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Research paper

Addressing socio-ecological development challenges in the digital age: Exploring the potential of Environmental Virtual Observatories for Connective Action (EVOCA)

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ABSTRACT

Climate change, (a) biotic stresses and environmental degradation are adversely affecting the sustenance of farming communities in Africa. Addressing such challenges requires effective collective action and coordination among stakeholders, which often prove difficult to achieve. Timely and context-specific information on relevant environmental dynamics holds considerable promise to overcome these problems.

This paper investigates the role of citizen science in facilitating knowledge co-creation and sharing between academia, development actors and users in developing country contexts. In our approach, we focus on information sharing platforms (known as Environmental Virtual Observatories, EVOs) and their potential to facilitate adaptive decision-making in six rural case-study areas in Africa.

We complement the existing theory on EVOs with a focused exploration of the connective function of ICT-enabled multi-stakeholder exchange. We propose that increased connectivity may enable new forms of collective action (labelled 'connective action'), relevant to addressing socio-ecological challenges. Along these lines, this paper presents the theoretical and conceptual grounding of a research program that aspires to develop Environmental Virtual Observatories for Connective Action (EVOCAs) and to explore their potential for improved crop, water, livestock and disease management in rural Africa.

1. Introduction

Global environmental change increases the spatial and temporal variability and sensitivity of many natural processes, directly affecting human health, agricultural production and water systems. This creates particular vulnerabilities for rural populations in developing countries. Modern agricultural and environmental sciences increasingly recognize the complexity of coupled human and natural systems and trans- and intra-disciplinary approaches are growing in popularity.

Studying the reciprocal interactions that link human (cultural, economic, social) and natural (biological, physical, chemical) domains is of particular interest in the context of multidimensional agro-ecological problems like plant epidemics, vector-transmitted diseases and water scarcity (Fischer et al., 2015). Cutting across the different societal and natural domains, these problems frequently involve joint community-level governance of common pool resources (McGinnis and Ostrom, 2014).

Collective management of natural resources by multiple actors, known as co-management of the commons, has recently sparked considerable interest in both academic and practitioner circles (Fischer et al., 2014; Nagendra and Ostrom, 2012). Following the groundbreaking work of Elinor Ostrom (1990), community-based resource management institutions have received increasing attention from governments, donors and NGOs (World Bank, 2005; United Nations, 2012). Ostrom observed that locally evolved institutions governed by indigenous communities and sheltered from outside forces have

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successfully maintained balance in agro-ecosystems for centuries (Ostrom, 1990, 1991; Ostrom et al., 1994; Dietz et al., 2003; Nagendra and Ostrom, 2012). At the same time, common pool management strategies often fail when communities are confronted with rapid change (e.g. climate-change induced extreme variability of weather) or irregular performance of new entrants to the system (Ostrom, 2010a,b, Agrawal, 2001; Dietz et al., 2003). The unavoidable integration of increasingly heterogeneous users triggers collective action problems, exacerbated by power imbalances and imperfect information (Olson, 1965, see also: van Zomeren et al., 2008). In fact, Ostrom found both the availability of information and ubiquitous inter-user communication to be of paramount importance for effective management of the commons (1990) and for the effective production and maintenance of public goods (Poteete et al., 2010).

Against this background, increasing access to information and communication technologies (ICTs) in rural communities in Africa has sparked optimism that their availability can alleviate collective action problems and foster coordinated action among hitherto dissociated populations. In fact, the growing use of ICTs (e.g. mobile phones and internet) has already profoundly affected development theory and practice (see Loh, 2015; Andersson et al., 2012), as acknowledged by the inclusion of ICT availability in the Sustainable Development Goals (UN 2014).

Drawing on these insights, this Special Issue investigates the role of information and communication technologies (ICT) in overcoming the challenges of integrating heterogeneous actors in collective management of common resources and/or the provision of public goods. We present the underlying rationale and assumptions of a research program led by Wageningen University ant titled EVOCA: *Responsible Life-Science Innovations For Development In The Digital Age: Environmental Virtual Observatories for Connective Action*. As a research-for-development project, EVOCA explores the potential of ICT-based platforms (Environmental Virtual Observatories, EVOs) to enable users to share environmental information across media networks. Our comprehensive case studies focus on different types of collective action challenges: the governance of common resources (water scarcity in rice-irrigation systems in Ghana, pasture and water shortage in Kenya); the management of common threats (crop disease epidemics in Ethiopia and Rwanda, vector-transmission of malaria in Rwanda and parasite-borne diseases in Kenya); and the provision of public goods (extension and credit services for smallholders in Ghana). By combining scientific modelling with participatory monitoring and broad information accessibility, EVOCA aims to foster dialogue and exchange between users, development organizations, scientists, state and business (Fischer, 1993; Jalbert and Kinchy, 2015, see Fig. 1).

As an action research project, EVOCA has a strong intervention component. Apart from deepening the scientific understanding of the challenges of joint management of the commons, the project builds on the methodological tradition of citizen science (Feldman and Ingram, 2009; Schut et al., 2013; Stilgoe et al., 2014; Raman and Mohr, 2014; Jalbert and Kinchy, 2015). Citizen science, encompassing the gathering, processing and distribution of scientific knowledge with and by ordinary people (i.e. non-scientists) brings participatory science to scale (Shirky, 2008; Bonney et al., 2009; Haklay, 2013). Often facilitated by different forms of ICTs, citizen science provides an integrated approach to fostering the capacity of communities to build actionable knowledge together with the scientists (Silvertown, 2009; Buytaert et al., 2014). Presently, a vast majority of citizen science initiatives are set in developed countries (see e.g. Cornell Lab of Ornithology, Wageningen Tick Radar, NASA Globe Observer) and involve affluent populations that engage in environmental monitoring as a pastime activity or civic engagement (Cooper et al., 2007; Cohn, 2008). Citizen science projects of today frequently build on the increased availability and use of ICTs. With the help of mobile phones, participatory monitoring can be performed in real-time and at very low cost by large groups of citizens-observers. Conceptually and practically, these developments have articulated the potential for integrating knowledge creation and inclusive participation: as an innovative approach to participatory research, engaging citizens in the process of scientific knowledge production and as a new, more equitable way of practicing evidence-based development (Irwin, 1995, 2001, Shirky, 2008; Silvertown, 2009; Haklay, 2013).

