Local management practices for dealing with change and uncertainty
– a cross-scale comparison of cases in Sweden and Tanzania.

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ABSTRACT

In the face of increasing human impact of ecosystems at all scales, a key question is how to secure production in agroecosystems also during periods of disturbance, in other words enhance the resilience of agroecosystem functioning. In this paper we compare and investigate management practices for dealing with uncertainty and agroecosystem dynamics in two cases of smallholder farming in different parts of the world, east-central Sweden and northeast Tanzania. Qualitative research methods were applied to map farmers' practices related to agroecosystem management. The identified practices were clustered according to a framework of ecosystem services relevant for agricultural production, and discussed using a theoretical model of ecosystem dynamics.

Almost half of the identified practices were found to be similar in both cases, with similar approaches for adjusting to and dealing with local variability and disturbances. Practices that embrace the ecological roles of wild as well as domesticated flora and fauna, and the use of qualitative bioindicators, were identified as building an insurance capital for change and enhance the capacity to adjust according to agroecosystem dynamics. Diversification in time and space, as well as more specific practices for mitigating pest outbreak and temporary droughts, can limit the effects of disturbances. In both cases we identified taboos as a social mechanism for protection of species that serve important functions in the agroecosystem.

We also found examples of how old practices can serve as a source of adaptations for dealing with new conditions, and that new knowledge is adjusted to local conditions. The study shows that comparing management practices across scales may reveal insights in the capacity to adjust and respond to ecosystem dynamics. We emphasize the role of continual learning for developing resilience management of complex agroecosystems and securing agricultural production for the future.

Key words: management practices, traditional ecological knowledge, local ecological knowledge, agroecosystem, resilience, uncertainty, taboos, bioindicators, biodiversity, Roslagen, Mbulu highlands

INTRODUCTION

Agroecosystems with human interactions as an integrated component are seen as complex adaptive systems (Röling and Wagemakers 1998). Dynamics with non-linear behavior and thresholds are inherent properties of any complex system, resulting in limited predictability and uncertainty on how the system will respond to change (Levin 1999). Global change and human impact on biogeochemical processes may yield ecological surprises with consequences for the production potential of agroecosystems all over the world (Paine et al. 1998, Folke et al. 2002). A key question for science and policy in this setting is how to secure production in agroecosystems for the future.

The sustained capacity of the agroecosystem to produce goods and services is referred to as resilience (Holling 1973). Resilience embraces the capacity to absorb and internalize disturbance and change while maintaining function, the capacity to self-organize following disruptive change and the capacity for learning (Carpenter et al. 2001, Gunderson and Holling 2002). Maintaining resilience requires understanding and managing vital ecosystem functions, as well as social mechanisms that can respond to feedback signals from the ecosystems in an adaptive way (Walters 1986, Berkes and Folke 1998, Kates et al. 2001). It has been suggested that ecological knowledge and understanding among local resource users, and the practices that has been developed in response to ecosystem dynamics can play a key role in this context (Olsson and Folke 2001, Folke et al. 2002).

This paper builds on work that addresses traditional resource use practices in the context of complex systems and capacity to deal with uncertainty and surprise (Berkes and Folke 1998, Berkes et al. 2000). To illustrate how management practices can contribute to resilience, Berkes and Folke (2002) relate traditional resource practices to the model of adaptive renewal developed by Holling (Holling 1986, Gunderson and Holling 2002). The model recognizes that systems pass through periods of accumulation and consolidation, called the *frontloop,* which are disrupted by periods of rapid change characterized by release, renewal, and reorganization, called the *backloop*. Berkes and Folke propose that traditional resource use practices can be complementary to conventional resource management science by qualitative monitoring and management during the *frontloop,* and by building capacity to deal with disruptive change during the *backloop*. They further propose that local and traditional management practices can provide long-term series of local observations and institutional memory for understanding ecosystem change (Berkes and Folke 2002).

Traditional ecological knowledge (TEK) is described as a cumulative body of knowledge, practices, and beliefs, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationships of living beings (including humans) with one another and with their environment (Berkes 1999). Here, we use the term local ecological knowledge (LEK), defined as knowledge held by a specific group of people about their local ecosystems, which acknowledges that relevant ecological knowledge can also be generated by and reside in communities lacking such historical and cultural continuity (Olsson and Folke 2001). LEK is a blend of knowledge generated locally through human-nature interactions and of insights incorporated from other sources, such as scientific knowledge (Figure 1).

In this paper, we investigate and compare local management practices for dealing with uncertainty and change in two cases of smallholder farming systems from northeast Tanzania and east-central Sweden. The focus on management practices is based on the assertion that studying what people actually do can reveal insights into the nature of tacit or experience-based knowledge on the complex interactions between people and nature (Berkes and Folke 1998, Scott 1998). A mapping of practices for agroecosystem management in the Tanzanian case was carried out in an earlier study, identifying a multitude of practices that enhance the functioning of key ecological processes (Tengö and Hammer 2003). A comparison with Swedish farmers was triggered by the interest among local farmers in east-central Sweden, when exposed to the results of the Tanzanian study. The farmers found many similarities in their way of management, in spite of different climatic and biophysical conditions. To our knowledge, no comparative assessment of management practices for coping with ecosystem variability and change between agroecosystems in a high-income and a low-income country has been carried out previously. Our interest lies primarily with how the local farmers respond to and learn from ecosystem dynamics, however we are aware that socio-economic disturbances and change are of critical importance for farm management decision and planning.

