyd sketched out a, now famous, example: a common land with pasture where anyone may let their cattle graze [5]. Each herdsman

adds one more animal at a time to increase their profit. After some time, the land becomes overgrazed, and all the cattle die. Hardin (1968) called this ‘the tragedy of the commons’. Although all herdsmen would prefer to have more and not less grass to feed their cattle, nobody achieves this because of self-interest-driven choices [6].

Following the same logic, a problem related to the prevention of a public bad is the production of a public good or sustaining a common good. As illustrated in Lloyd’s example, public bads reduce benefits and have the potential to impact a significant number of people negatively because they are non-excludable and non-rivalrous [7]. To further illustrate this, we can use an adaptation of Lloyd’s example: the cattle of a group of herdsmen graze on a common grassland. An infectious disease that is transmitted through ticks is reported in a few cattle. To reduce the risk of further disease spread, all herdsmen must treat their cattle with acaricides. However, since only a few herdsmen do this on time all the cattle become infected resulting in high mortality [8]. Thus, although all individuals would prefer to have fewer ticks and not more, they collectively fail to achieve this because of uncoordinated individual actions.

In both Lloyd’s example and our adapted version of it, livestock is the main agricultural resource sustaining a herdsman’s livelihood. In the first example, this resource is threatened by the hazard of overgrazing, in the second the spread of a tick-borne disease forms the hazard. While overgrazing relates to the overuse of a common good, the spread of the tick-borne disease relates to the management of a public bad. In a real-world context, herdsmen’s decision-making is multi-factorial and more than the sum of its parts. This property is called emergence [9]. The emergent phenomena create new conditions to which actors and biophysical entities may have to adapt in a continuously evolving process. Emergence is a particular characteristic of complex adaptive systems such as socio-ecological systems (SES) [10].

Understanding the factors at play in human cooperation is crucial for solving collective action problems, and consequently supports the production or use of a public or common good or to prevent and control a public bad. Therefore, the goal of our research is to contribute understanding about how collective action problems intertwine with different socio-ecological factors that either create or hinder conditions for public bad risks. Our objective is to propose a theoretical and methodological approach that considers expressions of dynamicity and emergence in complex systems and helps to explore public bad risk problems and decision-making about them.

This article presents an experimental board game, Musa-game, to study the role of human actions to prevent a public bad in the context of socio-ecological systems. In a separate article in the same issue of this journal, we present empirical findings from testing Musa-game with farmers in Rwanda. The theoretical and methodological novelty of Musa-game is that it adds attributes of SES, emergence, and spatial analysis to the study of public bads and collective action problems. Further, so far, neither classical laboratory and field experiments, nor ABM has integrated all these elements into one game-method. Hereafter, we first develop a theoretical framework to study a public bad problem in SES based on the complex-adaptive system approach [11,12]. We adapt the original approach by integrating conceptual thinking about livelihoods, economics, and risks; to then add the operational aspects of socio-ecological systems in terms of emergent phenomena and spatiality. We thereafter explore how economic games and agent-based models can contribute to the study of collective action problems in SES, and their potential application for studying dynamic public bad problems. Next, we describe the case study of Banana *Xanthomonas* Wilt (BXW) in Rwanda which we used to develop our methodological design. This method is then presented as an experimental board game to study how farmers’ decision-making (individual and collection actions) interplays with other SES factors and creates the conditions that hinder or enhance the spread of Banana *Xanthomonas* Wilt (BXW) disease (a public bad) in Rwanda.

2. Theoretical Framework

Agriculture sustains the livelihoods of 2.5 billion people globally [13], most of them smallholder farmers, herders, fishermen, or forest-dependent communities, who generate more than 50% of global agricultural production [14]. Agricultural livelihoods can be considered as socio-ecological systems (SES) [15] which consist of societal and ecological subsystems that interact with one another, are complex, dynamic, and continuously evolving [16]. A SES is said to be resilient if it can absorb disturbances and respond to change through reorganization thereby maintaining its functions, structures, and evaluations, without deviation from its original pathway [16].

We build upon the SES framework originally introduced by Elinor Ostrom (2007) [11,17]. Its most elaborate version emphasizes both direct and feedback interactions and integrates the role of emergent phenomena in the system. In this study, we integrate emergence in our theoretical framework, and design a methodology based on games to operationalize it. Ostrom (2007) proposed a multilevel and nested framework to analyze the sustainability of SESs [11]. The main subsystems in this framework are resource systems (RS), resource units (RU), governance systems (GS), and users (U). In her example, the RS is a protected park in a specified territory containing forested areas, wildlife, and water systems. The RU are the trees, wildlife, and water systems present in the park. The GS are the institutions managing the park, the specific rules related to the park's use, and how those rules are made. U are the individuals using the park for their livelihoods, recreation, and other purposes. We adapted Ostrom's (2007) original framework for application to a public bad risk management situation in which the assets and units form a livelihood system, which users rely on to generate ecosystem services and make a living, is threatened. Table 1 describes the framework used for analyzing a public bad risk that is threatening livelihood resilience, as shown in Figure 1. The descriptions and examples are adapted from Ostrom (2007) [11].

Table 1. Description of the components of the framework for analyzing a public bad risk threatening livelihood resilience.

Components	Description and Example
Agricultural livelihood system (ALS)	This is represented by a specific territory where diverse agricultural 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 agricultural activity providing ecosystem 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.
Public bad risk context (PBRC)	Conditions of vulnerability and characteristics of the hazard that hinder or limit the probability of a public bad.
Vulnerability	The vulnerability (of any system) is a function of three elements: exposure to a hazard, sensitivity to that hazard, and the capacity of the system to cope, adapt, or recover from the effect of those conditions [18].

Table 1. *Cont.*

Components	Description and Example
Hazard	A physical event, phenomenon, or human activity that has the potential to cause the loss of life or injuries, property damage, social and economic disruption, or environmental degradation. Its potential can be characterized by its probability (frequency) and intensity (magnitude or severity) [19].
Risk perception	Risk perceptions are formed by common-sense reasoning, 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 preventive measures [20,21].
Risk governance system (RGS)	Rules (operational, collective-choice rules, constitutions), property right regimes (private, public, common, mixed), network structure (centralized, non-centralized) [20].
Direct users	Farmers and households who depend on the livelihood unit.
Collective action problems	Coordination of responses to problems among direct users triggered by social dilemmas, risk perception, or coping capacities.
Action interactions (I) and outcomes (O)	Action situations are where all the action takes place as inputs are transformed by the actions of multiple actors into outcomes [22].
Social, economic, ecological, environmental, and political conditions (SEC)	Economic development, demographic trends, political stability, government (settlement) policies, market incentives, media organizations, the biophysical environment, and climatic conditions.
Related socio-ecological systems (ECO)	Other livelihood systems which are interlinked with the one in question.
Dashed arrows	These denote feedback from action situations [22].
Dotted-and-dashed lines	These surround the focal SES and are influenced by exogenous factors, which might emerge from dynamic processes at larger or smaller scales, either inside or outside the focal SES [22].

In our framework, there is an agricultural livelihood system (ALS) in which an agricultural activity (x) is the livelihood unit (LU). The direct user(s) (DU) rely on the LU to make a living in a specific territory. To produce and sustain this LU different livelihood assets (LA) are required (human, social, natural, physical, financial). Both the LA and the LU are vulnerable to different types of hazards. The covariate manifestation of the hazard (public bad risk) in the LU is strongly influenced by the DUs' collective actions to prevent and control the hazard. Those collective actions are constrained or enhanced by multiple factors (risk perspective, social dilemmas, capacity to adapt and respond). The DUs' actions continuously interact with the risk governance system, influencing and being influenced by the set of formal and informal rules and strategies to manage a public bad risk. If collective action between DUs fails, the likelihood of the risk of a public bad increases, which then impacts upon the system's interactions and outcomes, possibly leading to the emergence of a public bad risk that harms various essential LAs and LUs. The damage to the LAs and LUs in turn negatively impacts the provision of ecosystem services to the DU and, possibly, other SES.

