Reviews and Meta-Analysis

Implementation of a socio-ecological system navigation approach to human development in Sub-Saharan African communities

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Significance for public health

Recently, there is a growing interest in studying the link between human, animal and environmental health. The connection between these different dimensions is particularly important for developing countries in which people face the challenge of escaping vicious cycle of high diseases prevalence, food insecurity driven by absolute poverty and population growth, and natural capital as a poverty trap. The design and implementation of such efforts, aiming at human health improvement and poverty alleviation, should be framed into adaptive social-ecological system management perspectives. In this paper, we present few case studies dealing with human health improvement through anopheline malaria vectors control in Kenya, cattle health improvement through tsetse vectored nagana control, antitrypanosomal drug administration to cattle in Ethiopia and with the development of rural sustainable communities in Ethiopia. Some recommendations are given to rationalise human and cattle health improvement efforts and to smoothen the road towards enhanced sustainability.

Abstract

This paper presents a framework for the development of socio-ecological systems towards enhanced sustainability. Emphasis is given to the dynamic properties of complex, adaptive social-ecological systems, their structure and to the fundamental role of agriculture. The tangible components that meet the needs of specific projects executed in Kenya and Ethiopia encompass project objectives, innovation, facilitation, continuous recording and analyses of monitoring data, that allow adaptive management and system navigation.

Two case studies deal with system navigation through the mitigation of key constraints; they aim to improve human health thanks to anopheline malaria vectors control in Nyabondo (Kenya), and to improve cattle health through tsetse control and antitrypanosomal drug administration to cattle in Luke (Ethiopia). The second case deals with a socio-ecological navigation system to enhance sustainability, establishing a periurban diversified enterprise in Addis Ababa (Ethiopia) and developing a rural sustainable social-ecological system in Luke (Ethiopia).

The project procedures are briefly described here and their outcomes are analysed in relation to the stated objectives. The methodology for human and cattle disease vector control were easier to implement than the navigation of social-ecological systems towards sustainability enhancement. The achievements considerably differed between key constraints removal and sustainability enhancement projects. Some recommendations are made to rationalise human and cattle health improvement efforts and to smoothen the road towards enhanced sustainability: i) technology system implementation should be carried out through an innovation system; ii) transparent monitoring information should be continuously acquired and evaluated for assessing the state of the system in relation to stated objectives for (a) improving the insight into the systems behaviour and (b) rationalizing decision support; iii) the different views of all stakeholders should be reconciled in a pragmatic approach to social-ecological system management.

Introduction

The three essential but restricted requirements for human development are: to lead a long and healthy life, to acquire knowledge, and to have access to the resources needed for a decent standard of living.[1] Human development should satisfy the current needs without compromising the possibility of future generations to satisfy their needs in order to be sustainable.[2] The United Nations Member States and international organizations encouraged sustainable development through an agreement to achieve the Millennium Development Goals (MDG) by the year 2015.[3] This turned out to be a difficult task for sub-Saharan African countries where human societies are not only suffering from malnutrition but from the effect of multiple stressors including infectious diseases affecting human health, which constrains human development.[4] Hence, the mitigation of the effect of one stressor does not hold the promise to improve human livelihood. Rather, human development efforts have to be directed towards multiple objectives and be based on sustainability science focusing on the dynamic interactions between nature and society.[5,6] Substantial understanding of those interactions has been gained in recent decades through work in environmental science that includes human action on the environment and environmental impacts on humans, social and development studies that seek to account for environmental influences, and a small but growing body of interdisciplinary research.[7,8] With respect to the MDG Kenya achieved progress in eradicating extreme poverty and hunger, and in promoting gender equality and empowerment of women; it is also on track in universal primary education and in combating HIV/AIDS, malaria and other diseases; it is off-track in reducing child mortality, improving maternal help and ensuring environmental sustainability. The food security risk is high and the future vulnerability to climate change acute.[9] For Ethiopia, Jobarteh *et al*. reported progress with respect to economic development and most MDGs with the exception of environmental sustainability, but they reported that the country is at extreme risk of food insecurity and vulnerable to climate change.[9] Hence, it is unclear whether it can escape the vicious cycle of natural resource degradation and food insecurity driven by absolute poverty and population growth referred to as the poverty trap or as *poverty-environmental degradation and food insecurity circle*.[10-12]

The paper deals with sustainable development projects in Kenya and Ethiopia. The responsible agencies for project execution were the Nairobi-based International Centre of Insect Physiology and Ecology (ICIPE) (www.icipe.org) and the Addis Ababa-based BioEconomy Africa foundation (BEA) (www.bioeconomyafrica.org). The reliance on their work and the selection of the projects is an attempt to highlight some important aspects of socio-ecological system study and management rather than a reflection of the level of achievement in human development efforts. The projects have been designed within a previously described emerging conceptual framework for rationalizing human development efforts. In the meantime, this framework has been revised in the light of experience made by the stakeholders of the projects and new views reported in the recent literature. Therefore, a brief summary of basic framework components with literature references is deemed necessary for the reader interested in the specifics of the socio-ecological system navigation approach applied to human development in Sub-Saharan African communities. Before presenting the specifics, however, the basic framework components have to complement with so-called tangible framework components that are introduced to satisfy the particular needs of the various projects referred to as case studies. The paper focus on framework application to these case studies, on experience gained and on general project achievements; the reader interested in methodological details and detailed results is referred to the published literature whenever possible. The paper concludes with general recommendations for other projects with similar objectives.