The ten scoping papers included in this Special Issue provide detailed situation analyses of the program's six case study sites in Kenya, Ethiopia, Rwanda (two cases) and Ghana (two cases). These case studies serve as strategic sites to comparatively investigate the potential of citizen science to not only create scientific content via participatory sensing (data harvesting), polls and opinion surveys, but to also engage and connect citizens in a collective effort of equitable knowledge co-creation (Shirk et al., 2012; Wesselink et al., 2015). By highlighting the potential of ICT-based interventions to create knowledge sharing networks and to foster learning across different societal domains (academia and the general public, private and public sectors, governments and donors) we contribute to broader discussions on the role of communication and connective action in developing effective social and technological solutions to complex environmental challenges and collective management of the commons (Dewulf et al., 2005; Leeuwis and Aarts, 2011; Leeuwis, 2013) (Fig. 2).

The main purpose of this paper is to present the conceptual building blocks and assumptions that underpin our expectation that EVOCAs may contribute to addressing collective management challenges. Subsequently, the papers included in this Special Issue present situation analyses of several collective management challenges, and explore the role that EVOCAs may play in addressing them. In the concluding paper of the Special Issue we take stock, reflect on the plausibility of our ideas and assumptions and draw lessons for follow up action and research.

This paper is structured as follows. The next section focusses on the collective commons and the role of information and increased connectivity in fostering effective co-management strategies. We then introduce citizen science as an approach that allows for embedded, situated co-production of knowledge. Building on the presented theoretical considerations, we outline our assumptions concerning the potential of ICT-enabled connective action. We discuss how integrating the logic of connective action — made possible by low-cost mobile information generation and sharing — may change the logic of individual and collective decision-making in the context of environmental challenges. Subsequently, we outline some threats and challenges that need to be considered, and introduce the themes and lines of questioning that have shaped the diagnostic studies presented in this Special Issue. We end with a brief summary of all the papers included in this issue, followed by conclusion.

2. Managing the commons: shared use of resources and the role of communication

Much of the literature on common-pool resources perfunctorily assumes that the users of a given natural resource are homogeneous in terms of their assets, skills, discount rates and cultural views and that they operate within the same individual profit-maximizing mode (Ostrom, 1995). Within this logic, problems related to common pool resources are seen as resulting from rational economic individuals who tend to free-ride on the efforts of others, which could be remedied by sanctions and incentive systems, installed and managed by formal organizations (Olson, 1965).

Ostrom's observations contradict these claims and lay out the design principles that enable the local communities to effectively govern their common-pool resources and prevent the overuse of the core resource (Ostrom, 1990, 1998a,b, Fischer et al., 2014; Agrawal and Gupta, 2005; Agrawal and Chhatre, 2006; Brondizio et al., 2009). Similarly, Ostrom (1990, 2009), identified features of micro-situations that influence whether or not communities succeed in fostering effective cooperation while managing commons or creating public goods. Several of these

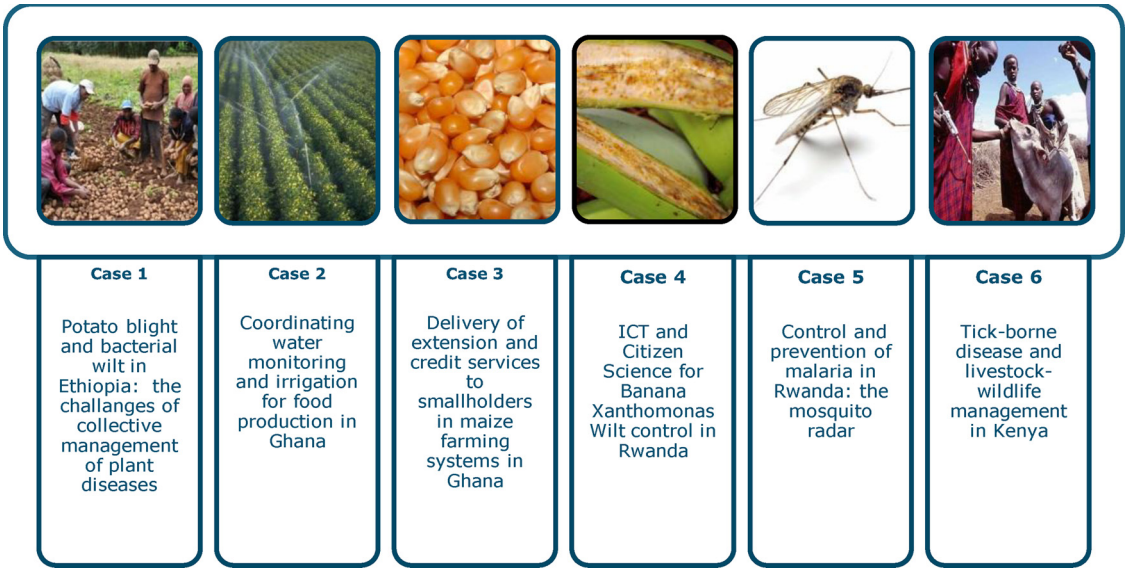

Fig. 1. EVOCA case studies.