The paper starts with an introduction to the two cases and the methods applied. The next section combines results and discussion, starting with a comparison of practices identified in the Swedish and Tanzanian case respectively. The practices are discussed according to how they a) build an insurance capital during the frontloop, through multi-species management and qualitative understanding of ecological processes and their interactions, and b) build capacity to dampen the effect of disturbance and make re-organization possible. We conclude that local ecological knowledge and practices relevant for flexible and adaptive agroecosystem management can exist in high-income countries like Sweden, as well as in low-income countries with less technologically intensive agriculture such as Tanzania and that general mechanisms for promoting social-ecological resilience can be identified across cultural geographical scales. Such understanding may enhance understanding for how to build resilient agroecosystems for the future.

STUDY SITES AND METHODS

The cases were selected on behalf of the authors' previous knowledge of the areas and LEK as an important factor in farm management in both cases (Tengö and Hammer 2003, Belfrage et al. forthcoming). In both cases farms are small scale, have integrated production of livestock and crops, and limited use of chemical fertilizers and pesticides. They have a long continuity of agricultural production and are located in regions that today are economically marginalized in their respective countries. In Tanzania, similar farming system can be found in other areas, as Tanzania still have a high percentage of smallholder farmers. However, the area in the Mbulu highland which constitutes the Tanzanian case is recognized for the long continuity of the intensive production system, which is comparatively rare in East Africa, and the locally developed soil and water conservation practices (Börjeson 2003). In Sweden, a dramatic transition from smallholder farm units to large scale, mechanized, and specialized farms has occurred during the last 50 years (Ihse 1995, Björklund et al. 1999), and there are few farms such as the ones included in this study left.

Some major characteristics of the farms in Sweden and Tanzania are shown in Table 1. The Tanzanian case study is located in the Mbulu highlands just above the Rift Valley Escarpment, in Mbulu region and Arusha district, northeastern Tanzania. The topography with numerous hills and valleys and limited soil fertility are important constraints on farming (NSS 1994). Variability and unpredictability in the onset, duration, and amount of precipitation strongly affects agricultural production. The East African region suffers from draught conditions on an irregular but recurrent basis and ENSO events occasionally trigger extreme amounts of precipitation in East Africa as happened in 1997-98 (McGregor and Nieuwolt 1998, Ngecu and Mathu 1999). Pest and diseases on crops and livestock are another source of disturbance for crop production.

The Swedish case is located in Roslagen, in the municipality of Norrtälje, east central Sweden, approx. 80 km north of Stockholm. Main constraints for farming are the short cropping season and cold winters. In Roslagen, relatively poor and stony soils and recurrent local dry spells in early spring affect crop production success as well as pests, especially on potatoes and vegetables. Late frosts in spring an early frosts in autumn are other sources of uncertainty in farming.

Management practices in the two cases were mapped using a qualitative research approach (Kvale 1996). In Tanzania, 18 households were selected on the basis of access to a common property resource, a pasture area, see Table 2. They were also grouped together in three neighborhood units for collaboration and mutual aid. At least one representative in the households was interviewed at least once, including both men and women, during two fieldwork periods 1998 and 2000. Interviews were semi-structured using checklists regarding key aspects of farm management (Kvale 1996) and involved farm transect walks (Chambers 1997). In addition to individual interviews, group interviews or workshops were carried out using participatory rural appraisal (PRA) techniques such as transect mapping and seasonal calendar (Scoones and Thompson 1994, Mikkelsen 1995). A local interpreter translated to English during all interviews.

In the Swedish case, the 12 farmers in the study were part of a loosely defined but distinct network that embraces farmers that manage their farms in a similar way, e.g. with low external input, and that collaborate in agricultural tasks. The network included a village senior who was identified as a potential carrier of local ecological knowledge. All twelve farmers in the network were interviewed, see Table 2. Participatory observation (Kvale 1996) was a central method, combined with deep interviews and informal discussion individually and in groups (Yin 2003), carried out during numerous occasions during 2002 and 2003.

The management practices identified in the Mbulu highlands were analyzed and clustered according to a framework of ecological functions and services related to agricultural production (Tengö and Hammer 2003). The analysis of these practices was presented to the farmers' network in Roslagen. The farmers directly recognized and could relate to many of the listed practices and found similarities to their way of farm management. We decided, in cooperation with the involved farmers, to carry out a similar mapping of management practices in Sweden, based on the results from the Tanzanian study.

After carrying out the mapping, a joint table for the both cases was developed, Table 3. In particular, we found many similarities in how the farmers deal with uncertainty and variability in the agroecosystem, and decided to focus our comparison on this. In both cases, socio-economic factors such as changes in market prices, political regulations, subsidies, or extension campaigns also came up as important sources of uncertainty for farm management. This study however focuses on the biophysical variables.