Basic framework components

An extensive literature proposes components of an emerging conceptual framework for rationalizing human development efforts.[5,7,13-28] The systems studied and managed for development efforts have a number of features that should be considered in an attempt to define components of the framework. In the projects of interest here, a series of basic components were identified and used in a pragmatic manner.[29]

The scope of this section is to list and elaborate on basic components and provide a concise summary with selected references for a multidisciplinary readership. For readers interested in a more in-depth description, the indexed terms are defined in the Appendix, to which the letters in brackets refer.

The *definition of the system under study and management and its properties* are addressed first. Human development efforts have to deal with social-ecological (eco-social) systems in that human societies interact with the ecological basis.[5] These systems are complex, that is, composed of many interconnected elements; importantly, knowledge on these elements is not sufficient for fully understanding the collective behaviour of the systems.[30] For example, a study on the separation of human health and agricultural elements in development efforts is unable to explain the sustainability (A) of the social-ecological system. Hence, the consideration of complexity is a key element in sustainable development (B) efforts.

The *dynamics of social-ecological systems in different dimensions* is studied and managed on the basis of the following aspects: i) the prediction of the temporal dynamics of these systems (C) is difficult;[31] this limitation is overcome by implementing adaptive management (D) procedures where interventions are continuously adjusted to the conditions in the biophysical being of systems. The moving of social-ecological system through adaptive management is referred to as navigation (E). The dynamics moves them not only in dimensions of time and space but also of sustainability. For Goodland (1995), sustainable development is a balanced movement of social-ecological systems in ecological, economic and social dimensions.[15] ii) The adaptive properties allow the social-ecological systems to adapt to a changing environment and improve their chances of success through learning or evolution.[30] iii) The systems are not viewed from a single perspective but contemplated from different legitimate perspectives or contexts.[32] In our work, the performance of a social-ecological system is qualified from human health (F), agro-ecological sustainability (G) and social-ecological sustainability standpoints. Social-ecological sustainability is assessed through the aspects of transformability (H) and resilience (I).

The *complex nature of social-ecological systems* is conceptualised in terms of hierarchies and scales. According to the hierarchy (L) theory, the system may appear as a construct organised at different levels and planes on that processes occur. For example, integrated pest management operates at the farm, village, provincial, and higher levels.[33] According to the scale (M) theory, system components and processes are characterised by dimensions or scales. For example, pest populations may be studied and managed at different spatial resolution scales.[33]

The *navigation of social-ecological systems towards enhanced sustainability* is facilitated by the implementation of new technologies.[34] We are advised to consider a wide range of technologies and to refrain from restricting them to low input technologies that suffer from poor adoption records.[35] The restriction to local and traditional technologies as the only legitimate, fair and appropriate technologies is not advisable when facing new developmental challenges including climate change and emerging diseases.[36] The use of a single technology is known as a silver bullet, *i.e.* a simple remedy for a difficult or intractable problem, is not recommended. Recently, silver bullets have been qualified as the most dangerous innovation misperception and an unpromising approach to development.[37] Rather, technologies should be integrated into a system or package. According to Chinsinga (2003) exogenous forces to developing countries produce an unsustainable reform and the will has to spring from within those countries with external stakeholders playing simply a facilitator role.[38] Internal forces should not be restricted to modern political and administrative structures but include also traditional governance structures (N). The Economic Commission for Africa (ECA, 2007) asks for political commitment and courage to take bold decisions on the role and involvement of traditional authorities in the service delivering and good governance process.[39]

Technology system selection and implementation occurs through an innovation process (O). Gebreselassie (2006)[40] shifts the attention from technologies to carefully designed innovation systems where the promotion of new technologies is linked to processes of farmer innovation, social and cultural institutions that govern uptake, and the economic and market conditions pertaining, particularly for poorer farmers in more marginal areas.[41,42] Science-based innovations have played an important role in our society for centuries. Smits (2002) refers to three major developments in the context of innovation processes: structural changes in the economy, the broadening of decision making processes, the emergence of the network society, and changes in the knowledge infrastructure.[43]

Agriculture has a predominant role in human development efforts, as exemplified by Ethiopia's agricultural development led industrialization (ADLI) strategy.[44] Successful projects in agriculture had seven common lessons for scaling up and spreading: i) science and farmer inputs into technologies and practices that combine crops–animals with agro-ecological and agronomic management; ii) creation of novel social infrastructures that build trust among individuals and agencies; iii) improvement of farmer knowledge and capacity through the use of farmer field schools (P) and modern information and communication technologies; iv) engagement with the private sector for supply of goods and services; v) a focus on women's educational, microfinance and agricultural technology needs; vi) ensuring the availability of microfinance and rural banking; and vii) ensuring public sector support for agriculture.[24]

Tangible framework components

This section introduces tangible components as an attempt to fine-tune the aforementioned basic components and satisfy the specific needs of the four project initiatives in Kenya and Ethiopia. The project partners received modest funding from international donors and national institutions and in return promised to provide assistance to neighbours in scaling-up operations.