design principles and features are directly linked to the availability of information and opportunities for communication. For example, Ostrom emphasizes that communication must be feasible among the entire group of participants involved in using or producing a resource. Similarly, the likelihood of cooperation increases if the reputations of participants are known; in other words if there exists information through which such reputations can be assessed. This relates to another important aspect, which is the availability of monitoring information regarding the extent to which users benefit from and contribute to a resource. Similarly, cooperation is more likely if participants have reliable information about the condition of the resource, which is again associated with regular environmental monitoring. Although it is clear that such informational and communicative features need to be complemented with other types of arrangements (e.g. community-based rules and sanctioning capabilities, conflict-resolution mechanisms, recognition of local users rights to govern, etc.), they do lend credibility to the idea that mobile phones and related technologies may play meaningful roles in overcoming collective action problems as discussed above. They may, for example, help shift the boundaries of effective community formation and belonging, in terms of whom can be feasibly communicated with. At the same time, their capacity to facilitate the generation, collection, storage, analysis, and sharing of information can help to enhance transparency in systems and thus address imperfect information issues. Accordingly, ICTs may catalyze new forms of network formation, dialogue, learning and accountability that are relevant to address coordination problems.

In their theory of connective action, Bennett and Segerberg (2012) argue that new digital media have fostered opportunities for communicative ways of organizing that are less reliant on formal organizational coordination. They observed (for example in relation to the Occupy and Arab Spring movements) that ICTs enable people to share cognitive resources (knowledge and information) and diffuse them

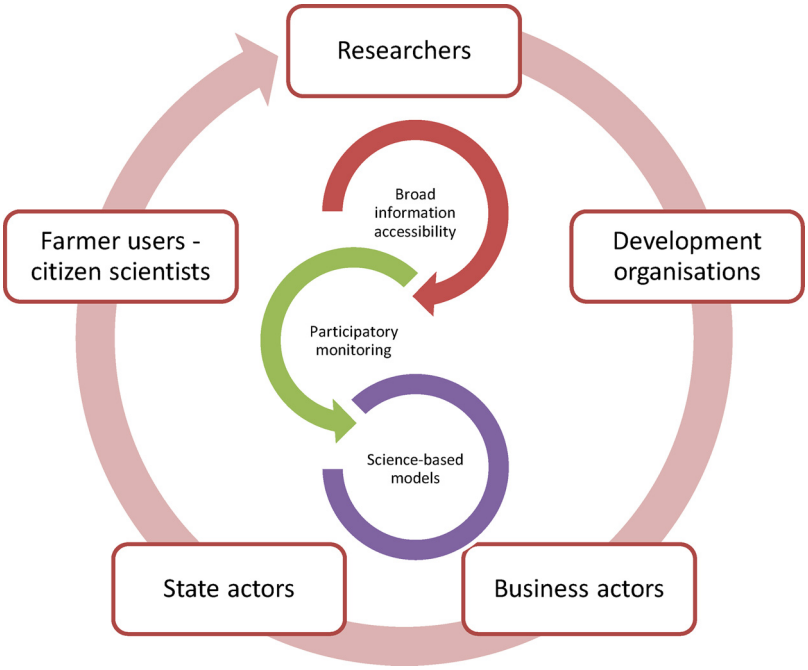

Fig. 2. The connective function of EVOCA and the project's three principal components.

Table 1
Elements of connective and collective action networks (adapted from Bennett and Segerberg, 2012: 756).

CONNECTIVE ACTION Self-Organizing Networks	CONNECTIVE ACTION Organizationally Enabled Networks	COLLECTIVE ACTION Organizationally Brokered Networks
Little or no organizational coordination of action	Loose organizational coordination of action	Strong organizational coordination of action
Large scale personal access to multi-layered social technologies	Organizations provide social technology outlays – both custom and commercial	Social technologies used by organizations to manage participation and coordinate goals
Communication content centers on emergent inclusive personal action frames	Communication content centers on organizationally generated inclusive person action frames	Communication content centers on collective action frames
Personal expressions shared over social networks	Some organizational moderation of personal expression through social networks	Organizational management of social networks – more emphasis on interpersonal networks to build relationships for collective action
Collectivities often shun involvement of existing formal organizations	Organizations in the background in loosely linked networks	Organizations in the foreground as coalitions with differences bridged through high resource organization brokerage

across social networks without formal ties or sanctioned commitment to organizations. As such, connective action (in opposition to collective action) relies on networks that '*self-organize without central or 'lead' organizational actors, using technologies as important organizational agents*' (Bennett and Segerberg, 2012:17; see also Table 1).

The prospect of increased connectivity may be of special relevance in the context of environmental management in developing countries, where formal organizations are often weak and suffer from the lack of resources to exert effective control (Dewulf et al., 2013). As indicated above, the potential power and significance of horizontal and informal governance arrangements (backed up by social control and informal sanctions) have already been demonstrated by Ostrom (1990). However, Ostrom's successful examples rely on close links to place and locality and on sufficiently close interaction among resource users (e.g. fishermen) within the relevant social-ecological system. The phenomenon of connective action transcends the limitations of place and locality but it can only be observed once interactive means of communication are technically available and widely distributed. Connective action, thus conceived, is about organizing collective action in a new way: with a limited or different role of formal organization, and easy, cheap and quick access to new spaces of interaction for many.

The participatory citizen science platforms that we envisage are most likely to operate through mobile phone SMS services, combined with more conventional forms of interpersonal communication and mass media use. Nevertheless, such monitoring platforms do in principle foster new kinds of connectivity, and enable the collection, processing and exchange of information that is personally and/or locally relevant. Moreover, depending on the context and the stakeholder setting, there may be possibilities to link up with social media as well. Overall, we assume that some forms of connective action may emerge even in the absence of broad Internet connectivity. At the same time, considering the technological limitations, and the active role that our program and its partners play in the initiation, development and testing of participatory monitoring platforms, the type of connective action that our program aims to foster is still organizationally enabled (see Bennet and Segerberg's typology in Table 1).