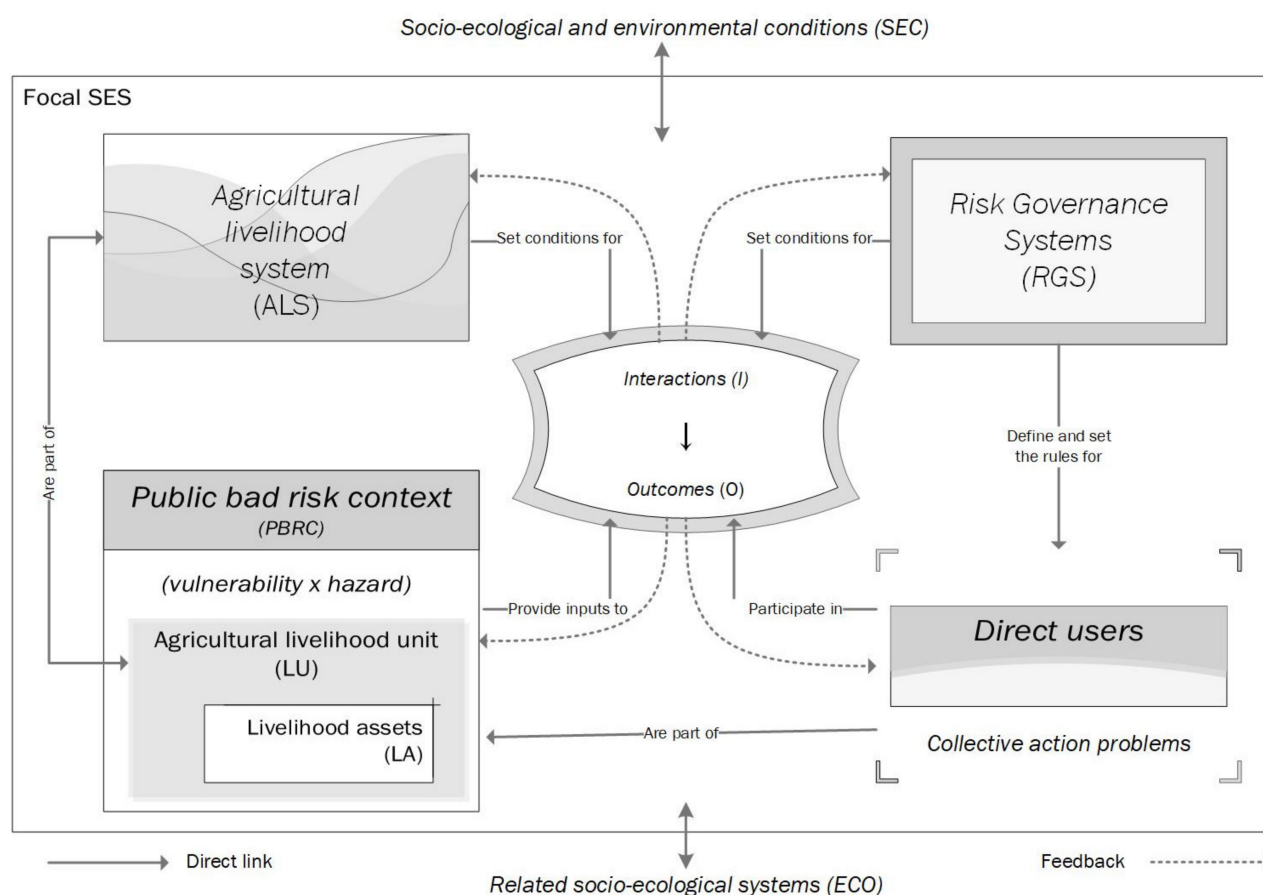


Figure 1. The core subsystems within a socio-ecological system that provide the framework for analyzing a public bad risk that threatens livelihood resilience from a risk and collective action problem perspective. Adapted from Ostrom (2007), Copyright (2007) National Academy of Sciences [11].

Humans intervene in natural systems that provide ecosystem services (i.e., crop or livestock production) to people (consumers) and a livelihood to those providing those services (farmers) [23]. A livelihood includes the capabilities, assets, and activities required for a means of living. It is resilient when people have the capacity, across generations, to sustain and improve their livelihood opportunities and wellbeing despite environmental, economic, social, and political disturbances [24]. The performance of agricultural livelihoods largely depends on the accessibility of assets (or capitals): natural, physical, human, financial, and social [25]. Assets are vulnerable to different kinds of hazards, such as natural, environmental, or biological hazards. Infectious diseases are among the most challenging biological hazards and can affect humans, animals, and crops. Those same people, animals, or crops are also critical assets for agricultural livelihoods. Hence, livelihood resilience to biological hazards, and especially infectious diseases, is critical for the food security of smallholder farmers and global society as a whole [26].

We further contextualize our framework for the context of infectious disease. There are numerous examples where our framework can support analysis of resilience to a public bad risk as a result of an infectious disease (Table 2.)

The spread of an infectious disease is a public bad because it is (mostly) non-excludible and non-rival. In effect, infectious diseases can affect large numbers of humans (epidemic), animals (epizootic), and plants (empathetic) and can have disastrous socio-economic and ecological consequences. According to the disease triangle model [31], the risk of disease damage to a host is a function of the interactions between the environment, host, and pathogen. These interactions are often determined by human behaviour and responses to environmental changes. Human activities enable pathogens to disseminate and evolve, creating favourable conditions for diverse manifestations of infectious diseases [32]. Gener-

ally, collective action is required to prevent and control the spread of diseases that threaten (agricultural) livelihoods and to achieve resilience.

Table 2. Components from a SES framework to analyze resilience to a public bad risk.

Host-Livelihood Units	Public Bad Risk Conditions (Vulnerability and Hazards)			Livelihood Units Fatality/Losses	Users Risk Management Strategies That Require Coordination and Cooperation
	Disease	Infectious Agent	Infection Mechanism		
A person (labor, knowledge, etc.)	Malaria	Various plasmodium parasites	Transmitted by the bite of the anopheles mosquito	Over 60 deaths per 1000 admitted in cases of children age < 5 years	Draining of standing water where mosquitos breed, spraying living and sleeping quarters, and the use of bed nets [27]
A person (labor, knowledge, etc.)	Coronavirus	SARS-CoV-2 (COVID-19) virus	Person to person transmission via respiratory droplets generated by breathing, coughing, sneezing or, hand-mediated transfer from contaminated surfaces to mouth, nose, or eyes [28]	2% case fatality due to alveolar [29] damage or respiratory failure	Social distancing, wearing facemasks in public spaces, rigorous disinfection, reporting confirmed cases, pro-active contact-tracing and testing of potentially infected individuals
A cow (meat, milk as food or income)	Tick-borne diseases (Babesiosis, ECF, others)	Different parasites and bacteria	Different kinds of ticks spread the diseases	Mortality rate of up to 80% in animals susceptible to ECF	Tick control measures (vaccination, applying acaricides, grass sward height reduction), resistant breeds [8]
Banana crop (banana as food or income)	Banana Xanthomonas Wilt (BXW)	Bacteria Xanthomonas vasicola pv. musacearum	Infected plant material, cutting tools, long-distance trade, soil, and vectors such as birds, bats, and insects	Yield losses up to 100% if control is delayed	Cultural management practices (male bud removal, tool sterilization), complete mat uprooting (CMU), removal of single diseased stems [30]

Collective action problems are coordination problems challenged by multiple factors, including resilience, socio-economic, and risk [33]. Resilience stresses the importance of individuals' capacity to adapt and respond as determinants of self-organization [34]. The economic perspective highlights self-interest-based choices as determinants of collective irrationality, influenced by different forms of social capital, such as trust, identity, and reciprocity [35]. Lastly, risk perceptions are determinants of people's behaviour towards threats [21]. These three factors play a critical role in risk governance. We define governance here as the actions, processes, traditions, and institutions, encompassing state and non-state actors, to bind decisions collectively, without superior authority. Risk governance, then, applies the principles of good governance to the identification, assessment, management, and communication of risks. Risk governance, involving various stakeholders, analyses and leads to the formulation of risk management strategies, which need to consider the broader legal, political, economic, and social contexts in which a risk can be managed [20].

3. Methodological Background and Proposal

Economic experiments have for decades been the most common method to test theories about social dilemmas with specific variables repeated in controlled settings. Laboratory and field experiments have been particularly useful in studying common and public goods in the context of resource and environmental issues. Experimental designs are mostly driven by behavioural and institutional concerns [36]. Both laboratory and field experiments involve humans as experimental subjects, in the latter case the participants are familiar with the problem being studied. Ostrom made ground-breaking contributions to collective-action research, using laboratory experiments and case studies to study the role of communication, sanctioning, and institutional rules, among other variables, for achieving collective action [37]. Inspired by her work, many other researchers have car-

ried out laboratory and field experiments in public goods (PG) and common goods (CG), with most of them keeping the production function externalities and resource dynamics simple [38]. Because of those experiments we today know that individuals may contribute to the production of a PG or limit their use of a CG, due to reciprocity, trust, identity, or general pro-social behaviour [39].

Growing awareness about the human influence on biophysical systems led to the focus of collective action research shifting to socio-ecological systems (SES) perspectives, resulting in new field experimental designs to study collective action problems. For example, Cardenas et al. (2013) designed three field experiments that were framed in fishery, forestry, and irrigation systems [40]. The major design innovation of those experiments was the introduction of the ecological complexities of social dilemmas in environmental and natural resource problems into behavioural analysis.

Although economic laboratory and field experiments still advance in their understanding of collective action problems, the interpretation of their results remains problematic. This is because individual motives are a function of social norms and other socio-ecological factors [11,35,41,42], putting emergence, a particular characteristic of complex adaptive systems such as an SES as a determinant of the socio-ecological outcomes the property of emergence [10].

An alternative method to understand human behaviour in complex systems is agent-based modelling (ABM), which has gained popularity in recent decades because of its ability to capture emergent phenomena [9]. ABM simulates simplified abstract versions of SES, representing the decision-making of autonomous computational individuals or groups of agents and their interactions with each other and with ecosystems. ABM has been used to study phenomena as diverse as traffic, markets, organizations, the diffusion of innovations, adoption dynamics, policy scenarios, and resource management. It is applied to study the interactions between heterogeneous agents that can generate network effects, in which individual behaviour becomes non-linear, path-dependent, and based on memory, learning, and adaptation [43,44]. The behaviour of each agent is based on a situational assessment yet restricted by a specific ruleset. Despite the wide use of ABM in different fields, its application in the social, political, and economic sciences is not without barriers. This is caused by human nature which comes with potentially irrational behaviour, subjective choice-making, and complex psychology, and can make the effects of the emergent processes difficult to predict or even counterintuitive [45]. The main implication of this is that a given social process cannot truly be understood when studied in isolation, out of its context, or frozen in time [46].