Project objectives

Two projects aim at the mitigation of human and livestock diseases as perceived key constraints to human development and health (disease management projects, DMP), while the other two projects deal with integrated sustainable development efforts (integrated sustainability enhancement projects, ISEP). The social-ecological systems operate at the community level. The DMPs aimed at reducing the impact of diseases considered as key constraints to human development by the respective communities. The diseases of interest were human malaria transmitted by anopheline mosquitoes and nagana of cattle vectored by tsetse and biting flies. The ISEPs aimed at livelihood improvement through the enhancement of eco-social sustainability.

Innovation

In both cases, the communities were trained by ICIPE or BEA collaborators in disease control technologies. They readily participated in technology selection and adaptive implementation procedures where ICIPE and BEA collaborators were charged with monitoring and facilitation tasks. Thus, the DMPs fall into technological innovation systems (TIS) where a dynamic network of interacting community members and collaborators of international institutions are involved in the generation, diffusion, and utilization of knowledge. In ISEPs, the communities inhabiting periurban or rural environments sought to improve the livelihood by developing agriculture for the production, processing and marketing of food. In contrast to DMPs, the farmers were given the opportunity to familiarise with agricultural technology options at BEA's training, demonstration and research facilities, named BioFarm, BioVillage or Model Farms. The periurban project focus on women's educational and agricultural technology needs; most cases engaged with the private sector for supply of goods and services and seek ensuring public sector support for agriculture and human health interventions.[24] Since the communities also selected the technologies of interest and engaged in a facilitation project with BEA collaborators, the ISEPs also fell into a TIS consisting of a dynamic network of agents interacting in a specific economic area under a particular institutional infrastructure and they were involved in the generation, diffusion, and utilization of knowledge.

Adaptive management

The uncertainties and non-linearity of complex systems limit the predictability of interventions and motivate the adoption of adaptive management (AM) procedures.[31] In AM, the state of the system is periodically evaluated for the dual purpose of improving insight into the dynamics and for supporting the decisions for system navigation.[45] AM is a strategy that can readily be adapted during development to take into account new knowledge during implementation.[46] AM may allow to rely on an approach that is neither too reductionist to capture reality nor too comprehensive embracing *everything* instead of focusing on the stakeholders and processes that matter.[18] AM may also allow a balance between expensive external expertise and neglected local knowledge, and it may allow efficient use of models for understanding, actions and negotiations.[18]

Facilitation

The implementation of the selected technology systems is adequately done in a facilitation process. Among the linear technology transfer, advisory and facilitation extension models that have found wide application in agricultural system development.[16,47] Moreover, it proved to be a useful complement to adaptive management in eco-social system management.[48] A facilitator is a knowledgeable person who assists groups to reach their goals without assigning himself to a participating party. Project execution procedures had to take into account that stakeholders composed of community members, ICIPE and BEA facilitators and their supervisors, representatives of national institutions, donors and international scientists had different and often divergent views on system qualities and management issues, often because of differently weighing utilitarian, deontological and virtue based moral systems.[49] To overcome these difficulties, Norton's (2005) pragmatic approach is generally adopted.[50,51] Accordingly, several divergent moral theories, which do not even agree on the determination of environmental ethics issues, can nevertheless work together as part of a single moral enterprise even though their respective commitment is in practice based on very different theoretical considerations.[51] In addition, stakeholders are also expected to engage in a convergent social discourse to overcome social heterogeneities.[52] After Rivera-Ferre *et al*. (2013), project execution procedures had to be developed into both realist and constructivist directions. While social and economic issues were treated primarily on constructivist views, we tried to avoid ecological issues positions that i) neglect underlying principles and accept only experimentally verifiable facts (logical positivism) and ii) legitimises or delegitimises statements by a particular culture (philosophical relativism).

Continuous system monitoring and assessment

Sustainable development has been qualified as a voyage with unknown destination where navigation is undertaken to position the social-ecological system in different dimensions. According to Goodland (1995), ecological, economic and social dimensions have received particular attention.[15] Recently, FAO's (2012) 4 dimensional sustainability evaluation scheme has successfully been applied to an evolving periurban system.[53,54] Rather than using dimensions, the dynamics of another system was analysed from the perspectives of animal health, ecosystem service provision and socio-ecological sustainability.[48] The selection of variables and their measurement or estimation proved to be a challenging task. In fact, very heterogeneous information and limited data sets from different sources were used for the assessment of sustainability and resilience, by means of multidimensional analyses.