In principle, certain forms of connective action may usefully complement more traditional forms of organization and collective action, and foster an atmosphere where contributing to the common good becomes a matter of personal integrity, and free-riding can be traced and punitively eradicated (Chesters and Welsh, 2006).

3. Citizen science and ICTs

The prominent role of information production and environmental monitoring in maintaining common pool resources or public good is associated with the need of developing credible and valid contextual knowledge about the resource and its users. This brings us to yet another potential benefit of ICTs, which relates to the opportunity of linking community-based information production to science-based models. Data from local level participatory monitoring (e.g. on water availability) may be linked to data and information generated elsewhere (e.g. long term weather forecasts) or serve as input to model-based tools for decision-support. The idea that ICTs may enable us to fruitfully link environmental management with action-oriented science is another core assumption in the EVOCA program, and underlies our interest in the idea of citizen science.

Within the past decade, citizen science has emerged as an alternative way of practicing societally meaningful research (Haklay, 2013; Shirky, 2008). Even though the degree of control that the participating citizens exhibit over the research cycle varies considerably across projects, the emphasis often falls on data collection only, referred to as 'crowdsourcing'. However, as outlined by Haklay (2013), the most engaged form of citizen science is what he calls 'extreme' citizen science (corresponding to 'action citizen science' in the typology by Wiggins and Crowston, 2011). Here professional scientists and citizens jointly decide on the problem for investigation, the method and scope of data collection and, to a certain degree, also the analysis and interpretation of the results. The research project in its entirety is indeed a result of a participatory co-creation, where the scientists assume the roles of facilitators or consultants while the users are the main stakeholders and decision takers. Haklay writes: '*this (level of participation) requires a different epistemological understanding of the process, in which it is accepted that the production of scientific insights is open to any participant while maintaining scientific standards and practices such as systematic observations or rigorous statistical analysis to verify that the results are significant*' (p. 115).

In the development context, citizen science provides an integrated approach to building the capacity of communities to address the pressing development challenges in a systemic, participatory and sustainable way (Buytaert et al. 2014). Citizen science based projects enable and encourage users to collect relevant environmental information such as the observation of infected crops, rainfall and water availability or malaria-mosquito densities (Buytaert et al., 2014; Pratihast et al., 2014; Loss et al., 2015). The increasing availability of ICTs across societal segments – in particular, mobile phones – opens up new ways of both gathering big data and accessing environmentally relevant information, re-configuring the dynamics of social interaction (Salemink et al., 2015). As part of this development, linking community-based environmental monitoring to scientific research may also serve to enhance the credibility of locally generated information and insight in policy processes, for example when such information forms the basis of scientific publications (Stephenson et al., 2016).

ICTs have been spreading rapidly, with a particularly fast pace in the developing world. Presently, even among the poorest 20 percent of populations in developing countries, 70 percent have access to mobile phones (World Bank, 2016). The mobile phones of today may be equipped with an array of sensors that can be utilized in scientific observation (Haklay, 2013). These sensors may become the first instruments for citizen-science measurements, sensing for water pollution (pathogens) (Au et al., 2000), detecting noise levels (Maisonneuve et al., 2010) or satellite-mapping the user's location (Stevens et al.,

2013). Even in the absence of the sensors, the measurement 'tool' of can be the citizens themselves, as they collect real observations in the physical world and transmit them through the mobile network onto the pre-designed scientific domain (Van Vliet et al., 2014).

Citizen science responds to observations such as those by Mol (2008) and Irwin (1995) that major gaps exist between the public's and the scientists' perceptions of each other. The major principle of scientific discovery: minimizing biases and striving for objectivity, is seemingly at odds with the growing recognition of the social embeddedness of environmental problems and conflicts. At the same time, recent advances in citizen science theory and practice (see e.g. the work of the Extreme Citizen Science Center ExCite at UCL) prove that it is the lived, highly subjective experience of the communities that in fact allows for a comprehensive analysis of all the challenges and opportunities of environmental management. When complex agro-ecological problems are defined, analyzed and addressed with and by the communities that actively experience them in their everyday life, the solutions that arise are more likely to be customized, workable and sustainable in the long term.

Utilizing ICTs to enable forms of citizen science stands in sharp contrast to classical, expert-centered approaches in e.g. agricultural extension, where ICTs are used primarily to support the dissemination of research-based information and advice. While this can certainly be a highly pertinent activity, such generalized information and advice cannot be expected to anticipate specific local agro-ecological conditions and the equally diverse goals, rationales and needs of rural households (Chapman and Slaymaker, 2002; Leeuwis, 2004). A comprehensive literature review by Qureshi (2015) reveals that a number of ICT-based interventions rather than improve the quality of life in target populations, ultimately only improve the quality of research done on them. Following a typology of projects that in fact do 'help build a better world', the author concludes that in order to fully realize their potential, ICT-based projects need to be integrated into a holistic, context-specific development strategy that builds on local needs and capacities (see also: Jensen, 2007; Avgerou, 2008; Dey et al., 2016).

There is a strong line of research documenting how isolated specialist knowledge, expert consulting and professional practices can in fact impede effective responses to complex problems (Brinkerhoff, 2008; de Vries, 2008; Escobar, 2008; Mowles et al., 2008). When knowledge is extracted from its context, analyzed and interpreted by experts and then projected back onto the area and its inhabitants, the chances of its appropriate utilization are slim. Criticizing such an approach, Dar and Cooke (2008) argued that within the managerial expert logic, globalization and economic efficiency are replacing Westernization and modernization as attempts to impose a certain kind of order on the world – a process that is as damaging as it is political.