The power of economic experiments and ABM lies in their capacity to simplify the complex and transform it into manageable dimensions. Both, despite their strengths, limitations, and degrees of complexity, attempt to anticipate agents' behaviour under different conditions. We believe that the limitation of economic experiments and ABM can be overcome by adding a qualitative component. This can increase our understanding of context-specific motivations and provides the next methodological design step for studying problems around collective action. Clancey (2008) notes, *"We cannot locate meaning on the text, life in the cell, the person in the body, knowledge in the brain, a memory in a neuron. Rather, these are all active, dynamic processes, existing only in interactive behaviours of cultural, social, biological, and physical environments"* [47] (p. 28).

To the best of our knowledge (i) neither laboratory nor field experiments have integrated emergent phenomena into their design to study collective action problems, (ii) ABM faces challenges in integrating the complexity of human behaviour into its models, and (iii) there are very few examples where economic experiments and ABM have been applied to study collective action problems to prevent and control public bads [36,48]. We respond to this by proposing a methodology that is a field boardgame experiment (or boardgame) that adds the attributes of an SES and its emergent phenomena. The experiment focuses on studying human cooperation under different stimuli in the prevention and control of a public bad in the context of agricultural livelihoods.

3.1. The Dynamic Socio-Ecological (DySE) Game Design Method

The SES framework to analyze resilience to a public bad risk, integrates a host (the livelihood unit), the public bad risk conditions (the disease, agent, and infection mechanisms), the threat (livelihood unit losses or fatality), and the strategies (based on coordination and cooperation) to prevent and control a public bad (disease spread) into the analysis. For this research, we developed a methodology to operationalize the theoretical framework. It consists of a public good game design method that integrates emergence and spatiality: *a dynamic socio-ecologic game design method*. The game design method is multi-dimensional since it considers ‘what I do’, ‘what others do’, and ‘what ‘it’ does’ (e.g., the vector) in a specific space and time, and under certain conditions. The DySE game’s purpose is to explore human behaviour and how this intertwines with socio-ecological factors surrounding behavioural decision-making.

The game mechanics include a board representing the geographical space, playing cards representing the livelihood units (humans, banana mats, cows), autonomous players (such as the disease vector or institutional actors who follow some ‘real-life’ rules), and the decision-makers (human players). We can understand the mechanical part of the game as the *hardware* where we can experiment. This allows us to test the players’ behaviour (when facing a social dilemma) under different experimental treatments or scenarios (communication, incentives, punishment, etc.), over the game structure that creates emergent conditions with specific factors. The game is followed by a focus group session to explore the reasoning behind the players’ actions, and the results of this are triangulated with quantitative game results. The social dilemmas (i.e., those faced by decision-makers/players), as well as the rules that govern the autonomous players, are a simplified version of the social, ecological, politico-institutional, and environmental rules governing real-life situations. The social dilemmas and scenarios of stimulus constitute the experimental dimension of the game and can be varied according to the research interest.

The same game methodology can be calibrated and tailored to different contexts. Table 3 shows that, in all contexts, the individuals face a social dilemma to take a determinate action. The social-dilemma might relate to an effort or money investment, as could be the case of Malaria and BXW disease, or could also be related to other more intangible aspects, such as the perception of risk or societal norms, as in the case of COVID-19 or gender violence [49,50]. In all the examples, the sum of individual defective choices might have a negative (direct or indirect) collective impact that goes beyond the personal temporary benefit. As the purpose of simplification is to explore behaviour under specific but dynamic circumstances, there are many other influential factors in the prevention and control of the same public bad risk that might not be taken into account. In the next sections, we contextualize the methodology—the *Musa-game*—to the case of banana smallholders in Rwanda, whose production is threatened by BXW disease.

3.2. Case Study: Operationalization of Theoretical Framework to the Case of BXW in Rwanda

For the development of our method, we chose a case study that represents a typical collective action problem: the transmission of the banana disease *Xanthomonas Wilt of Banana* (BXW) disease by insect vectors and its management by farmers in Rwanda. In this section, we describe the BXW disease problem and the existing practices to prevent and control BXW. Based on this input we operationalized the general SES framework (Figure 2).

Banana is one of the most important crops in sustaining household food security and livelihoods in Rwanda. However, BXW, caused by the bacterium *Xanthomonas vasicola* pv. *musacearum* (formerly *Xanthomonas campestris* pv. *Musacearum*) [55], endangers the livelihoods of millions of farmers in East and Central Africa [56] and can result in yield losses up to 100%. BXW is highly transmissible and can spread rapidly through infected plant material, cutting tools, long-distance trade, and vectors such as birds, bats, and insects [57]. The latter become vectors of BXW when visiting a male banana flower of a diseased banana stem in search of food, after which the bacterium is transmitted to the next visited, still healthy, stem with flower. Vector mediated transmission of BXW is especially

prevalent in lowland areas with high insect density [58], yet can be prevented if farmers comply with the cultural practice of cutting the male flower with a forked stick as soon as the last hand has developed (de-budding practice) [57].

Table 3. Examples of application of a dynamic socio-ecologic game.

Public Bad Risk	What I Do	What the Others Do	What It Does	Collective Impact
Malaria	I drain the standing water where mosquitos can breed	My neighbours do not drain the standing water where mosquitos can breed	Mosquitos breed in standing water close to where I live and become plasmodium vectors	Avoidable sickness or deaths; further impoverishment of poor households, and communities [51]
COVID-19	I stay at home with flu-like symptoms or get tested for COVID-19	My neighbour goes out to the supermarket with flu-like symptoms and is later tested COVID-19 positive	The virus spreads via droplets of infected saliva when my neighbour coughs in the supermarket	Avoidable deaths: potential collapse of the healthcare system, need for collective measures and law enforcement [52]
Banana Xanthomonas Wilt (BXW)	I remove banana flowers and disinfect my machete before working in my neighbours' banana plantation	My neighbour has BXW infected banana mats on his plantation. He does not remove banana flowers nor disinfect his machete before working on my plantation	The BXW bacterium spreads to my banana plantation through my neighbour's machete and infects my bananas	Decrease of local food security; further impoverishment of poor households; loss of livelihoods [53]
Gender violence and femicide	I maintain a relationship with my partner in which neither of us assaults the other and we stay away from substance abuse. However, I frequently hear my neighbour is assaulted. I do not report this to authorities	My neighbour has a drinking problem and violently assaults his wife when he is drunk. People in the community know this but shut their eyes to it, and do not report it to authorities	In a drunken outrage, the man assassinates his wife with a pistol	Gender violence becomes a public health problem [54]; abused women suffer from mental and physical issues; large numbers of women are killed annually, often by a (former) partner

No cure exists for BXW, once the pathogen has established in a stem it will inevitably die. Complete eradication of BXW is considered impossible, however, the disease can be managed with good preventative agricultural practices and early response to disease outbreaks. Disease symptoms appear soon after infection, causing yellowing and wilting of leaves, premature ripening of fruits, brown stains in the fruit pulp, and rotting of the male flower, and eventually wilting and rotting of the entire stem. Infected plots should not be replanted with bananas for up to 6 to 8 months due to soil-borne inoculum of the pathogen [59].

Provision of advice on disease prevention, control, monitoring, and response to outbreaks is the responsibility of the governmental agency, Rwanda Agriculture and Animal Resources Board (RAB). Its current policy for BXW disease outbreaks prescribes 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 to reduce chances of further disease transmission. In high incidence cases (>70% of the banana mats showing symptoms), the whole plantation must be uprooted [60]. Although effective, CMU is also labour intensive, time-consuming, and socially costly and has therefore major implications for food and income production. It has an impact on livelihoods making farmers reluctant to comply with good BXW management practices, which is further exaggerated by perceptions of the (in)effectiveness of disease management.

Some farmers hide the disease, by cutting down symptomatic stems or leaves, to avoid enforced uprooting [30,61].