As the Swedish interviews were analyzed according to the list of practices identified in Tanzania, further and more detailed practices could be identified in some instances in the Swedish case. It should be noted that the researchers have interpreted the significance of the practices, and we do not claim that the practitioners themselves would interpret or explain them in the same way. It should also be noted that the comparison of practices is qualitative, not quantitative, providing a basis for discussing similarities in structure and function.

RESULTS AND DISCUSSION

A comparison of the practices mapped in Sweden and Tanzania are presented in Table 3, clustered according to the ecological services with which they interact. Almost half of the practices (45 %) were found to be similar in both cases. Most practices concerned ecosystem services of nutrient re-circulation and biological control of weeds and pests. Differences in practices were found regarding management of water as an agent of disturbance. In both cases we found practices related to both the front- and backloop of the model of ecosystem dynamics, which build insurance for disturbance, monitor and circumscribe uncertainty, and alleviate ecological functioning and recovery.

Frontloop practices during exploitation and conservation

Ecological processes particularly relevant during periods of exploitation and conservation are plant production, mobilization and recycling of nutrients and pollination. Based on the list of practices, we identified two areas of practices that enhance efficiency and build insurance capital to buffer disturbances: multiple species management and the use of qualitative indicators in land use planning in time and space (Berkes and Folke 2002).

Agrobiodiversity is commonly used to mean the diversity of useful plants in managed ecosystems, including all crops, semi-domesticated and wild species (Brookfield 2001). In multi-species management, we also include fauna that plays a direct or indirect role in generating and securing services essential for agricultural production.

Farmers in both cases practice polyculture, that is, mixing crops in space, e.g. intercropping, and time, e.g. crop rotations. In Tanzania an example is the common intercropping of maize (*Zea mays)* and beans (*Vicia faba)*, often combined with pumpkins (*Cucurbita* sp.). In Roslagen, Sweden, intercropping of cash crops is not practiced as mixed products are not accepted, but it is commonly applied for fodder production consumed within the farm, for example oats (*Avena sativa)* and peas (*Pisum sativa)* or grain mixtures. Crop rotations are applied and recommended within organic farming to revitalize soils and avoid pest infestation (Lampkin 1990, IFOAM 1998), however the practice has a long history in Roslagen that extends beyond conversions to organic farming by the individual farmers. A typical crop rotation in Roslagen, which includes perennial leys with nitrogen fixating species, is shown in Table 5. On each farm, several rotations occur in parallel, adjusted according to soil type and current conditions. The use of improved leys with a blend of nitrogen fixing species is a factor in nutrient supply that is lacking in the Mbulu highlands. However, the rules we identified for crop sequencing in Mbulu highlands included leguminous crops such as beans or peas. The sequence of crops was adjusted according to factors such as soil type and fertility, manure availability and family needs.

Advantages of intercropping according to the Roslagen farmers are listed in Table 4, indicating awareness of enhanced production, pest control and risk spreading for crop failure. Practices of polyculture are receiving increasing academic interest and recent studies point at similar advantages as were expressed by the Swedish farmers. For example, intercropping of tall cereals and lower spreading crops has been shown to enhance production through more efficient use of light, space and nutrients (Granstedt 1994, Liebman 1995). Intercropping with leguminous plants also enhance plant availability of nitrogen (Drinkwater et al. 1998). Evidence is mounting that local practices of mixing species and varieties have beneficial effects on crop production over time, especially by buffering climate variability and reducing pest damage (Drinkwater et al. 1998, Wolfe 2000, Zhu et al. 2000). Further, practices such as intercropping, mixed land use in time and space, and organic manuring, as were found in the cases, have been shown to enhance diversity of flora and fauna in and above soil (McLaughlin and Mineau 1995, Altieri 1999, Mäder et al. 2002). It has been argued that internal regulation of function in agroecosystems is largely dependent on the level of plant and animal biodiversity present (Altieri 1999).

The practices of the interviewed farmers also embraced the roles of farm animals, non-cultivated plants, birds, and soil flora and fauna as components and actors in the agroecosystems. Management of farm animals in the two cases emphasizes additional roles rather than merely as production factors, e.g. cows and sheep that function as converters of nutrients from areas not suitable for cultivation. In Roslagen, geese are used as weed controllers in gardens and hens as controllers of livestock parasites. Further, in both cases, non-cultivated plants are utilized as primary producers, shade plants, temporary storage of nutrients, and indicators of ecosystem feedback, see Table 6 a-c. For example, in the Mbulu highlands, weeds that do not propagate vegetatively are important for mulching and are also often used as vegetables and medicinal plants. As has been shown in studies of agrodiversity, such associated diversity (Swift et al. 1996) of agroecosystems can be closely related to production success (Altieri 1999, Brookfield 2001).