Navigation

Bioeconomic models were developed for better understanding pathways of development and for assessing the impact of alternative policies on the natural resource base and human welfare.[55-57] They integrate important biophysical information, including monitoring data, and ecological processes with economic decision behaviour and they proved to be useful for improving the knowledge on the dynamics and navigation of the social-ecological system.[56,58] Until now, navigation was further supported by subjecting monitoring information to the aforementioned contextual and multidimensional evaluations.[48,54] The communities or their representatives assisted by ICIPE/BEA collaborators and facilitators were joined by two authors of this paper (J. Baumgärtner and G. Gilioli) who analysed the system for the dual purpose of improving the insight into the dynamics and providing decision support.

Case studies and achievements

System navigation through mitigation of key constraints

The objective was to contribute to human development and health through control of arthropod transmitted diseases. The communities of Nyabondo (Kenya) and Luke (Ethiopia) considered these diseases as major constraints to development. Both communities were aware of available technology systems and prepared for their implementation. At onset of the project, the communities sought assistance from ICIPE or BEA to mitigate the effects of diseases on human and animal health through implementation of familiar technologies. The communities were ready to participate in a facilitation process and to provide assistance in monitoring activities. Hence, the projects could be initiated with the establishment of a TIS involving networking and institution building. In both cases, navigation was facilitated through collaboration with international scientists conducting studies on vector presence and disease prevalence.

Case study 1: malaria and malaria vector control in Nyabondo (Kenya)

The lack of rigorous implementation of integrated vector management strategies over long time periods is one of several factors why malaria remains a serious public health problem in Africa. A project aiming at reducing malaria incidence by relying on integrated management of anopheline vector populations was undertaken at Nyabondo, Western Kenya, over a time period of several years. The management system relied on breeding site reduction and the application of *Bacillus thuringiensis israelensis* (*Bti*) based larvicides in granular formulation to the remaining water bodies, and on the use of bednets for protecting the people. These management measures were applied within a 35 km^2 area divided into 35 cells of 1×1 km^2. In addition, community training, project planning and participatory activities were undertaken to establish an adaptive management system of malaria vectors. The system of community-based adaptive integrated vector management was repeated in other project sites in Kenya and Ethiopia.

The cell was the basic unit for the analysis of the risk posed by anopheline vectors based on continuous monitoring of larval and adult abundance. The cell was also considered as the unit for control intervention based on the information collected on the vectors. GIS-based methods allowed the representation of larval and adult abundance in order to direct control intervention to cells with higher level of risk due to the presence of malaria vectors. Adaptive integrated vector management required continuous monitoring activities to gain insight into the dynamics of vector populations and guide interventions. In this overview, however, the densities of adults recorded on three occasions only are presented for illustration purposes (Figure 1). For sake of simplicity, we focus on the adaptive control strategy and refrain from commenting on the information obtained from two hospitals and one health centre used to evaluate the impact of integrated vector management on confirmed malaria cases. The implementation of the former technologies was a challenging task, since new water bodies were continuously produced during the process of brick making, the major source of income for the Nyabondo inhabitants.

The project revealed the potential of the approach to malaria control and helps Kenya to meet the MDGs, in the area of human health by reducing child mortality and improving maternal health in particular. During project activities positive results were obtained in the control of immature and adult stages of *Anopheles gambiae* s.l. and *An. funestus* and *culicines*. The available information indicated a reduction in the reported malaria cases. The project implementation, however, suffered from the difficulty of implementing an adaptive approach that required the full support of data analysis for targeting spatial-temporal fluctuations of mosquito populations and a coordinated continuous interaction between the different actors involved in risk analysis and management. The information from the hospitals and the health centres were indicative but inconclusive for use in an adaptive management system and for a satisfactory project evaluation.

Case study 2: cattle trypanosomiasis (Nagana) and cattle trypanosomiasis vector control in Luke (Ethiopia)

The animal disease control system consisted of two components: i) antitrypanosomal drug administration to infected cattle by Ethiopian institutions, and ii) a tsetse vector control system selected by the community. The community created a vector control committee that, in collaboration with facilitators and their supervisors, carried out tsetse monitoring and control tasks by deploying odour baited traps.[59] Biweekly, the facilitators were expected to inspect monitoring traps and make available monitoring information to scientists who carried out geo-statistical analyses for identifying areas with high tsetse presence named *hot spots*.[60,61] The respective maps were planned to be passed regularly to facilitators who, in collaboration with the tsetse control committee, deployed control traps to hot spots. The communities or their representatives, the facilitators and their supervisors held monthly meetings to discuss navigation issues and decide on actions. Figure 2 depicts the decrease in tsetse densities and disease prevalence over a period of 137 months from 1995 to 2006. The catch data during month 62 to 65 was plagued by initial organizational problems and variable trapping efficiency; hence the data were viewed as qualitative, reflecting relative tsetse abundance patterns. A real decrease in tsetse numbers appeared to have occurred during months 67 to 91. The data on disease incidence reported in Figure 2 do not allow the specification of the period of disease prevalence reduction, but show that it decreased from 29% to less than 10%. This reduction is similar to the 63% reduction reported by Rowlands *et al*. (1999).[62] The project was considered as a successful application of an innovative adaptive disease management system to livestock health improvement.[63-65]