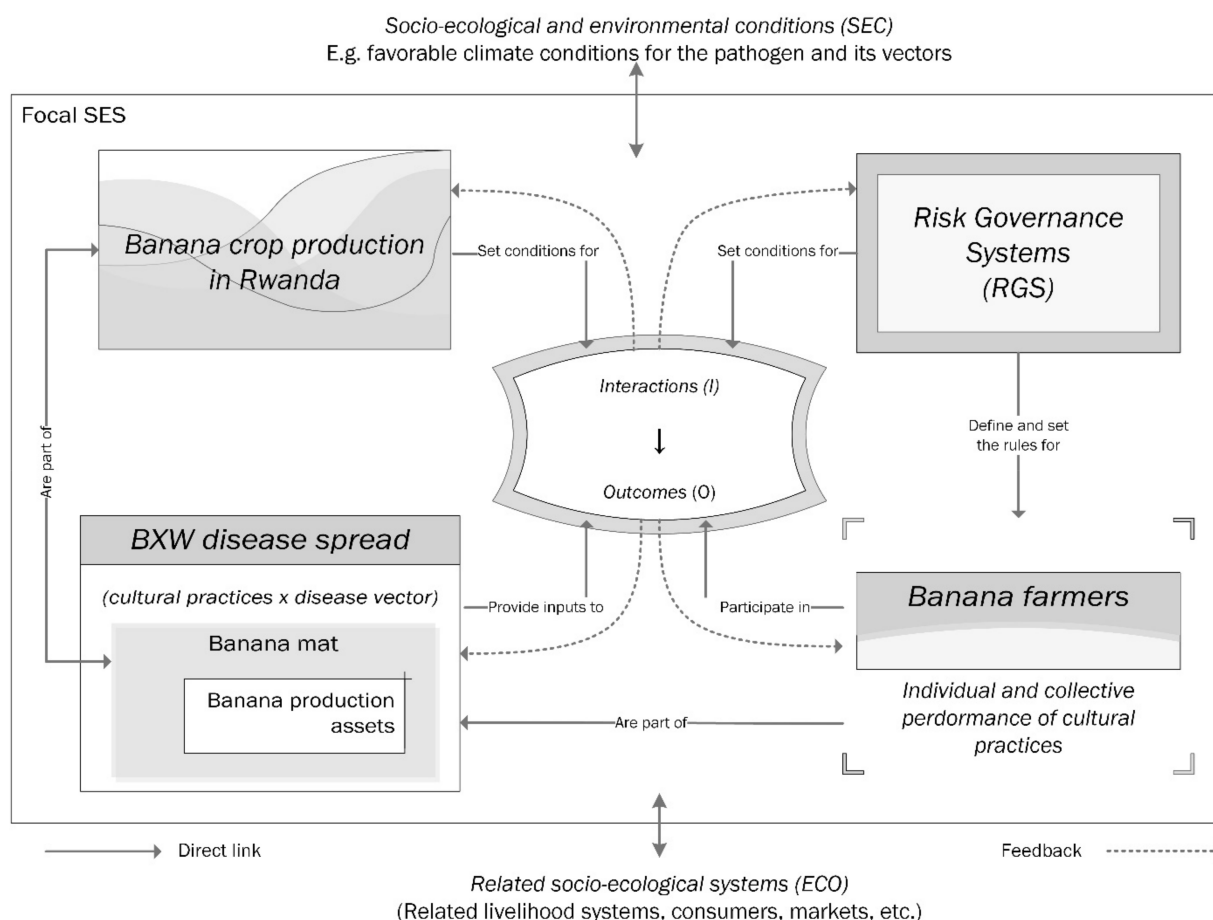


Figure 2. The core subsystems in a framework for analyzing a public bad risk (BXW disease spread) threatening agricultural livelihoods based on banana production in the context of a socio-ecological system from a risk and collective action problem perspective. Adapted from Ostrom (2007), Copyright (2007) National Academy of Sciences [11].

Regardless of the disease control practice, effective management always requires at least a combination of specific knowledge and know-how (e.g., to understand disease epidemiology, recognize disease symptoms, and uproot diseased stems), timely use of cultural prevention and control practices, and, preferably, collective action. A study in DR Congo showed the latter to be more effective for BXW control than individual action [59]. Additionally, the Government needs to provide effective support mechanisms, e.g., advisory services, monitoring [61]. Prevention of the spread of the disease can only be achieved (efficiently) if all the involved stakeholders work in a coordinated manner.

4. The Musa-Game: A Dynamic Socio-Ecologic Method

In this section, we describe step-by-step the design of the experimental board game to evaluate farmers' performance when facing a hypothetical crop disease outbreak in different risk governance scenarios. We named this game the Musa-game ('musa' meaning banana in Kiswahili language). The Musa-game is an experimental and participatory evaluation tool, representing principles from an economic field experiment, an agent-based model, and a role game within a dynamic socio-ecological context. The main properties of the game's mechanics and arena are: (1) represent a simplified and abstract depiction of the social-ecological forces that affect farmers' risk perception (and dilemmas) and decision-making about disease management and control; (2) allow for the performance of different risk governance scenarios through specific operationalization of experimental variables

for different treatments; (3) make it possible to trace the development of strategic game behaviour through the use of audio-visual data collection methods; (4) simple calculation of individual and collective outcomes (benefits and losses) immediately after the game ends; (5) achievement of common experience through facilitating post-game discussions, and; (6) collection and analysis of qualitative and quantitative data using mixed methods.

Before coming to the version of Musa-game presented in this paper we went through several iterative cycles, involving various scientists and practitioners in the design and pre-testing, to develop game mechanics and physical design. Feedback on the design was given by individuals and in group sessions. The data collection process was designed and pre-tested similarly. Real-life operationalization of the Musa-game requires the involvement of real actors who (have) experience (d) the social dilemma to adopt or not adopt strategies to prevent or control a public bad that threatens their livelihood. Individual farmers' decisions are influenced by the interplay between different farmers, other autonomous agents in the system, and environmental changes. This interplay is simultaneous as each agent plays with its individual ruleset. The game rules are a simplified version of real-world SES characteristics. To make simultaneous agent actions and system outcomes possible the experimental arena is a square-board that represents the biophysical space where actions and interactions take place. Qualitative tools, such as focus groups or in-depth interviews, are used post-experiment to better understand context-specific motivations behind peoples' decision-making.

The Musa-game gives an abstract representation of the socio-ecological dynamics between a group of four farmers, their banana mats, the bacterial disease agent (BXW), the insect vectors transmitting the disease, and an external agent who monitors the spread of the disease. The game rules are based on the context of banana production in Rwanda. Being banana farmers themselves, the players are confronted with a realistic representation of the collective action problems which they face in real-life when preventing or controlling the BXW disease. Like in real-life, complete eradication of the disease is impossible. However, minimizing the disease's impact is possible through rigorous and coordinated action. In contrast, uncoordinated action, due to behaviour driven by self-interest, lack of capacity to respond, or poor risk perception, may devastatingly impact livelihoods. Players' profits directly relate to their game performance. The final individual and collective results depend on decisions made by individual players in combination with the influence of events in the game's socio-ecological system. In this section, we present stepwise the theory behind the experimental game design, its implementation, and the data analysis strategies.

The board game's mechanics, physical structure, and experimental treatments were designed based on our specific scientific interests. They could easily be adapted for other purposes or contexts and used to study other SES problems.

4.1. Operationalizing Risk Governance Models in the Game

In the Musa-game farmers encounter a system that is governed top-down. Both the Government's and the farmers' goals are to minimize the risk of disease spread and preserve the continuity of banana production. Government agents determine which agricultural practices must be employed to prevent and/or respond to a disease outbreak. Players are externally organized through random assignment to a treatment group.

Based on Newman's (2001) institutional governance models [61], we have contextualized the dynamics between the governmental agents and the farmers toward the control of BXW disease, as a rational goal model as this comes closest to the reality in Rwanda today [62,63]. The rational goal model is oriented toward a centralized distribution of power and arrangements that create conditions for change. The state divides a problem into manageable fragments and sets goals. Power is dispersed across various agencies, and the responsibility to act is at the local level. Focus is on shorter timelines and maximisation of outputs. Performance is tightly monitored, inspected, and audited. In terms of goal setting, relationships are vertical, cascading from the Government. Relationships are instrumental,

pragmatic and there are efficient horizontal connections. It follows a managerial rather than bureaucratic approach [61].

The Musa-game aims to test farmers' cooperation when preventing or responding to a public bad risk: BXW disease. While the overall game mimics the rational goal governance model, players, who are actual banana farmers, can also self-govern the public bad risk through various risk governance strategies. For this, we used risk governance principles from Van Asselt and Renn (2011): communication, inclusion, integration, and reflection. According to Van Asselt and Renn (2011), these should not be considered separate steps or stages but principles for each step or stage in a risk governance process. These principles create space for risk governance strategies within the complex, uncertain, and ambiguous risk contexts. As such, this approach to risk governance fits with our objective to study a public bad risk within dynamic, emergent, and complex socio-economic systems [20].

4.2. The Physical Environment, and Mechanics, of the Musa-Game

The Musa-game is performed on a square gameboard. Its sides are divided into six rows and six columns, resulting in a total of 36 cells. The X-axis has alphabetical codes from A to F. The Y-axis has numerical codes from one to six. Individual squares can be identified using the (X, Y) coordinates. The board is divided into four quadrants composed of nine cells each, each cell representing one productive banana mat. Quadrants are identifiable through symbols: square, circle, rhombus, and triangle (\square , \circ , \diamond , Δ) (Figure 3). The four quadrants together represent one banana production zone (or banana farming community) in Rwanda, with each quadrant representing a banana field managed by one independent farmer.

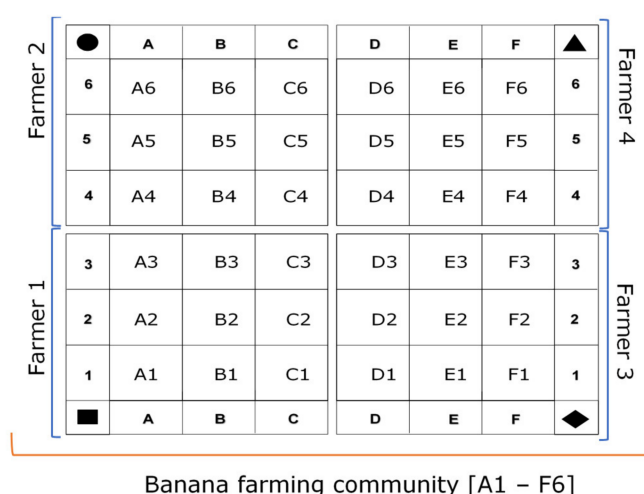
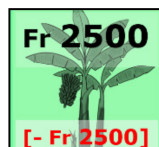
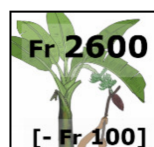


Figure 3. Schematic representation of the game board and the different sections of the board as shown to players. Each farmer has nine cells, e.g., the nine cells D4 to F6 belong to Farmer 4. Each cell contains one productive banana mat, e.g., Cell D4 has one productive banana mat. All farmers start the game with nine productive banana mats.