In both cases, management of associated diversity includes social protection of some wild animals and plants, see examples in Table 6c. The protection regards prohibitions on harming the species and/or management recommendation. Table 6c shows examples of species embraced by social protection and also indicates their ecological function. Among the Roslagen farmers, bumblebees are recognized as important pollinators for garden and field production. Social protection of bumblebees and restrictions on cutting tree species that flower in early spring when pollen and nectar producing species are rare enhance the preconditions for successful pollination. Also in Mbulu highlands are pollinator species protected, and in both cases pollination is enhanced by beehive keeping and management of field boundaries and mixed land use that provides suitable habitats (Weibull and Östman 2003). Species involved in nutrient re-circulation and soil formation are also protected in Roslagen and the Mbulu highlands. In Roslagen the "subsurface creatures", which includes e.g. earthworms and mycorrhiza, are important agents in soil structuring and nutrient re-circulation (Hendrix et al. 1990, Kling and Jakobsen 1998, Paoletti 1999). They are protected by several recommendations regarding soil preparation managements, such as avoidance of certain tools. Species involved in pest control will be further discussed below.

Wild flora and fauna were also found to be used as indicators for fine-tuned interpretation of and response to ecosystem variability and change in both cases, see table 6b. The behavior and development of plants and animals were studied to plan and adjust land management in both cases, although more detailed practices could be identified in the Swedish case. In variable environments, timing of planting or harvesting is critical to e.g. avoid late frost nights or capture erratic rainfall. In Roslagen, indicators such as the size of birch leaves for deciding when to sow, and the maturity of höskallra (*Rhinanthus serotinus)* for when to start harvesting hay, gathers information on multiple parameters, such as day length, air temperature, soil temperature and moisture content. Scott (1998) describes a similar indicator, the size of oak leaves for deciding when to sow in New England, developed by Native Americans. He shows that this type of indicator relies on the recognition of an orderly succession of events. While the timing of these events might be earlier or later in a given year and while the pace of the succession might be slowed down or accelerated, the sequence of events is almost never violated. Thus, it becomes a very reliable "rule of thumb" for avoiding frost. It seems that such "rule of thumb" for ecosystem management (Gadgil et al. 1993) can provide valuable site-specific information on i.e. when to start sowing on individual field, but also that it as a rule or principle can function in a wide geographical setting.

Multiple sets of indicators for i.e. changes in local climate, such as the behavior of birds and insects, improve the farmer's capacity for successful planning in spite of uncertain climatic conditions. Qualitative indicators of soil properties, such as presence or absence of certain species, may reveal information of the direction or trend of change in the soil and hence allow for a flexible response. Taken together, the body of indicators suggests a qualitative understanding of ecosystem processes and their interconnectedness. Berkes and Folke (2002) propose that qualitative indicators generated through experience of local ecosystem dynamics can provide an important complement to scientific indicators, which more often have focused on quantitative monitoring of environmental variables.

The practices discussed above can in many cases serve multiple functions, e.g. improve resource use efficiency and build insurance for disturbance. Holt-Gimenez (2002) showed that smallholders in Nicaragua, farming according to agroecological principles of e.g. intercropping, compost and animal manure, terracing and integrated pest management, suffered less damage and recovered more quickly after hurricane Mitch 1998 compared to farms with higher mechanization levels and more use of chemicals. In the following section, practices that work to dampen the effect of variability and disturbance and allow for ecosystem recovery will be presented and discussed.

Backloop practices for dampening effect of disturbance and enable reorganization

Ecosystem services in Table 3 that are particularly related to the backloop are biological control, buffering of climate variability and erosion control. Ecological disturbances are similar at a general level in the Roslagen and the Mbulu highlands agroecosystems (pest outbreaks, parasites, drought), but the disturbance regimes differ in terms of magnitude, intensity, regularity, and predictability. In spite of this, many mechanisms for dealing with change are similar in both cases.

Diversification of crops within fields in time and space as described above are applied to spread the risk of crop failure in both cases, although crop diversity is higher in the Tanzanian case. There, farmers select their own seed and use local varieties that are adapted to local conditions, including the disturbance regimes. This practice is only carried out by a few of the Swedish farmers, as most of them used hybrid seed. In the Mbulu highlands, topography and varying exposure to sun and wind creates field types with different microclimate and soils characteristics. The farmers take advantage of the local heterogeneity and arrange cultivations to include a variety of conditions, and thus create a diversification in space that improves the likelihood of crops success. Multiple sowing dates for important crops, as carried out in both cases, spread risk over time for variable climate conditions, as the vulnerability of the seedlings to temporary droughts vary during crop development. Hence, diversification at species and landscape level is enhanced to secure the output from the agroecosystem that sustains local livelihoods. Redundancy of diversity in ecosystem has been suggested to function as an insurance capital (Folke et al. 1996), as seemingly redundant species may play new and critical roles in buffering disturbance and re-organizing the ecosystem after disruption (Peterson et al. 1998, Levin 1999, Elmqvist et al. 2003). In the studied cases, diversity is enhanced at species level, both among cultivated and non-cultivated species, and at patch and landscape level.

Precipitation can act as a disturbance via scarcity, drought, high intensity, and by temporary flooding of fields. In Tanzania rainfall often has high intensity and due to the sloping fields, erosion control is an important ecosystem service to maintain soil fertility. Many practices identified in the Mbulu highlands are related to dampening the effect of erosive run-off, such as contour planting, mulching, and construction of cut-off drains and sluices (Reijntjes et al. 1992, Reij et al. 1996). Such practices are lacking in the Swedish case, where the landscape is flatter and rainfall events less intensive.