Accordingly, the EVOCA program aims to link science-based models of dynamic natural processes (e.g. related to climate and the spreading of diseases) with mobile-based participatory monitoring, in order to generate real-time feedback to users in our case-study countries in Africa (see Fig. 2). We expect that this can complement and strengthen environmental monitoring efforts that serve to inform those involved in managing commons or public goods. Moreover, we assume that the enhanced connectivity implied by digital citizen science platforms may complement traditional ways of organizing for collective action (Fig. 3).

As Fig. 3 illustrates, the design of the EVOCAs mirrors the research cycle: from problem definition, through the ICT-enhanced data collection and analysis to results interpretation and distribution. Importantly, all of these stages entail the participation of both the concerned communities and the professional scientists, resulting in a user-driven design of the envisioned EVOCA intervention (Zulkafli et al., 2017).

4. Caveats regarding technological optimism: towards responsible EVOCA design

In development, new technologies tend to generate optimism and excitement that, more often than not, are eventually 'dashed by disappointing realities' (Kuriyan et al., 2008, Toyama 2010). As critics point out, technology, however innovative, is only a magnifier, and not a substitute of, human intent and capacity (Andersson et al., 2012). Technology has positive effects only to the extent that people are willing and able to use it in a constructive and responsible way. *The challenge of international development is that, whatever the potential of poor communities, well-intentioned capability is in scarce supply and technology cannot make up for its deficiency* (Toyoma, 2010). Thus, we should combine our interest and excitement regarding the potential of EVOCAs with critical reflection on possible risks and unfulfilled conditions. This section serves to identify such potential pitfalls, and propose a design approach that fosters responsibility in our endeavors.

In relation to EVOCA – the amplifying function of technology may in fact exacerbate the existing inequalities instead of eradicating them (Heeks, 2002). A virtual exchange platform may not deliver the benefits of connectivity to communities unless the concerned users already have social-capital rich communication networks to build on (Harris, 2015; Loh, 2015). Where literacy, human and social capital are unevenly distributed the potential availability of new information does not translate into broadly usable knowledge (Kleine and Unwin, 2009; Kleine, 2010). In addition, any initiative to change the status quo in relation to the management of resources is likely to meet with resistance from dominant interests who benefit from the current situation (Geels and Schot, 2007; Carmody, 2012).

If indeed the existing divide in capabilities gets amplified by the omnipresence of digital technology the result might be increased social polarization and the development of new forms of dependency (Wade, 2002; Schmidt, 2004). If the communicative function of the EVOCA platforms is used only in one direction – i.e. eliciting information from local populations - the new technology loses its potential to strengthen civil society and limits itself to increasing the managerial capacity of development agents or becoming the tool of mass surveillance (Kleine et al., 2015; McLennan, 2015).

By design, EVOCAs offer the possibility to overturn the typical top-down flow of information from scientists to citizens into a more interactive actor dialogue (knowledge co-creation). At the same time, EVOCAs may also bring to the surface new modalities of power and contestation between different visions and expectations held by the stakeholders about the purpose, design or use of EVOCAs. Professional scientific communities that have a central role in the design of EVOCAs bring their own academic representations, disciplinary methods and expectations about outcomes such as impact, as do the funders, the international development agencies and the NGOs. Different actors can therefore exercise significant power over the design of this virtual space for interactive dialogue but also spark new forms of inequality.

Apart from the above mentioned issues related to equity and politics, the developments in ICT applications suggest that it is notoriously difficult to assess the relevant information needs of prospective users because it is hard to explicate needs in relation to something that one is not familiar with (e.g. geographical information or climate data), or in relation to unknown technological opportunities (Leeuwis, 1993). Such needs may rather have to be discovered over time, which may be in scarce supply in the context of a research project. And even when information needs in relation to a possible EVOCA are identified, they may be short-lived and change rapidly in the face of evolving experiences and external developments (McGee and Carlitz, 2013; IDS, 2013). For this reason, EVOCA design needs to be organized as an iterative feedback and learning process.

Finally, it is well known that the sustainable functioning of ICT applications (and technological innovations in general) depends to a large degree on an enabling social and institutional environment in which sufficient capabilities and resources (financial and otherwise) can be mobilized to maintain and further develop an application. While an enabling social and institutional environment may already be available for a range of social media (e.g. Whatsapp) and citizen science

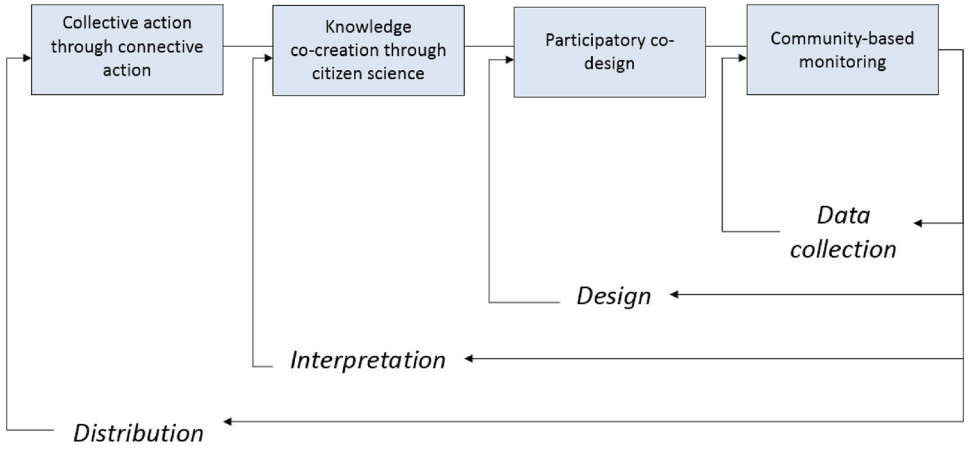

Fig. 3. EVOCA project's conceptual framework.

applications, it is likely that our EVOCAs will need to include tailor made components. Thus, developing an EVOCA will not just be a matter of technology and software design, but also requires the building and co-evolution of appropriate organizational and institutional arrangements, capacities and 'business models' for the maintenance and adaptation of the system over time. Clearly, there may well be a tension between this possible need for organization, and the notion of connective action referred to above.