System navigation for enhancement of socio-ecological sustainability

The objective was to contribute to human development through the establishment of sustainable social-ecological systems. Since the communities were ready to participate in a facilitation process and to provide assistance in monitoring activities, the projects could be initiated with the establishment of a TIS involving networking and institution building. Three Ethiopian communities located at the outskirts of Addis Ababa and in rural Ethiopia (Luke, Mamede) benefitted from development efforts. For the sake of simplicity, this paper is restricted to project activities undertaken in collaboration with the Addis Ababa and the Luke communities. At all sites, the awareness of adequate technology systems was low. As previously mentioned, the promise and implementation characteristics of the technology systems were demonstrated to community members during visits of the BioFarm and the on-site Luke BioVillage demonstration, training and research facilities managed by BEA and ICIPE.

Case study 3: the establishment of a periurban diversified enterprise in Addis Ababa (Ethiopia)

At project beginning, the authorities of the Addis Ababa municipality made available land to an impoverished commune consisting of about 500 female headed households at the outskirts of the city. A

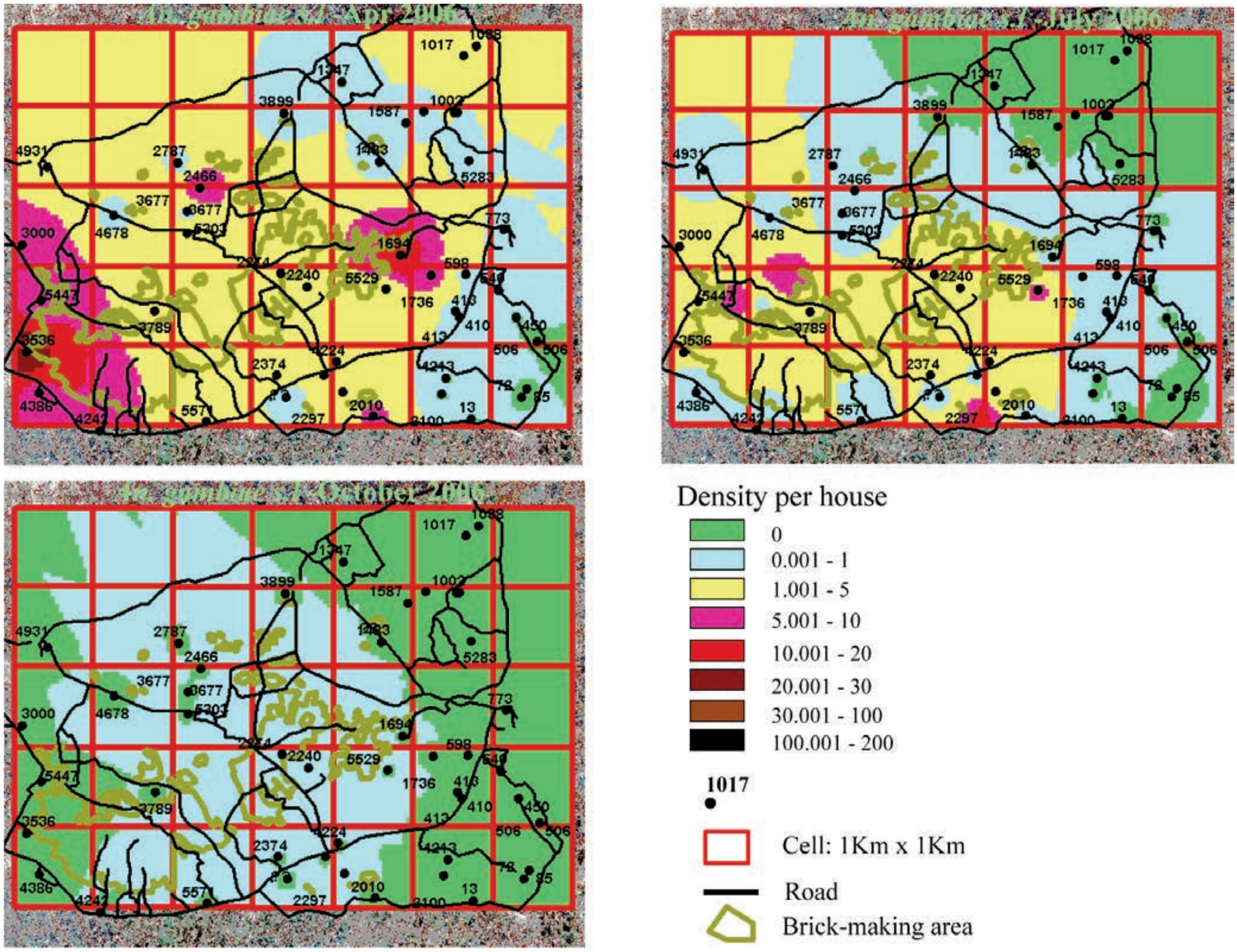

Figure 1. The area of project intervention aiming at integrated management of *Anopheles gambiae* s.l. malaria vectors at Nyabondo (Kenya). The GIS-based methods allowed the representation of the spatio-temporal distribution of vectors abundance assisting in the spatial allocation of mosquito control efforts. The figures report the number of mosquito catches in surveyed houses in close proximity to mosquito larval control sites: the first figure reports the catches during the pre-intervention period in the long-rains season, the second figure reports the catches in the pre-intervention period during the dry season, and the figure on the lower left reports the catches during the dry season. Additional information is given in reports of the International Centre for Insect Physiology and Ecology (ICIPE), Nairobi.