To improve capacity to deal with temporal periods of drought, we found similar practices that aim to conserve moisture in the soil, such as use of cover crops that can enhance survival of crop seedlings (Reijntjes et al. 1992), but also some differences. In the Mbulu highlands, mulching is a widespread practice that serves many functions in addition to moisture conservation (Lal 2000), but which is not commonly applied in Roslagen. In the Swedish case, the farmers harrow their fields in early spring to disrupt soil pores and thus prevent capillary rise and evaporation. An interesting difference in the two cases was the rational for protecting trees in the landscape. In the Mbulu highlands, single large trees such as *Ficus* sp. are protected partly because they are considered to conserve water and protect water sources. In Roslagen, it is agreed that groups of alder trees (*Alnus glutinosa*) and birch *(Betula sp.)* in swamps and wetlands must not be cut, as they regulate the water level and thus protects the nearby fields from flooding. Spread and development of weed and pests are controlled through practices of manual (or mechanized) removal i.e. by hoeing or harrowing, crop rotation and intercropping (Liebman 1995), by using plants as antagonists of weeds and pests and wild or domesticated animals as consumers of unwanted species (Altieri 1999), and by rotational grazing to prevent infestation and contagion (Tables 3 and 6c). Such practices do not prevent the disturbance of a pest outbreak, but limit the impact of the outbreak and the resulting loss of production. Crop combinations including species that deter pests and parasites through chemical compounds and smell are used in vegetable gardens and leys in the Swedish case (Table 6a). For example, species that contain condensed tannins prevents growth of visceral parasites (Niezen et al. 1993). In both cases, the small scale agriculture has created a patchy landscape with fields and wood lots interspersed with pastures and tree-rich home gardens. Together with the practice of leaving strips of natural vegetation between fields, this creates and enhances habitats that support populations of natural enemies of pests and of pollinators (Reijntjes et al. 1992, McLaughlin and Mineau 1995).

In both cases we found predators of pest species to be supported by social protection, Table 6c. The oxpecker (*Buphagus erythrorhynchus*), which feeds on ticks on livestock, is protected specie in the Mbulu highlands (Lawi 1999). In Roslagen, some known predators of pests on crops and livestock e.g. birds such as owls, starlings, titmice and swallows, and insects such as spiders and lady-bugs are not harmed by the farmers, and bird habitats are enhanced by leaving nesting opportunities in barns and by constructing boxes (Table 6).

Rules that guides people's behaviors that are enforced by informal sanctions are often referred to as taboos. According to Colding and Folke (1997; 2001) informal institutions such as taboos can be seen as an invisible system of local ecosystem management that in many cases has been shown to be important for resource conservation and for maintaining ecosystem function. Colding and Folke (1997) found several examples of taboos of keystone species that carry out important functions. In this study, we found taboos protecting species that e.g. act as pest controllers, pollinators, and decomposers. The taboos, including management recommendations that enhance food availability and nesting opportunities, may thus play a role in preserving agroecosystem function, as well as maintaining knowledge on their role in ecological processes. Further, taboos on species and habitats can function to nurture sources of renewal following disturbance, by providing seeds, seedlings, or larvae that can re-colonize a disturbed area and by maintaining key ecological functions (Berkes and Folke 2002).

In the Swedish case we found that some practices have been revitalized among the interviewed farmers in the face of altered intensity and new sources of disturbances. During the 1990s, a series of mild winters increased the intensity and severity of pest outbreaks, especially fungal infestation of crops. This led to experimentation with new crop varieties, but also old varieties of for example vegetables, to test whether they were more pest resistant. Furthermore, the farmers in Roslagen have recognized that the multiple species leys, common in older days, can produce a more reliable harvest during varying climatic conditions. However seeds for many of the old ley species are difficult to get hold of today. Another example regards the severe potato blight fungus (*Phytophtora infestans*), which for a few years has made cultivation of the most common and favored potato variety, King Edward, impossible without heavy use of fungicides. As they wanted to avoid use of fungicides, the farmers in the network experimented with spraying the potato with an infusion of stinging nettles (*Urticaria dioica*). Stinging nettles have long been known to strengthen livestock and vegetables against diseases and were also found by the farmers to have a clear effect on the survival of the potato crop. By transmitting old knowledge to a new problem, the farmers are able to continue to cultivate the desired potato variety. This case shows how local management practices can serve as a reservoir of adaptations that enhance resilience by increasing the capacity to re-organize and respond adaptively to change (Folke et al. 1998).