The above considerations underscore that community engagement in the design of the EVOCAs is of particular importance (Heeks, 2008), and that the design process needs to be iterative and sensitive to both intended and unintended societal and developmental consequences that EVOCAs may have. Such questions have also emerged in relation to other technologies (e.g. nanotechnology and synthetic biology), and given rise to approaches for enhancing 'responsible innovation' (Von Schomberg, 2011; Stilgoe et al., 2013). As described by Macnaghten (2016) this entails process designs for 'improving the conversation between today and tomorrow' (Macnaghten, 2016). The responsible innovation framework proposes to systematically address questions about the impacts of the *product*, the management of the innovation *process* and the *purpose* of an innovation during the design trajectory (Table 2).

Moreover, the framework proposes that process designs should ensure (a) anticipation of potential consequences of the innovation, (b) inclusion of all affected parties and viewpoints, (c) responsiveness to changing societal demands and concerns, and (d) reflexivity on values and assumptions underlying design choices. This framework is a final conceptual and methodological building block underlying the EVOCA program.

5. Questions and issues to be addressed in the diagnostic phase and beyond

This introduction has outlined key ambitions and assumptions that underlie our research program. In essence, we are interested in whether, how and when mobile-based citizen science platforms can support the management of natural resources through a combination of (a) enhanced communication within communities, monitoring-based information generation and knowledge co-creation, and (b) by fostering more self-organized forms of collective action that are enabled by enhanced connectivity (i.e. 'connective action'). Accordingly, we set out to investigate whether connective action may complement traditional forms of collective organizing that currently fail to address environmental challenges in full. Similarly, we aim to understand whether and how the application of responsible innovation principles in the design process enhances the effectiveness, legitimacy and sustainability of our environmental monitoring systems, and how this may affect the distribution of the individual and collective benefits and risks related to new modes of environmental management.

Studying the collective/connective action phenomena in relation to different environmental challenges and in different social contexts offers opportunities to generate a range of interesting cross-cutting and comparative insights. These include investigating how the outcomes relate to (a) the characteristics of the bio-physical issues; (b) the features and communicative modalities of the citizen science platforms used; (c) the interplay and complementarity between connective action and conventional forms of collective action; (d) the broader socio-political and institutional environment; and (e) the manner in which responsible innovation principles are operationalized in the design process.

This Special Issue reports on insights generated during the early stages of our program. As a first step in the process, the interdisciplinary research teams (composed of PhD candidates and natural and social science supervisors) have been asked to conduct so-called diagnostic studies (see Hounkonnou et al., 2004; Röling et al., 2004). Such studies constitute the first comprehensive analyses of the problematic situation, based on a mixture of literature study, technography, original data collection and engagement with stakeholders. Like other such studies published in this journal (see Röling et al., 2004) our diagnostic issues aim at developing a better understanding of the bio-physical and social dimensions of problematic situations, while leaving space for the different methodological approaches and theoretical traditions that tend

Table 2
Lines of questioning on responsible innovation (source: Stilgoe et al., 2013).

Product questions	Process questions	Purpose questions
How will the risks and benefits be distributed?	How should standards be drawn up and applied?	Why are researchers doing it?
What other impacts can we anticipate?	How should risks and benefits be defined and measured?	Are these motivations transparent and in the public interest?
How might these change in the future?	Who is in control?	Who will benefit?
What don't we know about?	Who is taking part?	What are they going to gain?
What might we never know about?	Who will take responsibility if things go wrong?	What are the alternatives?
	How do we know we are right?	

Table 3
Overview of EVOCA cases and corresponding papers in this special issue.