The game is facilitated by one game master and played by four farmers and two autonomous players: an insect, and a monitor (Figure 4). As a field experiment, the four farmers are people whose real-life livelihood depends on banana production. The movements of the autonomous players are defined randomly by throwing two dices, one with letters and one with numbers (done by the game master) or using statistical software. The combination of the letter and number corresponds with a coordinate on the board, e.g., Combination A and four equals the coordinate A4 on the board. The game's socio-ecological conditions are dynamic and defined by the decision-making of farmer players plus the autonomous actions of the insect and monitor.



3			
2			
1			
	A	B	C

(a) WHITE: healthy mat with flower (b) GREEN: healthy mat without flower

(c) initial conditions of the game per farmer

Figure 4. Initial conditions for each player/farmer. (a) A healthy banana mat with a mother plant in the flowering stage is represented by a white card. The card's value is Fr. 2600. If the farmer decides to cut the flower it costs Fr. 100 (b) A healthy banana mat with a mother plant without a flower is represented by a green card. The card value is Fr. 2500. (c) All players start the game with eight white cards and one green card. The total value of the nine cards is Fr. 23,300.

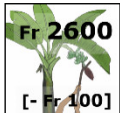




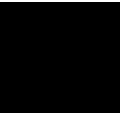
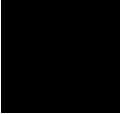

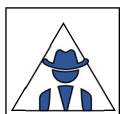

Upon starting the game, each player has nine stacks of four or five cards (one stack for each cell) representing different health stages of a banana mat depending on players' decisions and locations of autonomous players (see Figure 1 and Table 4). The different cards have different economic values, ranging from a maximum profit to a maximum loss. The two cards at the top of the stack are healthy banana mats: (1) white (value = 2600, and (2) green (value = 2500). The next two cards are infected mats: (3) yellow, and (4) red. The bottom card is (5) grey card equalling a dead banana mat (value = 0). The backsides of the yellow and red cards are uprooting cards (value = −500). Only cards (1), (2), (3), and (4) can be removed by the player. To eliminate the chance of a player losing all his or her banana mats in one round the cells E2, E5, B2, and B5 (the central position for each player's quadrant) have no white maximum profit card. The composition of cards at the end of the game determines the player's score, i.e., the total profit or loss made.

4.3. Farmers: Livelihood and Risk

In the game, we assume that each player relies on banana production to meet the basic weekly income needs to sustain their family's livelihood and be food secure. The behaviour of each player is triggered by the experimental setting and changing socio-ecological conditions. Each banana mat faces two threats: one biological, and one institutional. The biological threat is BXW disease, transmitted by the insect visiting a flower in search of nectar. The institutional threat is the disease control measure of the Rwandan Government, existing of random visits by an extension agent whose responsibility it is to contain the disease. The monitor intervenes only when finding a diseased banana mat. Both threats are influenced by the social component, i.e., the farmer's behaviour. This translates into complying with the practice of cutting the banana flower to avoid a biological hazard (white card) or uprooting an infected mat and avoiding an institutional hazard (yellow and red cards).

The goal of the farmer is to safeguard food security and maximize the household's livelihood. The minimum amount of money needed to be food secure is Fr. 15,000. Any surplus at the end of the game represents a profit. When the game starts the player has nine healthy banana mats, eight with a flower (white card) and one without a flower (green card) (Figure 4) together these represent the maximum amount of money that can be earned: $8 \times \text{Fr. } 2600 + 1 \times \text{Fr. } 2500 = \text{Fr. } 23,300$. The maximum profit that can be made by the player is: $\text{Fr. } 23,300 - \text{Fr. } 15,000 = \text{Fr. } 8300$.

Table 4. Overview of cards in the game.

Card	Name	Code	Description
Health stage cards			
	White card	1	Healthy mat with flower
	Green card	2	Healthy mat without flower
	Yellow card	3	A BXW infected banana mat in the first disease stage. An idiosyncratic institutional threat. The card value is Fr. 0
	Red card	4	A BXW infected banana mat in the second disease stage. The card value is Fr. 0. A covariate institutional threat. The cost of uprooting is Fr. 500
	Grey card	5	A dead banana mat that was not uprooted in disease stage one or two. The mat is no longer a threat. The card value is Fr. 0
Uprooting cards			
	Yellow uproot	31	The backside of the yellow uproot card appears when the player decides to uproot a yellow BXW infected mat. The action costs the farmer Fr. 500.
	Red uproot	41	The backside of the red uproot card appears when the player decides to uproot a red BXW infected mat. The action costs the farmer Fr. 500.
Autonomous player cards			
	Insect card	I	Biological threat. The insect is the BXW vector and searches for nectar from a healthy mat with a flower. A visited mat becomes BXW infected and turns yellow.
	Monitor card	M	Institutional threat. The monitor represents a governmental agent monitoring banana mats and intervenes when a yellow or red card is found (Codes 3 or 4). Codes 1, 31, 41, 5, 6 do not represent an institutional threat, when the monitor inspects them there is no intervention.
Other cards			
	Monitor intervention card	6	Monitor intervention card (uprooting activity in progress). Placed on the stack after a monitor finds a yellow or red card and intervenes.

Therefore, Equations (1) and (2):

$$\text{Net income} = [(n. \text{ cards } 1 \times 2600 \text{ Fr.}) + (n. \text{ cards } 2 \times 2500 \text{ Fr.}) - (n. \text{ cards } 31 \times 500) - (n. \text{ cards } 41 \times 500)] \quad (1)$$

$$\text{Individual net profit} = \text{Net income} - \text{individual food security threshold} \quad (2)$$

Each banana mat with a flower is at risk of BXW infection. As a preventative measure against BXW, the player can decide to cut the flower. The investment cost of cutting the flower is Fr. 100, which represents the real-life mobility and labour effort of the farmer. After cutting, the top card becomes green (value = Fr. 2500) and the mat is protected against the biological hazard.

4.4. The Insect Vector and Disease Progress

The insect player card represents the autonomous insect vector that carries the BXW bacterium which causes BXW in bananas. The purpose of the insect is to find nectar in banana flowers. While doing so the insect can transmit the disease from mat to mat. In the Musa-game, the insect is always a carrier of BXW. The insect moves randomly in search of a flower (white card), creating the effect of emergence. The random location can be any of the game board's coordinates (A1:F6). By definition, the insect always searches for a white card. If there is no white card at a defined location, the insect moves clockwise (from the perspective of the player in whose quadrant the location is) without considering quadrant boundaries until finding a white card (Figure 5). The mat in this location becomes infected with BXW (yellow card value = Fr. 0). This is the first disease stage. In the next round, the player can decide to invest and uproot this mat (yellow uproot card, investment = Fr. 500), or not invest and let the disease progress to the second stage (red card, value = Fr. 0). In the latter scenario, uprooting is again possible in the next round (red uproot card, investment = Fr. 500). If again not uprooted, the mat dies (grey card, value Fr. 0). A mat in the first or second disease stage is an idiosyncratic institutional threat.

4.5. The Monitor

The monitor card represents an extension agent who is responsible for keeping the community BXW disease-free. Every game around the monitor checks one banana mat at random, creating the effect of emergence. The random location can be any of the coordinates on the game board (A1:F6) and is also the monitor's final location for that round (Figure 6). The intervention takes place (or not) depending on the health status of the mat in that location. If the mat is healthy (i.e., white or green card) or dead (grey card) no action is taken. If it is diseased (yellow or red card) the control measure is performed. The control measure involves uprooting the infected mat plus, depending on infection status, all mats neighbouring the diseased mat either in that specific quadrant (yellow card) or in all quadrants (red card). In both scenarios, the neighbouring mats are uprooted regardless of their health status. Thus, six mats (belonging to one or more farmers) could be lost.

4.6. Identifying Corner Solutions: Fully Cooperative and Fully Defecting Playing Strategies

The most cooperative strategy is to form blocks of nine mats from the centre of the board (Figure 7). This minimizes the potential harm to neighbour farmers if the monitor discovers an un-uprooted diseased mat. The value zero represents the initial condition without a flower of cells B2, B5, E2, and E5. Values one to four represent the potential order that players could choose to cut flowers in a cooperative strategy scenario. The three scenarios assume the maximum investment in cutting flowers per round (=2 flowers/round/player). If farmers defect, i.e., fail to invest in cutting flowers and/or start cutting from the centre the other players are more at risk of being harmed by a neighbour's diseased mat.