The Swedish farmers mentioned several examples of research results that have been incorporated and adjusted to local conditions, e.g. catch crops, undersown crops, green manure and different methods for parasite control, e.g. rotational and alternating grazing. Two recently adopted practices were mentioned as particularly useful, preparation of seed with steam to kill pathogens, especially fungi, and flaming, which is used as weed control in vegetable cultivations. These new practices have been shown superior to elder control managements. Also in the Mbulu highlands, some farmers carry out experimentation with new crop varieties that matures quicker in the relatively cool climate, and soil and water conservation practices has been improved by information spread in extension projects. In both cases, it seems that local institutional networks within and between villages functions as a bridge for transmission of both old and new farming practices among villages and generations (Tengö and Hammer 2003), which is a precondition for keeping LEK vital and dynamic. Several of the Swedish farmers were also active in NGO's such as *Ekologiska Lantbrukarna* (Ecological Farmers), *Svenska Naturskyddsföreningen* (The Swedish Society for Nature Conservation), *Förbundet Sveriges Småbrukare* (The Association for Swedish Smallholder Farmers), which are important sources of new knowledge. Such networks were found to be crucial for dealing with social disturbances such as political regulations, EU subsidies and lobbying from chemical and plant breeding companies, which drive a transition towards intense, large-scale agriculture.

The system of management practices based on local ecological knowledge found in our cases deals with and adjusts to the dynamic environment and does not aim to block out disturbance as has been common in conventional agricultural practices (Holling and Meffe 1996). The practices have evolved during long-term interaction and the farmers seem to have an agroecosystem perspective on farm management. Practices identified that deal with the backloop are based on an understanding of ecosystem dynamics and the existence and role of disturbance in ecosystem behavior and management (Berkes and Folke 1998). The farmers are aware that individual seasons, climate irregularities or pest outbreaks will affect crop production. By diversifying and adjusting their practices, the farmers can minimize the impact on their livelihoods.

This knowledge of how to deal with and interpret changing environments makes locally developed management practices a useful component in designing sustainable agriculture, wherever in the world it is located. We argue that comparisons of management practices can reveal insights on how to sustain the capacity of an ecosystem to generate services during conditions of uncertainty and change.

However, the local aspect and dynamic nature of LEK must be considered. Our mapping of practices represents a snapshot in time of a dynamic process. To be able to draw on the potential of LEK, subventions and political decisions regarding agricultural development need to embrace and acknowledge local scale conditions but also the knowledge that is continuously generated and updated at that very scale.

CONCLUSIONS

Human interference with ecological processes at all scales push for increased awareness of ecological surprises and the need to build resilience for change. This calls for complex systems approaches to natural resource management that acknowledge the non-linearity and unpredictability of ecosystem behavior. This study shows that management practices for dealing with the unpredictability and variability in an agroecosystem can be identified in local farming systems and that they can have many similarities across cultural and geographical scales. In our comparison of two cases we found a multitude of fine-tuned management practices that improved comprehension of and adaptation to local dynamics. Some of these practices also seem to be applicable over a wide geographical scale as general mechanisms or rules of thumb for adjusting and responding to ecological dynamics.

In our analysis, the practices mapped were discussed in relation to the front- and backloop in the model of adaptive renewal (Holling, 1986). We found that the farmers in both Roslagen and the Mbulu highlands recognize the unpredictability and the dynamic behavior of the ecosystem with which they interact, and have developed management practices that increase their capacity to deal with recurrent disturbances such as pests and climate variability.

The management practices identified in our cases seem to be flexible and innovative. The body of knowledge residing among the farmers that underlies the practices is not static, but incorporates new knowledge, both from the farmers' practical experimentation and from agricultural research. Such continual learning is essential for developing resilient management of complex agroecosystems and securing agricultural production for the future.

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FIGURES AND TABLES


Locally generated
and transmitted
knowledge
External knowledge
(e.g. scientific)
Local
ecological knowledge
management practices

Table 1.

Study site	Average farm size	Temp. range	Vegetation period	Average annual rainfall	Pest problems	Livestock pathogen problems	Mechani-zation level	Main crops
Roslagen, Sweden	30 ha	-30°C +30°C	4 months	550 mm	Moderate	Moderate	High	Wheat, oats, barley, potatoes, vegetables
Mbulu highlands, Tanzania	2 ha	0 °C 35 °C	10-12 months	1000 mm	High	High	Low	Maize, beans, wheat, sweet potatoes

Table 3.

Ecosystem services	**Management practices**	**References**	**Examples**
Plant Production	Polyculture	[1-9]	**Mixed grains** **Cereals intercropped with leguminous plants** **Crop rotation** Diverse perennial leys in crop rotation
	Local variety improvement		**Seed selection**
Biological control	Weed control management	[9-11]	**Hoeing (manual weeding)** **Crop rotation and intercropping within fields** **Undersown crops and catch -crops to deter weed** Black fallows, see Table 5 Weed harrowing Delayed sowing after harrowing of annual weeds Geese as weed consumers Flame treatment on newly sown vegetable fields
	Pest control management	[3, 4, 12 -17]	**Social protection of pest-controlling species (Table 6)** **Enhancing/creating habitat for pest-controlling species (Table 6)** **Manual removal of pest insects on crops** **Intercropping and crop rotation within fields** **Crop diversification among fields** **Rotational grazing among pastures** **Alternating grazing of different livestock species to deter parasites** Reserving parasite free grazing for young stocks Timing of manure application to prevent infestation of visceral parasites Ley species that contain condensed tannins to prevent infestation of visceral parasites Hens as parasite controllers Spraying with nettle infusion to strengthen crop Preparation with steam to kill pathogens *Over-planting* *Fallowing* *Burning of tick-infested areas*
Nutrient re-circulation	Nutrient supply	[1, 2, 5, 18-24]	**Integrated production of crops and livestock** **Composting and manuring of cattle dung and other organic matters** **Incorporating residues and weeds into the soil** **Intercropping and rotation with N-fixing crops** **Timing of manure application to maximise nutrient availability** Improved leys with N-fixing species in rotations Green manure Social protection of subsurface creatures, such as earthworms and mycorrhiza *Long and short term fallowing* *Mulching with crop residues and weeds* *Leaving N-fixing weeds in the fields* *Trees and deeply rooted plants in and along fields*
Buffering climate variability	Diversification	[25-27]	**Crop diversification among fields** **Intercropping and crop rotation within fields** **Landscape diversification** **Multiple sowing dates**