Case	Country	Authors	Topic
Potato blight and bacterial wilt the challenges of collective management of plant diseases	Ethiopia	Damtew, E., Tafesse, S., Lie, R., van Mierlo, B., Lemaga, B., Sharma, K., Struik, P. and Leeuwis, C.	Diagnosis of management of bacterial wilt and late blight in potato in Ethiopia: A systems thinking perspective.
		Tafesse, S., Damtew, E., van Mierlo, B., Lie, R, Lemaga, B., Sharma, K., Leeuwis, C. and Struik, P.	Farmers' knowledge and practices of potato disease management in Ethiopia.
Coordinating water monitoring and irrigation for food production	Ghana	Nyamekye, A. B., Dewulf, A., Van Slobbe, E., Termeer, K., Pinto, C.	The Potential of hydro-climatic Environmental Virtual Observatory (EVO) to improving adaptive decision-making in Rice Production Systems in Northern Ghana.
		Nyadzi E., Nyamekye B. A., Werners, S. E., Dewulf, A., Biesbroek, G. R., Fulco, L., Van Slobbe, E., Hoang P. L., Termeer, C.	Hydroclimatic Environmental Virtual Observatory For Connective Action In Rice Farming Systems In Ghana.
Delivery of extension and credit services to smallholders in maize farming systems	Ghana	Agyekumhene, Ch., de Vries, J.R., van Paassen, A., Macnaghten, P., Schut, M. & Bregt,A.	The Role of ICTs in Improving Smallholder Maize Farming Livelihoods: The Mediation of Trust in Value Chain Financing.
		Munthali, N., Leeuwis, C., van Paassen, A., Lie, R., Asare, R., van Lammeren, R. and Schut, M.	Innovation Intermediation in a Digital Age: Comparing Public and Private ICT Platforms for Agricultural Extension in Ghana.
ICT and Citizen Science for Banana Xanthomonas Wilt control	Rwanda	McCampbell, M., Schut, M., Van den Bergch, I., van Schagend, B., Vanlauwee, B., Blommef, G., Gaidashovag, S., Njukweh, E., and Leeuwis, C. (2018).	Xanthomonas Wilt of Banana (BXW) in Central Africa: opportunities, challenges, and pathways for citizen science and ICT-based control and prevention strategies.
Control and prevention of malaria: the mosquito radar	Rwanda	Asingizwe, D., Poortvliet, M., Koenraadt, C. J. M., van Vliet, A. J. H., Murindahabi, M., Ingabire, Ch., Mutesa, L., Feindt, P.H.	Applying citizen science for malaria prevention in Rwanda: an integrated conceptual framework.
		Murindahabi, M., Asingizwe, D., Poortvliet, P.M., van Vliet, A.J.H., Hakizimana, E., Mutesa, L., Takken, W., Koenraadt, C.J.M.	A community-based malaria mosquito surveillance approach in Ruhuha, Rwanda.
Tick-borne disease and livestock-wildlife management	Kenya	Chepkwony, R., van Bommel, S., Prins, H.H.T., van Langevelde, F.	Citizen science for development: The potential role of mobile phones in sharing of information on ticks and tick-borne diseases in semi-arid savannahs of Kenya.
		Mutavi, F., Heitkönig I., van Paassen, A., Wieland, B., Aarts, N. (2018).	Tick management practices from a metis perspective.

to be represented in large interdisciplinary programs. A key difference is that our studies started with a particular kind of solution in mind (i.e. the idea of EVOCAs) and that cases were selected where we assumed (basing on largely theoretical premises) that such digital citizen science platforms might make a difference. Thus, our diagnostic studies are more oriented towards assessing the possible value of ICT enhanced communication, information provision and knowledge co-creation in a specific context, and less focused on identifying action research lines for agricultural technology development and/or the generation of enabling institutional conditions.

In relation to the above, our diagnostic studies set out to address the following issues and themes:

Unravelling the societal problem in bio-physical and social terms - The research program assumes that societal problems like water shortage and the spread of diseases arise from how people interact with their bio-physical environment (e.g. from how they use water or deal with seed), and simultaneously from how they interact with other stakeholders (e.g. from how farmers interact with other farmers, and with government officials or seed suppliers). And of course bio-physical mechanisms play a role as well (e.g. the way bacteria respond to temperature or moisture). The diagnostic studies aim to unravel the current interplay, and identify practices and organizational forms related to environmental management that are especially problematic, and place these in their broader institutional and historical context.

Assessing the role of information, knowledge and connectivity – In essence, the program hypotheses that new kinds of information and connectivity can change the logic of individual and/or collective practices and decision-making. The diagnostic studies therefore assess how problematic practices relate to issues of information, interpretation, knowledge and connectivity, and how these intertwine with the effectiveness of existing forms of organization, collective action and/or problem solving in the various cases. This may involve analysis of available information and different interpretations of phenomena, how these become dominant or are being ignored, and who participates (or not) in existing formal and informal spaces where people exist discuss and make sense of the problematic situation.

Situating where an EVOCA may make a difference – Based on the previous analysis, the diagnostic studies aim to generate preliminary hypotheses about where in the problematic situation EVOCA type technologies may make a difference. This involves a strategic analysis of which actors in the system are in a position to drive positive change, if they were able to engage with new kinds of information and connectivity. Moreover, this may include an assessment of the stakeholders and interactions at which EVOCA might be usefully targeted, and whether EVOCA should operate merely at local levels (involving e.g. farmers and other citizens) or involve actors in different levels and spheres (e.g. extension staff, policy makers or credit providers).

Further detailing the EVOCA idea – The analysis of how current practices and interactions are linked to information, knowledge and connectivity may give rise to further ideas and discussions with stakeholders about the possible features an EVOCA. Relevant features to be discussed may relate role of citizen science and/or social media platforms, the kinds of data collection and processing needed, arrangements for sharing and discussing information, and the organizational forms and incentive systems needed to motivate stakeholders and make EVOCA sustainable.

Designing the process of further development and testing – The diagnostic studies are likely to yield further insights in how and with whom the idea of an EVOCA may be further developed and tested. This can involve discussion of relevant steps to be taken, the questions that still need to be addressed in order to make further design choices, the way in which responsible innovation principles may be operationalized and/or the manner in which desired effects, risks and unintended consequences arising from EVOCA use may be monitored and assessed.

6. Overview of the papers in this Special Issue

In this Special Issue, we present an array of cases that critically engage with the aforementioned questions, building on scoping studies executed by EVOCA interdisciplinary teams (Table 3).

The presented environmental challenges range from the governance of common resources (water scarcity in Ghana, pasture and water

shortage in Kenya) to the management of public goods/ bads (vector-borne diseases in Rwanda and Kenya, disease control in Rwanda). Diverse as they are, our six case studies allow us to investigate both: the problem and its socio-environmental setting. The case study methodology entails focusing on an issue or a process in-depth and in-context. As such, it is considered most appropriate where 'the boundaries between the phenomenon under investigation and the context are unclear' (Cundill et al., 2014). Although our authors focus on different complex problems in different socio-environmental settings, they critically engage with the same key concepts and theories, as outlined in this introductory paper.