group of women leased the land and began to establish a periurban farm.[54] The women were ready to participate in a facilitation process and to provide assistance in monitoring activities. BEA made available facilitators and assisted in administrative and logistic matters, while ICPE and external scientists carried out sustainability assessments.

Initially the farming activities focused on vegetable production. Later on the vegetables were sold in a shop contributing to income generation. Efforts to diversify the farm were subsequently intensified and culminated in the opening of a restaurant. The imbalance in investments allocated to vegetable production, sale of agricultural goods and provision of services to customers of the restaurant lead to a near collapse of enterprise. Remarkably, the enterprise recovered to reach the highest level of production in the 15 years process of development. The re-organised farm further diversified agricultural production by adding a biogas digester to produce energy and organic fertiliser, and cattle as well as poultry to improve the nutrition of the families and broadening the offer of goods in a restaurant, which also integrated a shop.[54] To assess the sustainability of the social-ecological system, the changes in transformability and resilience were evaluated.[54] Figure 3 shows the

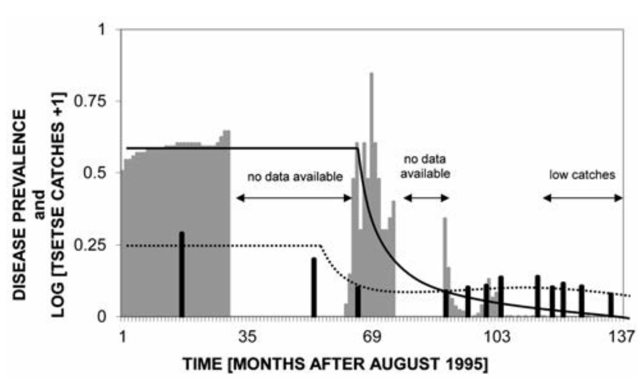

Figure 2. Trends in biweekly tsetse trap catches in odour-baited monitoring traps [dashed line, expressed in log [(catches per trap and day + 1), marked with light colour] and in occasional recordings of trypanosomiasis prevalence (dotted line, expressed as proportion of examined cattle, marked with dark colour) at and near Luke in Southwestern Ethiopia.

changes in transformability reflecting the voyage of the system on a bumpy road towards the highest level reached after 15 years. Transformative and adaptive capacities, often related to different system properties, react in diverse modes to external and internal stress and perturbations.[66] In the case under study, the transformability was strongly related to the self-organizing capacity of the system and leveraged internal components ready to react and to evoke stimuli for external actions. The development of the adaptive capacity on the other hand implied a series of attitudes and capacities of the communities that required time for acquisition and functioning. The stabilization of the adaptive capacity is a prerequisite for reducing the vulnerability of the system. The assessment of resilience was based on three aspects: self-organization capacity, disturbance absorption capacity, and learning and adaptability.

The study aimed at the understanding whether the social ecological system had the ability to absorb disturbances, to change and then to reorganise in function of adaptation objectives. The strong reaction to initial inputs and the evolution towards more developed states reflects social as well as ecological capacities which move the system from the initial state into a new and more desirable basin *sensu*.[23] These capacities correspond to a high degree of social-ecological transformability.[67]

Case study 4: the development of a rural sustainable socio-ecological system in Luke (Ethiopia)

At onset of the project, the Luke community sought assistance from ICIPE and BEA to improve their livelihood through cattle disease control (see above). The community was ready to participate in a facilitation process, created a tsetse control committee and provided assistance in monitoring activities. An attempt was made to efficiently navigate the social-ecological system toward sustainability enhancement through collaboration with international scientists analysing the monitoring information for improving the insight into the dynamics of the development process and providing guidance in the decision making progress.[60,64]

Figure 4 summarises the consequences of successful control of Nagana (cattle trypanosomiasis) in the Luke community. For a more detailed description of social-ecological consequences, the reader is referred to Getachew *et al.*[65] and Baumgärtner and Getachew (2012).[68] The cattle numbers increased between 1995 and 2011 (Figure 4). Concomitantly, there was an increase in calving rates (not reported here) and milk production. The increase in oxen greatly augmented availability of traction which led to a substantial extension of the cultivated area from 12 ha in 1995 to 546 ha in 2011. As the land area remained constant, the pasture area decreased from 440 (1995) to 305 ha (2011). During the same time period, the human population augmented from 1834 persons in 1995 to 3005 in 2011. Nevertheless, each person had USD 3540 at disposal in 2012, whereas the income was only 182.2 in 1995. Getachew *et al*. (2006) suspected that the income in 1995 was higher because the part derived from the sale of farm products and off-farm labour had been underestimated.[65] They also reported that the income was invested into a school which was attended by an ever increasing number of students to reach a 98% attendance in 2011. Unfortunately, these positive effects on the socio-economic plane were not followed by positive changes in the ecological direction.