	Moisture conservation	[28]	**Nurse crops or trees as shade** Early spring harrowing to prevent capillary rise and evaporation *Mulching* *Keeping continuous land cover (by crops, weed or mulch)* *Shading trees*
	Water harvesting	[29, 30]	Dams for irrigation of vegetables *Field structures to enhance infiltration*
	Ground water regulation		**Forest or tree protection*** Protection of water sources
Pollination	Protection and enhancement of pollinators	[31-33]	**Enhancement of species habitats** **Social taboos on pollinator species** **Beehives** Protection of early flowering species
Information services	Bioindicators (Table 6b)	[34]	**Indicators for timing of planting and harvest** **Indicators to predict weather** **Indicators of field conditions**
Erosion control	Soil retention and water regulation	[28, 29, 35]	*Contour planting* *Leveled fields* *Planting on tied ridges* *Mulching* *Keeping continuous land cover (by crops, weed or mulch)* *Perennial crops along contours and field edges* *Cut-off drains and sluices*

*Tree protection has different roles in the cases. In the Mbulu highlands, trees are considered to conserve water sources, whereas in Roslagen, stands of trees are saved to lower the groundwater level.

1. (Granstedt 1995)
2. (Granstedt 1994)
3. (Brown 1991)
4. (Jackson 1997)
5. (Mader, et al. 2002)
6. (Drinkwater, et al. 1998)
7. (Isselstein, et al. 2001)
8. (Naeem, et al. 1994)
9. (Lampkin 1990)
10. (Ghersa, et al. 1994)
11. (Rydberg and Milberg 2000)
12. (Altieri 1994)
13. (Dimander 2003)
14. (Kromp 1999)
15. (Holland and Thomas 1997)
16. (Zhu, et al. 2000)
17. (Wolfe 2000)
18. (Paul, et al. 1997)
19. (Giller, et al. 1997)
20. (Magdoff 1992)
21. (Parton and Rasmussen 1994)
22. (Matson, et al. 1998)
23. (Paoletti 1999)
24. (Kling and Jakobsen 1998)
25. (Brookfield 2001)
26. (Altieri 1999)
27. (Tilman and Downing 1994)
28. (Reijntjes, et al. 1992)
29. (Reij, et al. 1996)
30. (Rockstrom 2000)
31. (Allen-Wardell, et al. 1998)
32. (Feber, et al. 1997)
33. (Weibull, et al. 2000)
34. (Scott 1998)
35. (Scoones 2001)

Table 4.

- Increase production
- Enhance supply of nutrients, especially nitrogen
- Attract insects and birds that control pests and diseases
- Protect the crop against fungi by naturally occurring chemical compounds
- Repel harmful insects by fragrance
- Increase taste and aroma in the crop
- Increase the compound of ethereal oils in herbs
- Increase crop quality in vegetables
- Buffer for crop failure during climate irregularities

Table 5.

Year		Time	Practice and comments
1	Black fallow	Apr-June	Repeated harrowing and plowing to deter weeds, especially couch grass *(Elymus repens)*, thistles, and other vegetatively propagated weeds*.
		Aug	Manure spread in the field and an autumn cereal is sown
2	Autumn cereal		Autumn cereals are demanding of nutrients and absorb the nutrients mineralized during the black fallow and in the manure
		Aug	Harvest of cereals, plowing and sowing of multi diverse perennial ley.
3	Perennial ley		During the ley the soil rests. Deep rooted and leguminous crops enrich and aerate the soil,
		July	Harvest of hay or silage. On most farms, an additional harvest is carried out in August or September.
4	Perennial ley	July	Harvest of hay or silage.
5	Perennial ley	July	Harvest of hay or silage.
		Aug	Plowing of ley, sowing of autumn cereal. The autumn cereal absorbs the nutrients released from the ley
6	Autumn cereal	Aug	Harvest of cereal
		Nov	Plowing
7	Oat	May	Sowing of oat. The oat crop is less demanding and is able to absorb the remaining nutrients.
		Sep	Harvest of oats.

* Black fallow is not compatible with the rules for EU subsidies.