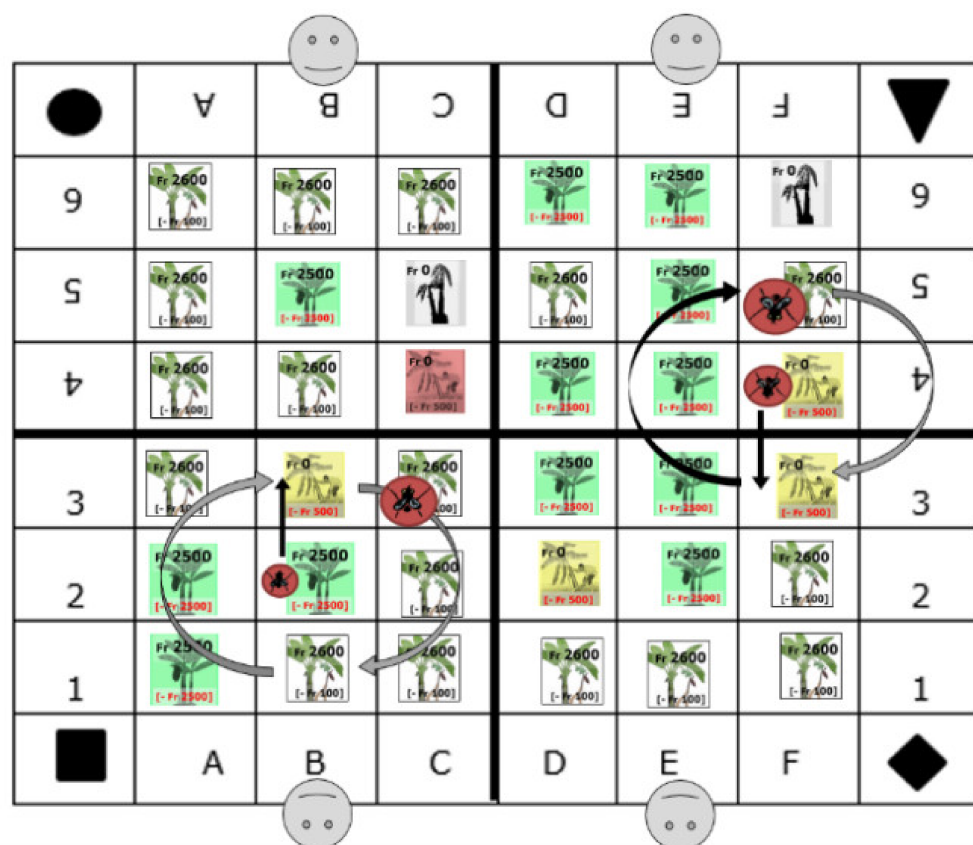


Figure 5. Schematic example of how the insect moves until it finds a white card (= with flower).

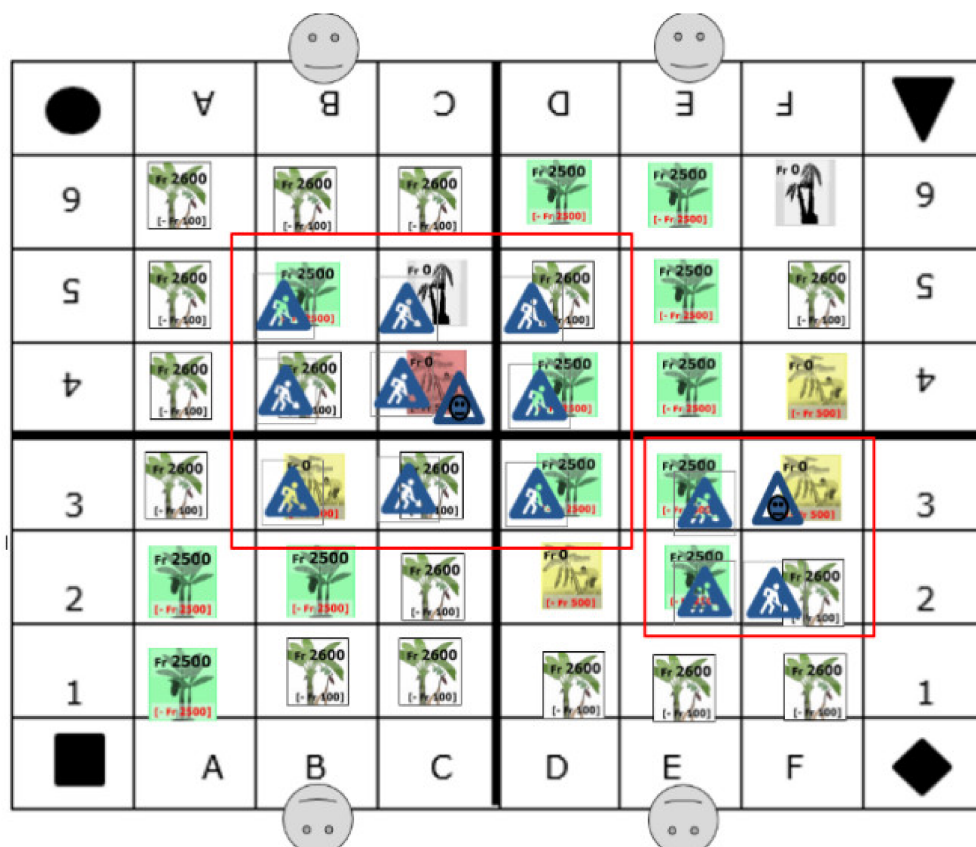


Figure 6. Intervention rules for the monitor.

○	A	B	C	D	E	F	△
6	4	4	3	3	4	4	6
5	3	0	1	1	0	3	5
4	2	2	1	1	2	2	4
3	2	2	1	1	2	2	3
2	3	0	1	1	0	3	2
1	4	4	3	3	4	4	1
□	A	B	C	D	E	F	◇

(a)

○	A	B	C	D	E	F	△
6	4	3	2	2	3	4	6
5	4	0	2	2	0	4	5
4	3	1	1	1	1	3	4
3	3	1	1	1	1	3	3
2	4	0	2	2	0	4	2
1	4	3	2	2	3	4	1
□	A	B	C	D	E	F	◇

(b)

○	A	B	C	D	E	F	△
6	4	4	3	3	4	4	6
5	3	0	1	2	0	3	5
4	2	2	1	1	1	2	4
3	2	1	1	1	2	2	3
2	3	0	2	1	0	3	2
1	4	4	3	3	4	4	1
□	A	B	C	D	E	F	◇

(c)

Figure 7. Disease spread scenarios (explained by quadrants) if players perform cooperative strategies (a,b), or (c) with the insect assigned randomly to one of the mats without a flower in the first round.

4.7. Method Implementation

The Musa-game, as a DySE-game method, serves as a tool to represent the (biophysical) context in which interactions between entities take place during the experiment. These interactions create emergent conditions in a given place and time. The framing of the interactions and the rules and limitations attached to them are the outcome of design choices: experimental subjects, sampling method, variables to study, and experimental design (to review some principles for behavioural experiments and design choices, see [64]). The DySE-game is hence an adaptable tool that can be used to perform a variety of experiments, depending on the research interest. Examples of variables that have previously been studied concerning commons include the role of communication, gender participation, and identity [37,39]. The same variables could be used in a DySE-game to evaluate the emergence and impact of new conditions in a given place and time.

For the framing and design of the Musa-game, we chose the variable of risk communication as our main variable of interest. Other variables may be added by integrating them into the game mechanics. For example, the effect of nudging could be studied by e.g., adding nudging cards to the game which give individual players specific disease management advice. We, however, advise researchers to be cautionary with adding more variables as it significantly increases the experimental design's complexity and consequently the data collection, traceability, and analysis process, and error chances. With this in mind, we recommend careful consideration of the research interest and a selection of variables that concisely fit that interest, as we did with the risk communication variable. In terms of sampling, we recommend a randomized complete blocks design with oversampling to compensate for potential no-shows of sampled players.

Traceability of the data can be challenging given that there are multiple (autonomous) players, rounds, and locations where events can emerge. Based on experiences from designing and pre-testing Musa-game we recommend as follows:

Data collection method: A combination of paper data-entry forms to collect data in real-time and a camera set-up that records audio and video of the full game from above the game table.

Guarding playing anonymity: The camera set-up only captures the gameboard and hands of players; no faces are visible. Players are assigned a unique identifier code to anonymize the data.

Facilitation process: Two facilitators per game table who speak the players' language and the language used by the researchers (e.g., English). The game is facilitated in the local language. One person takes the role of the game master, the other one is note-taker (filling data-entry forms and taking observational notes). Both conduct pre-game surveys. One game master leads the post-game discussion.

Game protocol and training of facilitators: A step-by-step protocol for the game is required, including instructions about the game mechanics, set-up of the game-board and data collection equipment, data management, player consent and anonymity (forms),

scripted explanation of the game to be given to players. Facilitators need extensive training on the method and the philosophy behind it to become true masters of the game.

5. Discussion and Conclusions

This paper presented a framework and experimental game method (Musa-game) for analyzing a public bad risk that threatens livelihood resilience and is Part 1 of a two-part study. We studied a public bad from a risk and collective action problem perspective, building upon Ostrom's SES framework (2009) [11]. Like Ostrom's framework, our public bad adaptation of it emphasizes the role of emergent phenomena in decision-making. These emergent phenomena were operationalized for the context of BXW disease management and included in the design of Musa-game. In the game, the theoretical definition of emergence is reflected by the game's entities (i.e., insect, monitor, and farmer players) and the socio-ecological rules of the system that create new conditions to which players (i.e., farmers) need to adapt via individual and collective action. Part 2 of our study (published separately in this journal) presents preliminary results that support our claim in this article that Musa-game can give relevant insights in the diverse interactions between entities and their decisions and lead to the emergence of unpredictable and interdependent risk scenarios.

Games are useful tools to deal with sensitive topics (e.g., the role of self-interest, institutional arrangements, perceptions of risk, knowledge) in a self-exposed way. Scientists and practitioners participating in pre-testing the game design noted that playing Musa-game provided powerful learning about the interconnectedness of individuals' decisions, and technical disease aspects [65]. We further explored this when testing the method in Rwanda and confirmed that Musa-game can be a relevant learning tool too (see Part 2 of our study for more detail). The specific design features of Musa-game, e.g., addition of emergence and spatial analysis could enable us to contribute to understanding about the intertwinement of the biophysical environment and individual choices and their shaping of both individual and collective resilience. Playing a game together before a focus group discussion offers players a shared experience, triggering their thought processes around real-life situations, and collective sense-making of how individual decisions affect collective resilience [65–68].