The effects of intensification of agriculture at Luke on species diversity are unknown, but the associated increasing pressure on land use showed to be disadvantageous for ecological sustainability in the long run. Negative consequences of tsetse control including overstocking rates and environmental degradation due to intensified land use have been reported in the literature for some time and careful planning has been recommended.[69-71]

The data on cattle (Figure 4) are not sufficient to calculate precise stocking rates in tropical livestock units (TLU).[72] Nevertheless, the rate of 9.7 in 2005 and the 11.6 cows per ha in 2011 were considerably higher than the recommended 2-5 TLU per ha for the Southern Ethiopian Highlands.[73] The intensified cattle husbandry threatens the ecological

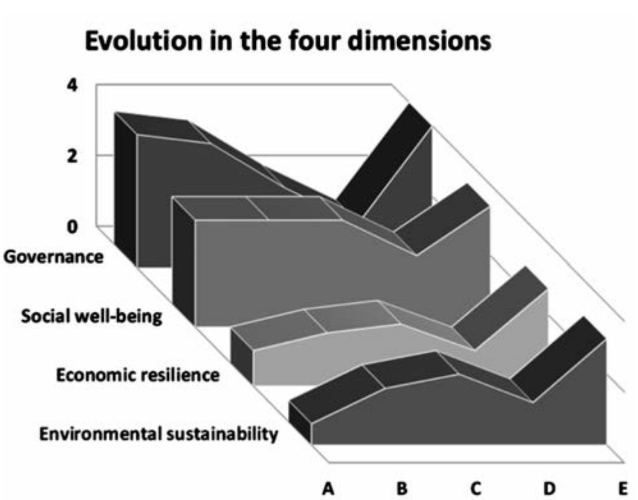

Figure 3. Transformability assessment of an evolving socio-ecological system in the outskirts of Addis Ababa (Ethiopia) on the basis of a background document for FAO's (2012) multidimensional evaluation scheme that considers four development dimensions (*i.e.* pillars in FAO's terminology): environmental sustainability, economic resilience, social well-being, and governance. The 15 years period was subdivided into 5 Macrophases (A, B, C, D, E), the ordinate expresses the level of fulfilment of the project's sustainability objectives on a scale 0-4.

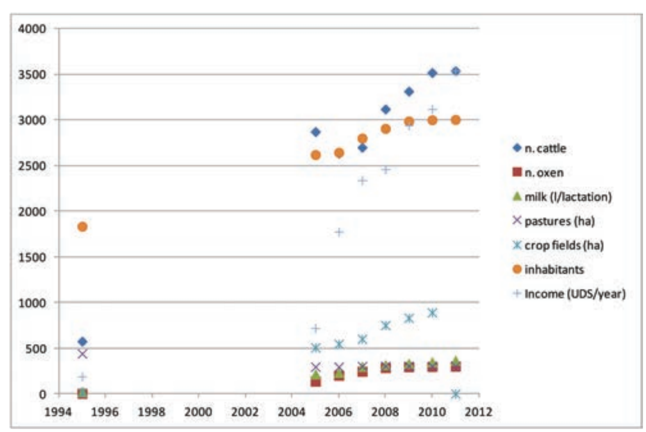

Figure 4. The changes in measurements of selected social-ecological variables after successful implementation of a tsetse control project (Figure 2) and attempts made to navigate the system towards enhanced sustainability as illustrated in Figure 1A (Appendix) [series 1: number of cattle; series 2: number of oxen; series 3: milk production during the lactation period (l), series 4: area of pastures (ha), series 5: area of arable fields for the cereal teff (*Eragrostis tef*) production (ha), series 6: number of inhabitants; series 7: per capita income per year (USD)].

sustainability of the Luke area. This threat is aggravated by increased land cultivation without soil fertility conservation. It would appear that the current use pattern of land for pastures and cultivation may already have exceeded the biophysical limits of the Luke ecosystem leading to a decrease in ecological capital and reduced ecological sustainability. In the words of Gliessman (2000), the intensification of agriculture appears to threaten the basis on which it is built.[74]

Experiences and recommendations

Case study 1: malaria and malaria vector control in Nyabondo (Kenya)

The project activities produced positive results with respect to control of anopheline malaria vectors, and there were indications that mosquito management reduced the number of confirmed cases of malaria. However, the scarce monitoring information on vector densities and on malaria incidence was a hindrance for project execution and demonstrating human health benefits through malaria vector control. Furthermore, the inadequate data quality is an impediment for explaining the relationship between the variables in the malaria system as a prerequisite for obtaining improved insight into the disease epidemiology and for guiding interventions. The availability of tools that enabled elaboration of detailed projections of the dynamics of malaria vectors and epidemiology could have facilitated the decision support addressing the complexity of managing spatial-temporal fluctuation of *Anopheles* spp. into the more general framework of the malaria system dynamics.[75]

Uncertainties and complexities require continuous learning through trial and error, while analysing mistakes and successes should be equally rewarding.[18] Undoubtedly, the project had a considerable learning effect among all stakeholders (villagers, donors, ICIPE facilitators and administrators, and external scientists) and provided opportunities for the improvement of the facilitation process.