The paper by Tafesse et al. (this issue) disentangles the complex interdependencies between the activities undertaken by different stakeholders in the potato production chain in Ethiopia. Taking the systems thinking perspective, the authors analyze the information lock-ins and coordination failures in bacterial wilt and potato blight control and prevention. They argue that improved connectivity and digitally-enabled horizontal information sharing have the potential to foster exchange and learning among the local actors in the system. This diagnosis is in line with the findings of Gobena et al. (this issue), whose paper focusses on comparing the different perspectives on the causes of the potato diseases among three groups of Ethiopian potato farmers. The authors' quantitative assessment of farmers' knowledge has led them to the conclusion that a mobile-based community monitoring system would allow for a more efficient control and prevention of bacterial wilt and potato blight.

Also focusing on plant diseases but in the context of Xanthomonas wilt of banana (BXW) in the African Great Lakes Region, McCampbell et al. (2018) argue that apart from technological and biophysical dimensions, socio-cultural, economic and institutional factors play an important role in preventing and containing the disease. Their case-study of banana farmers in Rwanda critically assesses the role of data, information, knowledge, and connectivity in addressing the 'wicked problem' of banana wilt in a comprehensive, systemic and sustainable way.

Also located in Rwanda, the case study explored respectively by Asingizwe et al. (2018) and Murindahabi et al. (2018) points to similar conclusions with reference to malaria control and prevention. While the authors attribute the recent upsurge in cases and increased mortality rates to climate variability and insecticide resistance, they also point to the inefficiency of risk communication among stakeholders. They propose that instead of relying on the human landing catch (HLC) as a diagnostic of vector-carrying mosquito populations, a virtual, community-based malaria mosquito surveillance system (mosquito radar) could make a difference in providing reliable, real-time data on the spatial-temporal distribution of malaria vectors.

This improved reporting function of ICTs is also explored by Chepkwony et al. (2018) who investigated the potential of mobile phones in communicating wild-life/livestock conflicts in the National Park in Laikipia, Kenya. Apart from competition for water and pasture, these conflicts also trigger parasite transmission between species. Cautious in their conclusions, the authors stress the importance of prioritizing the actual needs of the users of an ICT-enhanced reporting system.

These results resonate with the findings of Mutavi et al. (2018). Their in-depth anthropological study builds on the contrasts between techne (abstract and technical) and mētis (practical and experiential) knowledge(s) on tick ecology and control practices in Laikipia, Kenya. Apart from documenting and categorizing the plethora of existing approaches to the parasite transmission problems, the authors carefully analyze their contexts of application. Their findings reveal that event though techne knowledge is relatively widespread among the different stakeholders, it is the mētis knowledge that dominates communities of practice. This is largely due to the lack of supportive institutional environment and lack of context-specific infrastructure.

The contributions in this Special Issue extend beyond analyzing the potential of ICTs to effectively manage and control diseases. The last two cases of the program are based in Ghana and focus on the potential of increased connectivity and improved information sharing for the delivery of public goods and for the management of a scarce natural resource.

Looking into the role of ICTs in enhancing credit provision to smallholder farmers, Agyekumhene Ch. de Vries et al. (2018) argue that digital platforms offer clear potential to mediate creditor-farmer relations and mutual trust. Taking a more critical perspective, the paper by Munthali et al. (2018) is a comparative study of two existing ICT platforms embedded in Ghanaian public and private extension organizations. Their findings reveal that the two virtual platforms understudy largely fail as innovation intermediators as their design represents the top-down information dissemination logic of the extension. The authors argue that a more flat, informal information sharing within and between stakeholder groups would provide a more promising way of triggering the *connective action* logic and respective coordinated action.

The last two case-study papers in the Special Issue investigate the role and potential of a hydro climatic EVOCA - a decentralized platform for knowledge information and exchange – to address information deficiencies and trigger coordinated action in rice farmer communities. According to Nyadzi et al. (2018), climate change induced water shortage is a primary concern for the rice farmers in Northern Ghana. Their data from interviews, focus group discussions and document allow them to outline the key elements and features for an EVOCA innovation to provide tangible outputs - actionable knowledge – for improved local governance. Tapping into this, Nyamekye et al. (2018) zoom onto the decision-making processes in the rice production cycle and analyze the information needs in the local governance systems. They argue that in order for a virtual platform to make a difference in the lives of the farmers, particular governance arrangements must be in place to sustain and drive the adaptation process.

7. Conclusion

In this paper, we have we have outlined the core assumption underlying our expectation that EVOCAs may contribute to addressing collective management challenges in a range of problem settings across Africa. Building on the work of Ostrom (1990, 2009) we argue that digital citizen science platforms have the potential of realizing (communication and information related) design principles and community conditions that are known to be conducive for sustainable use of common pool resources and/or the creation of public goods. Specifically, we expect that mobile ICTs may enhance communication within communities, and strengthen opportunities for the participatory monitoring of resources and their users. Moreover, linking community-based monitoring to citizen science initiatives is expected to contribute to co-creation of knowledge among relevant parties within and around communities. We propose that increased connectivity may strengthen the capacity of local communities to organize via connective action, which constitutes a new form of collective mobilization that is less reliant on formal organizational coordination.

At the same time, we have warned against naive technological optimism, and proposed a design approach that fosters critical reflection and responsible choice-making in our efforts to develop and test EVOCAs. As a first step in this endeavor, six case-studies in this Special Issue present diagnostic situation analyses that serve to assess whether or not the development of EVOCA-type platforms is likely to be of use in the specific context. In the closing paper of this Special Issue, we present the cross-cutting insights generated regarding the nature of the challenges at hand, reflect on the plausibility of our assumptions and expectations regarding the potential of EVOCAs, and discuss implications for the next steps in our action research program.

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