Pre-test participants suggested that this kind of game could have great potential for studying and learning about various other complex problems. Although Musa-game was designed to study BXW disease management, we believe that the same method, in some adaptations, is also suitable for a variety of other complex socio-ecological problems. Examples of such problems are those in Table 2, including malaria and COVID-19. Additionally, the design of Musa-game offers opportunities to gain insight into issues regarding risk governance and communication and the kinds of interventions needed to address these issues. The next step is to field-test the method with banana farmers in Rwanda to try out practical implementation and verify if playing the game in a real-world setting indeed results in the type of data we expect based on the theoretical and conceptual design.

Author Contributions: Conceptualization, J.A.G.-V.; methodology, J.A.G.-V., M.M.; validation, J.A.G.-V., M.M.; formal analysis, J.A.G.-V., M.M.; investigation, J.A.G.-V., M.M.; writing—original draft preparation, J.A.G.-V.; writing—review and editing, J.A.G.-V., M.M., C.L. and F.C.; visualization, J.A.G.-V.; supervision, C.L. and F.C.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was undertaken as part of the CGIAR Research Program on Roots, Tubers, and Bananas (RTB). Additional support for this work was provided by the German Federal Ministry of Economic Cooperation and Development (BMZ) commissioned and administered through the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Fund for International Agricultural Research (FIA), Grant Number: 81219434, the Wageningen University Interdisciplinary Research and Education Fund (INREF), SENESCYT (Secretaría de Educación Superior, Ciencia, Tecnología e Innovación), and ESPOL (Escuela Superior Politécnica del Litoral).

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Wageningen University and Research (protocol code Netherlands Code of Conduct for Research Integrity 2018 and approved on 1 April 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Acknowledgments: The authors acknowledge the valuable early contributions of Luís García and Ynte van Dam in developing this method.

Conflicts of Interest: The authors declare no conflict of interest. This paper is intended to disseminate research and practices about the production and utilization of roots, tubers, and bananas and to encourage debate and an exchange of ideas. The views expressed in the paper are those of the authors and do not necessarily reflect the official position of RTB, CGIAR, or the publishing institution.

References

1. Olson, M. *The Logic of Collective Action*; Harvard University Press: Cambridge, MA, USA, 1971.
2. Dawes, R.M.; Van De Kragt, A.J.; Orbell, J.M. Not me or thee but we: The importance of group identity in eliciting cooperation in dilemma situations: Experimental manipulations. *Acta Psychol.* **1988**, *68*, 83–97. [\[CrossRef\]](#)
3. Kollock, P. Social Dilemmas: The Anatomy of Cooperation. *Annu. Rev. Sociol.* **1998**, *24*, 183–214. [\[CrossRef\]](#)
4. Sonnemans, J.; Schram, A.; Offerman, T. Public good provision and public bad prevention: The effect of framing. *J. Econ. Behav. Organ.* **1998**, *34*, 143–161. [\[CrossRef\]](#)
5. Lloyd, W.F. Lloyd on the Checks to Population. *Popul. Dev. Rev.* **1980**, *6*, 473. [\[CrossRef\]](#)
6. Hardin, G. The Tragedy of the Commons. *Science* **1968**, *162*, 1243–1248. [\[CrossRef\]](#) [\[PubMed\]](#)
7. Hall, J.C.; Harper, S. (Eds.) *Economic and Political Institutions and Development*; Springer Nature: Cham, Switzerland, 2019.
8. Mutavi, F.; Aarts, N.; Van Paassen, A.; Heitkönig, I.; Wieland, B. Techne meets Metis: Knowledge and practices for tick control in Laikipia County, Kenya. *NJAS Wagening. J. Life Sci.* **2018**, *86–87*, 136–145. [\[CrossRef\]](#)
9. Bonabeau, E. Agent-based modeling: Methods and techniques for simulating human systems. *Proc. Natl. Acad. Sci. USA* **2002**, *99*, 7280–7287. [\[CrossRef\]](#)
10. Schlüter, M.; Haider, L.J.; Lade, S.; Lindkvist, E.; Martin, R.; Orach, K.; Wijermans, N.; Folke, C. Capturing emergent phenomena in social-ecological systems: An analytical framework. *Ecol. Soc.* **2019**, *24*. [\[CrossRef\]](#)
11. Ostrom, E. A diagnostic approach for going beyond panaceas. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 15181–15187. [\[CrossRef\]](#)
12. Hamlin, A.; Ostrom, E.; Gardner, R.; Walter, J. Rules, Games, and Common-Pool Resources. *Econ. J.* **1995**, *105*, 1034. [\[CrossRef\]](#)
13. Coff, C.; The Gatsby Charitable Foundation; de Jong, W.; Galloway, G.; Katila, P.; Pacheco, P.; Schwartz, B. Benchmarking the Policies and Practices of International Hydropower Companies. *World Dev.* **2015**, *28*, 26.
14. Samberg, L.H.; Gerber, J.; Ramankutty, N.; Herrero, M.; West, P. Subnational distribution of average farm size and smallholder contributions to global food production. *Environ. Res. Lett.* **2016**, *11*, 124010. [\[CrossRef\]](#)
15. Rivera-ferre, M.G.; Ortega-Cerdà, M.; Baumgärtner, J. Rethinking Study and Management of Agricultural Systems for Policy Design. *Sustainability* **2013**, *5*, 3858–3875. [\[CrossRef\]](#)
16. Gunderson, L.H.; Holling, C.S. *Panarchy: Understanding Transformations in Human and Natural Systems*; Island Press: Washington, DC, USA, 2001.
17. Ostrom, E.; Cox, M. Moving beyond panaceas: A multi-tiered diagnostic approach for social-ecological analysis. *Environ. Conserv.* **2010**, *37*, 451–463. [\[CrossRef\]](#)
18. Turner, B.L.; Kasperson, R.E.; Matson, P.A.; McCarthy, J.J.; Corell, R.W.; Christensen, L.; Eckley, N.; Kasperson, J.X.; Luers, A.; Martello, M.L.; et al. A framework for vulnerability analysis in sustainability science. *Proc. Natl. Acad. Sci. USA* **2003**, *100*, 8074–8079. [\[CrossRef\]](#)
19. Blaikie, P.; Cannon, T.; Davis, I.; Wisner, B. *At Risk: Natural Hazards, People's Vulnerability and Disasters*; Routledge: London, UK, 1994.
20. Van Asselt, M.B.; Renn, O. Risk governance. *J. Risk Res.* **2011**, *14*, 431–449. [\[CrossRef\]](#)
21. Wachinger, G.; Renn, O.; Begg, C.; Kuhlicke, C. The risk perception paradox-implications for governance and communication of natural hazards. *Risk Anal.* **2013**, *33*, 1049–1065. [\[CrossRef\]](#)
22. McGinnis, M.D.; Ostrom, E. Social-ecological system framework: Initial changes and continuing challenges. *Ecol. Soc.* **2014**, *19*. [\[CrossRef\]](#)
23. Cabel, J.F.; Oelofse, M. An indicator framework for assessing agroecosystem resilience. *Ecol. Soc.* **2012**, *17*, 18. [\[CrossRef\]](#)
24. Tanner, T.; Lewis, D.; Wrathall, D.; Bronen, R.; Cradock-Henry, N.; Huq, S.; Lawless, C.J.; Nawrotzki, R.; Prasad, V.; Rahman, A.; et al. Livelihood resilience in the face of climate change. *Nat. Clim. Chang.* **2015**, *5*, 23–26. [\[CrossRef\]](#)
25. Niehof, A.; Price, L. *Rural Livelihood Systems: Conceptual Framework*; UPWARD Working Paper Series No. 5; International Potato Center: Wageningen, The Netherlands, 2001.
26. Food and Agriculture Organization of the United Nations (FAO). The Impact of Disasters and Crises on Agriculture and Food Security. 2017. Available online: www.fao.org/publications (accessed on 20 August 2020).