The experience showed a need to reconcile the different value systems and expectations of all stakeholders in a pragmatic approach to ecological system management.[49,50] The experience also showed the importance of seeking a common denominator for project execution that could be achieved by more frequent meetings and continuous sharing of information.

Case study 2: cattle trypanosomiasis (Nagana) and cattle trypanosomiasis vector control in Luke (Ethiopia)

The successful implementation of the trypanosomiasis management system at Luke suffered from some shortcomings that should be avoided to rationalise the system. First, continuous monitoring data acquisition and processing for the purpose of improving the insight into the spatial-temporal dynamics and rationalizing control operations proved to be too big a challenge to ICIPE and BEA collaborators charged with facilitation. Since timely data acquisition and transfer was difficult, external scientists were unable to deliver in due time information to guide control operations. Undoubtedly, the cost efficiency of project execution would have been increased if facilitators and their supervisors had been better prepared for their work. The limited preparedness and willingness to engage in a discourse among all stakeholders including donors was another hindrance to efficient innovation and facilitation procedures. More frequent meetings to discuss project promise and progress could solve many problems including decision making despite of diverging moral and philosophical views.[49]

Case study 3: the establishment of a periurban diversified enterprise in Addis Ababa (Ethiopia)

The periurban farming project indicated the need to make transparent measurements and estimates for recording transitions and assessment of social ecological system transformability and resilience. This supports the UN DESA's premise according to which we cannot manage what we cannot measure.[28] Although there is room for improvements, the selection of the explanatory variables were largely satisfactory for both guiding the facilitation process and, to some extent, for assessing the transitions.[54]

The assessment of Gilioli *et al.* (2013) dealt with transitions occurring during the 15 years of project execution.[54] For the evaluation of both transformability and resilience, the period was sufficient for obtaining some insights into relevant social ecological changes. In fact, very different conclusions would have been drawn after a shorter period of project execution. This would have had important implications for the evaluation of development projects since an evaluation after a short project execution period would have underestimated the outcome of development efforts.[18] Moreover, repeated monitoring is necessary since insight into the dynamics cannot be acquired in a single evaluation at project conclusion.

The work shows that the road towards enhanced sustainable development is paved with progress and failures. Hence, the experience made here permits to make some recommendations on how to make this voyage smoother and more efficient.

Case study 4: the development of a rural sustainable socio-ecological system in Luke (Ethiopia)

Many farmers participated in training courses at the Biovillage technology testing, demonstration and training facility, but only few technologies including organic fertiliser and to some extent, vegetable production, were adopted by the villagers. Interestingly, the villagers took the initiative to use the energy produced by the Biovillage biogas digester to pump water to the village. This can be interpreted as a positive response, although we expected the energy to be used for cooking purposes to substitute dung cakes.

The slow adoption of adaptive management (AM) and the reluctance in integrating a modelling process useful in knowledge acquisition, decision support and negotiation was a major hindrance for project execution. Towards the end of the project period, however, most stakeholders recognised the utility of AM and the important role of models in connecting research with management so that the research meets management needs and management helps answer relevant research questions.[18] A more intensive dialogue among stakeholders than done so far is considered indispensable for making efficient use of mathematical, conceptual and the here presented graphical models.

Apparently, technology testing, demonstration and training at the Biovillage site were difficult to build into the facilitation process and had only a limited impact. However, uncertainties and complexities require continuous learning through trial and error, and analyses of mistakes and successes should be equally rewarding.[18] The facilitation process employed in this project emphasises the learning process and, albeit not recognised by all stakeholders, did allow for trial and error. Moreover, the demonstration and training site does not necessarily restrict technologies to preconceived notions of stakeholders[35] and allows improvements of already implemented technologies.[76] In the evaluation of the project, the criteria of technology selection and implementation may have been overemphasised. Sayer and Campbell (2004) argued that indicators of natural resource system performance should reflect adaptability and a capacity for learning, rather than, for example, increased yields or adoption of new technology.[18] An evaluation of the succeeding phase (2007-2011) may allow a revision of the methodologies and a re-interpretation of the results.

During the project phase (1995-2006) the fundamental role of adaptive governance was increasingly recognised by some but not all stakeholders. Accordingly, societies can improve adaptive governance through the continuous improvement of structures and processes by which they share power to shape individual and collective actions.[77,78] In adaptive governance, efforts could be made to harmonise traditional and modern governing structures.[79] In particular, the stakeholders should agree on mechanisms to enhance traditional leaders' interaction with the various arms of the government (legislative, executive and judiciary).[39] In Ethiopia, the strengthening of the interactions between existing formal and informal local governance systems may be a particularly promising strategy in development efforts.[80]

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