Table 6a) wild species considered by the farmers as agents in agroecosystem

Mbulu highlands			**Roslagen**		
Species		**Use/ functional role**	**Species**		**Use/ functional role**
Scientific name	**Local name**		**Scientific name**	**Local/ English name**	
Commelina sp. *Solanum nakurense* *Kedrostis hirtella* *Physalis peruviana* *Desmodium sp.* *Fabaceae sp.* *Poaceae sp.* *Asteracea sp.* *Brassicaceae*	*Nii* *Mnafu* *Tangi* *Maandu* *Tsamu* Several species *Fongi* *Lilaway* *Mangananaati* *Qalmi*	”Good weeds”, nitrogen fixation, nutrient storage, shade.	*Plantago major* *Centaurea cyanus* *Bromus secalinus* *Medicago lupulina* *Matricaria chamomilla*	Groblad/ Greater plantain Blåklint/ Cornflower Råglosta/ Rye brome Humlelucern/ Lucerne Kamomill/ Chamomile	“Good weeds”, nutrient fixation, nutrient storage, shade.
			Lotus corniculatis *Cichorium intybus* *Plantago lanceolata*	Käringtand/ Common Bird’s foot-trefoil Cikoria/ Chickory Svartkämpe/ Ribwort plantain	Sown in leys to prevent growth of visceral parasites (contains high content of condensed tannins REF?).
			Urtica dioica	Brännässla/ Stinging nettle	Strengthening plants to avoid pest infestation

Table 6b) Wild species used as agroecosystem indicators

Mbulu highlands

Species: Scientific name	Species: Local name	Monitored feature	Indicates
Pteridium aquilinium	Tslarhama	Presence	infertile soils
Species with shallow roots and broad leaves		Presence and density.	fertile soils

Roslagen

Species: Scientific name	Species: Local/English name	Monitored feature	Indicates
Betula sp.	Björk/ birch	leaf size	time for sowing
Jynx torquilla	Göktyta/ Eurasian wryneck	song (in spring)	
Dryocopus martius	Spillkråka/ black woodpecker	song	approaching rain
Hirundinidae	Svalor/ swallows	low flight	
Formica sp.	Myror/ ants	flying	
Rhinanthus serotinus	Höskallra/ greater yellow -rattle	seed capsule maturity	time for hay harvest
Urticaria dioca	Nässlor/ stinging nettles	presence	fertile soil
Chenopodium pl.	Målla/ goose-foot		
Centaurea cyanus	Blåklint/ cornflower	presence	silty soils poor in nutrients
Papaver rhoeas	Kornvallmo/ common poppy		
Equisetum arvense	Åkerfräken/ common horsetail		
Persicaria sp.	Pilört/ red shank	presence	humid organic soils
Ranunculus repens	Revsmörblomma/ creeping buttercup		
Tussilago farfara	Tussilago/ coltsfoot	presence	clayey soils
Sonchus arvensis	Åkermolke/ corn thistle		
Pinguicula vulgaris	Tärört/ butterwort	presence	insufficiently drained soils
Juncus effusus	Veketåg/ soft-rush		
Bryoohyta species	Mossor/ mosses	presence	compacted soils
Elymus repens	Kvivkrot/ crouch grass	presence	well-aerated soils.
	Måsar/ gulls	High abundance during soil preparation	active soil biota

Table 6c) Species embraced by social protection and their ecological function.

Mbulu highlands

Species or species groups		**Social protection**	**Functional role**
Scientific name	**Local/ English name**		
Apis sp.	Honeybees	Not harm bees or beehives	Pollination
Dendroaspis polylepsis	*Tlawqati*/ Black mamba	Not harm	Regulator of pest species
Dendroaspis angusticeps	*Amaposi*/Green mamba		
Buphagus erythrorhynchus	oxpecker	Not harm	Regulates ticks on livestock
	Earthworms	Not harm	Nutrient re-circulation and soil formation
Single large trees in the landscape, i.e.		Not harm	Conserves water and biodiversity[1]
Ficus sp.	*Antsi*		
Acacia sp.	*Gaermo*		
Erythrina abyssinica	*Tiita*		
	Guami		
	Har-i		
	Taewi		
	Sonkaramo		

Roslagen

Species or species groups		**Social protection**	**Functional role**
Scientific name	**Local /English name**		
Hypnorum sp.	Humla/ bumblebee	Not harm, habitat enhancement	Pollinator
Salix caprea	Sälg/ great sallow	Cutting restrictions	Early season food for pollinators
Coccenellidae sp.	Nyckelpigor/ ladybugs	Not harm	Regulators of pest species
Araneidae	Spindlar/ spiders	Not harm	Regulators of pest species
Sturnus vulgaris	Stare/ starling	Improve nesting habitats	Regulator of insect populations
Paridae	Mesar/ titmice	Improve nesting habitats	Regulator of insect populations
Hirundinidae	Svalor/ swallows	Improve nesting habitats	Regulator of insect populations
Strigiformes	Ugglor/ owls	Not harm, improve nesting habitats	Regulators of pest species such as mice
Underjordingar /“Subsurface creatures”, i.e. earthworms and mycorrhiza forming species		Management recommendations	Nutrient re-circulation and soil formation

[1] Colding and Folke 2001.