27. Murindahabi, M.M.; Asingizwe, D.; Poortvliet, P.M.; van Vliet, A.; Hakizimana, E.; Mutesa, L.; Takken, W.; Koenraadt, C.J. A citizen science approach for malaria mosquito surveillance and control in Rwanda. *NJAS Wagening. J. Life Sci.* **2018**, *86–87*, 101–110. [\[CrossRef\]](#)
28. ECDC. Transmission of COVID-19. *European Centre for Disease Prevention and Control*. 2020. Available online: <https://www.ecdc.europa.eu/en/covid-19-pandemic> (accessed on 20 August 2020).
29. Xu, Z.; Shi, L.; Wang, Y.; Zhang, J.; Huang, L.; Zhang, C.; Liu, S.; Zhao, P.; Liu, H.; Zhu, L.; et al. Pathological findings of COVID-19 associated with acute respiratory distress syndrome. *Lancet Respir. Med.* **2020**, *8*, 420–422. [\[CrossRef\]](#)
30. McCampbell, M.; Schut, M.; Bergh, I.V.D.; Van Schagen, B.; Vanlauwe, B.; Blomme, G.; Gaidashova, S.; Njukwe, E.; Leeuwis, C. Xanthomonas wilt of Banana (BXW) in Central Africa: Opportunities, challenges, and pathways for citizen science and ICT-based control and prevention strategies. *NJAS Wagening. J. Life Sci.* **2018**, *86–87*, 89–100. [\[CrossRef\]](#)
31. Scholthof, K.-B.G. The disease triangle: Pathogens, the environment and society. *Nat. Rev. Genet.* **2006**, *5*, 152–156. [\[CrossRef\]](#)
32. Mayer, K.H.; Piezer, H.F. (Eds.) *The Social Ecology of Infectious Diseases*, 1st ed.; Academic Press: London, UK, 2008.
33. Meinzen-Dick, R.; DiGregorio, M.; McCarthy, N. Methods for studying collective action in rural development. *Agric. Syst.* **2004**, *82*, 197–214. [\[CrossRef\]](#)
34. Berkes, F.; Ross, H. Community Resilience: Toward an Integrated Approach. *Soc. Nat. Resour.* **2013**, *26*, 5–20. [\[CrossRef\]](#)
35. Ostrom, E. A Behavioral Approach to the Rational Choice Theory of Collective Action: Presidential Address, American Political Science Association, 1997. *Am. Political Sci. Rev.* **1998**, *92*, 1–22. [\[CrossRef\]](#)
36. Kurzban, R.; Houser, D. Experiments investigating cooperative types in humans: A complement to evolutionary theory and simulations. *Proc. Natl. Acad. Sci. USA* **2005**, *102*, 1803–1807. [\[CrossRef\]](#)
37. Ostrom, E. The value-added of laboratory experiments for the study of institutions and common-pool resources. *J. Econ. Behav. Organ.* **2006**, *61*, 149–163. [\[CrossRef\]](#)
38. Ostrom, E. How Types of Goods and Property Rights Jointly Affect Collective Action. *J. Theor. Politics* **2003**, *15*, 239–270. [\[CrossRef\]](#)
39. Rand, D.; Nowak, M.A. Human cooperation. *Trends Cogn. Sci.* **2013**, *17*, 413–425. [\[CrossRef\]](#)
40. Cardenas, J.-C.; Janssen, M.; Bousquet, F. *Dynamics of Rules and Resources: Three New Field Experiments on Water, Forests and Fisheries*; Edward Elgar Publishing: Cheltenham, UK, 2013; Volume 12964, pp. 319–345.
41. Hagen, E.H.; Hammerstein, P. Game theory and human evolution: A critique of some recent interpretations of experimental games. *Theor. Popul. Biol.* **2006**, *69*, 339–348. [\[CrossRef\]](#)
42. Ostrom, E.; Ahn, T.K. *The Meaning of Social Capital and Its Link to Collective Action*; Handbook on Social Capital; Castiglione, D., van Deth, J.W., Wolleb, G., Eds.; Edward Elgar: Northampton, UK, 2007; pp. 17–35.
43. Balbi, S.; Giupponi, C. Reviewing Agent-Based Modelling of Socio-Ecosystems: A Methodology for the Analysis of Climate Change Adaptation and Sustainability. *SSRN Electron. J.* **2009**, *93*, 2873–2886. [\[CrossRef\]](#)
44. Duffy, J. Chapter 19 Agent-Based Models and Human Subject Experiments. In *Handbook of Computational Economics*; Tesfatsion, L., Judd, K.L., Eds.; Elsevier North Holland: Amsterdam, The Netherlands, 2006; Volume 2, pp. 949–1011. [\[CrossRef\]](#)
45. Smith, E.R.; Conrey, F.R. Agent-Based Modeling: A New Approach for Theory Building in Social Psychology. *Pers. Soc. Psychol. Rev.* **2007**, *11*, 87–104. [\[CrossRef\]](#)
46. Castillo, D.; Bousquet, F.; Janssen, M.A.; Worrapimphong, K.; Cardenas, J.-C. Context matters to explain field experiments: Results from Colombian and Thai fishing villages. *Ecol. Econ.* **2011**, *70*, 1609–1620. [\[CrossRef\]](#)
47. Clancey, W. Scientific Antecedents of Situated Cognition. In *The Cambridge Handbook of Situated Cognition (Cambridge Handbooks in Psychology)*; Robbins, P., Aydede, M., Eds.; Cambridge University Press: Cambridge, UK, 2008; pp. 11–34.
48. Sabzian, H.; Shafia, M.A.; Maleki, A.; Hashemi, S.M.S.; Baghaei, A.; Gharib, H. Theories and Practice of Agent Based Modeling: Some Practical Implications for Economic Planners. 2019. Available online: <http://arxiv.org/abs/1901.08932> (accessed on 20 August 2020).
49. Van Bavel, J.J.; Baicker, K.; Boggio, P.S.; Capraro, V.; Cichocka, A.; Cikara, M.; Crockett, M.J.; Crum, A.J.; Douglas, K.M.; Druckman, J.N.; et al. Using social and behavioural science to support COVID-19 pandemic response. *Nat. Hum. Behav.* **2020**, *4*, 460–471. [\[CrossRef\]](#)
50. Powell, K.E.; Mercy, J.A.; Crosby, A.E.; Dahlberg, L.L.; Simon, T.R. Public Health Models of Violence and Violence Prevention. In *Encyclopedia of Violence, Peace, & Conflict*; Elsevier BV: Amsterdam, The Netherlands, 2008; Volume 679, pp. 1806–1819.
51. Ricci, F. Social implications of malaria and their relationships with poverty. *Mediterr. J. Hematol. Infect. Dis.* **2012**, *4*, e2012048. [\[CrossRef\]](#)
52. Anderson, R.M.; Heesterbeek, H.; Klinkenberg, D.; Hollingsworth, T.D. How will country-based mitigation measures influence the course of the COVID-19 epidemic? *Lancet* **2020**, *395*, 931–934. [\[CrossRef\]](#)
53. Tripathi, L.; Mwangi, M.; Abele, S.; Aritua, V.; Tushemereirwe, W.K.; Bandyopadhyay, R. Xanthomonas wilt: A Threat to Banana Production in East and Central Africa. *Plant Dis.* **2009**, *93*, 440–451. [\[CrossRef\]](#)
54. UNODOC. Global Study of Homicide. *Gender-Related Killing of Women and Girls (Vol. 20)*. United Nations, Vienna. 2018. Available online: https://www.unodc.org/documents/data-and-analysis/GSH2018/GSH18_Gender-related_killing_of_women_and_girls.pdf (accessed on 20 August 2020).

55. Studholme, D.J.; Wicker, E.; Abrare, S.M.; Aspin, A.; Bogdanove, A.; Broders, K.; Dubrow, Z.; Grant, M.; Jones, J.B.; Karamura, G.; et al. Transfer of *Xanthomonas campestris* pv. *arecae* and *X. campestris* pv. *musacearum* to *X. vasicola* (Vauterin) as *X. vasicola* pv. *arecae* comb. nov. and *X. vasicola* pv. *musacearum* comb. nov. and Description of *X. vasicola* pv. *vasculorum* pv. nov. *Phytopathology* **2020**, *110*, 1153–1160. [[CrossRef](#)]
56. Tripathi, L.; Tripathi, J.N. Relative susceptibility of banana cultivars to *Xanthomonas campestris* pv. *Musacearum*. *Afr. J. Biotechnol.* **2009**, *8*, 5343–5350.
57. Tinzaara, W.; Karamura, E.; Kubiriba, J.; Ochola, D.; Ocimati, W.; Blomme, G.; Ssekiwoko, F. The banana *Xanthomonas* wilt epidemic in east and central Africa: Current research and development efforts. *Acta Hort.* **2016**, *1114*, 267–274. [[CrossRef](#)]
58. Jones, D.R. *Handbook of Diseases of Banana, Abacá and Enset*, 2nd ed.; CABI: Boston, MA, USA, 2018.
59. Blomme, G.; Ocimati, W.; Sivirihauma, C.; Lusenge, V.; Bumba, M.; Ntamwira, J. Controlling *Xanthomonas* wilt of banana: Influence of collective application, frequency of application, and social factors on the effectiveness of the Single Diseased Stem Removal technique in eastern Democratic Republic of Congo. *Crop. Prot.* **2019**, *118*, 79–88. [[CrossRef](#)]
60. Hakizamungu, L.; Rukundo, P.; Muhigirwa, J.C.; Mukamuhirwa, F.; Umfuyisoni, J.; Uzayisenga, B.; Kalisa, J.P. *Pest Management Decision Guide: Banana Xanthomonas Wilt (BXW)*; CABI Plantwise: Wallingford, UK, 2020.
61. Uwamahoro, F.; Berlin, A.; Bylund, H.; Bucagu, C.; Yuen, J. Management strategies for banana *Xanthomonas* wilt in Rwanda include mixing indigenous and improved cultivars. *Agron. Sustain. Dev.* **2019**, *39*, 22. [[CrossRef](#)]
62. Newman, J. Joined-Up Government: The Politics of Partnership. In *Modernising Governance: New Labour, Policy and Society*; SAGE Publications Ltd.: London, UK, 2001; pp. 104–126.
63. Harrison, G. Rwanda: An agrarian developmental state? *Third World Q.* **2015**, *37*, 354–370. [[CrossRef](#)]
64. Van Damme, J.; Ansoms, A.; Baret, P.V. Agricultural innovation from above and from below: Confrontation and integration on Rwanda's Hills. *Afr. Aff.* **2013**, *113*, 108–127. [[CrossRef](#)]
65. Eckerd, S.; DuHadway, S.; Bendoly, E.; Carter, C.R.; Kaufmann, L. On making experimental design choices: Discussions on the use and challenges of demand effects, incentives, deception, samples, and vignettes. *J. Oper. Manag.* **2021**, *67*, 261–275. [[CrossRef](#)]
66. Villamar, J.A.G. Social Capital, Collective Action, and Livelihood Resilience: A Multidimensional Approach. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands, 2021.
67. Wilkinson, S. Focus group methodology: A review. *Int. J. Soc. Res. Methodol.* **1998**, *1*, 181–203. [[CrossRef](#)]
68. Chater, N.; Loewenstein, G. The under-appreciated drive for sense-making. *J. Econ. Behav. Organ.* **2016**, *126*, 137–154. [[CrossRef](#)]