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Report

Local Management Practices for Dealing with Change and Uncertainty: A Cross-scale Comparison of Cases in Sweden and Tanzania

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ABSTRACT. We investigated and compared management practices for dealing with uncertainty in agroecosystem dynamics in two cases of smallholder farming in different parts of the world: northeast Tanzania and east-central Sweden. Qualitative research methods were applied to map farmers' practices related to agroecosystem management. The practices are 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 disturbance. Practices that embraced the ecological roles of wild as well as domesticated flora and fauna and the use of qualitative biological indicators are identified as tools that built insurance capital for change and enhanced the capacity to respond to changing agroecosystem dynamics. Diversification in time and space, as well as more specific practices for mitigating pest outbreaks and temporary droughts, can limit the effects of disturbance. In both Sweden and Tanzania, we identified social mechanisms for the protection of species that served important functions in the agroecosystem. We also found examples of how old practices served as a source of adaptations for dealing with new conditions and that new knowledge was adjusted to local conditions. The study shows that comparing management practices across scales and in different cultural settings can reveal insights into the capacity of farmers to adjust, respond to, and shape ecosystem dynamics. We emphasize the importance of continuous learning for developing the sustainable management of complex agroecosystems and securing agricultural production for the future.

INTRODUCTION

Agroecosystems are complex adaptive systems in which humans are an integral part (Röling and Wagemakers 1998, Levin 1999). Non-linear behavior and thresholds are inherent features of any complex system (Levin 1999). Dynamics of this kind limit certainty and the ability to predict how a complex adaptive system will respond to change (Gunderson 1999). Farmers have always faced a challenge sustaining food production in the context of uncertain conditions and disturbances such as temporary droughts, pests, and diseases. Today, global change and human impacts on biogeochemical processes may lead to unexpected ecological effects with consequences for the production potential of agroecosystems all over the world (Matson et al. 1997, Tilman 1999). In this setting, a key question for science and policy is how to ensure that agroecosystems remain productive into the future.

The underlying capacity of agroecosystems to generate goods and services is herein referred to as resilience (sensu Holling 1973). Resilience encompasses 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). To maintain resilience, it is necessary to understand and manage 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). Ecological knowledge and understanding among local resource users and the management practices that have been developed in

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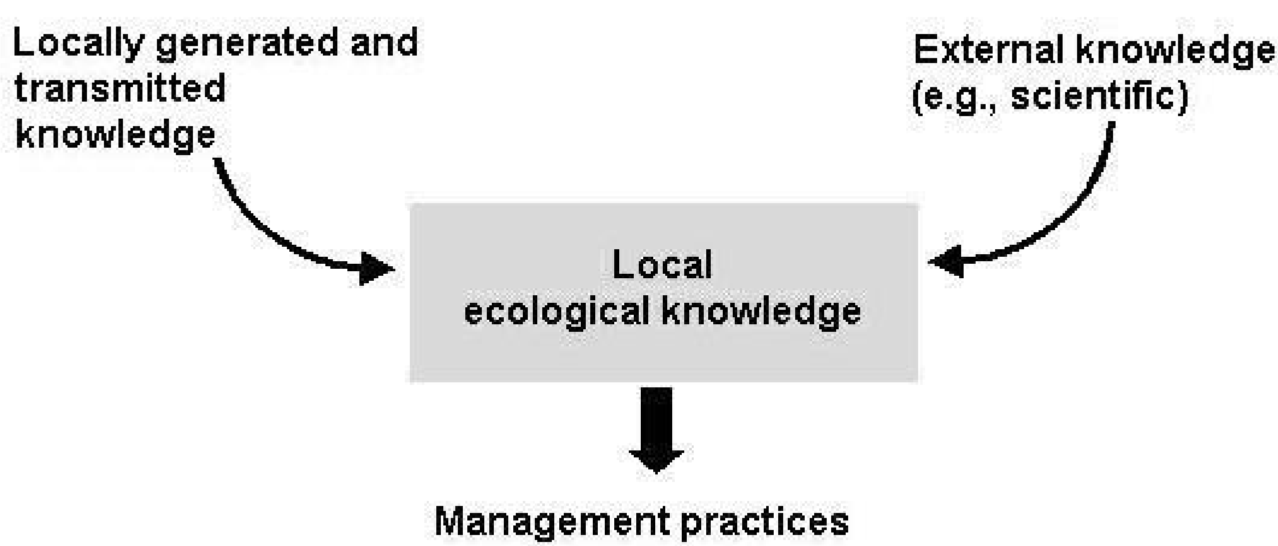
response to ecosystem dynamics may contribute to the resilience of an agroecosystem (Berkes et al. 2000, Olsson and Folke 2001, Folke et al. 2002).

This paper builds on work that addresses locally developed resource-use practices in the context of complex adaptive systems and their capacity to deal with uncertainty and surprise (Berkes et al. 2000, Olsson and Folke 2001, Berkes and Folke 2002). To illustrate how management practices can contribute to resilience, Berkes and Folke (2002) relate traditional resource-use practices to the heuristic model of adaptive renewal developed by Holling (Holling 1986, Gunderson and Holling 2002). The model recognizes that systems pass through a period of accumulation and consolidation called the “frontloop.” This is disrupted by a period of rapid change, called the “backloop,” that is characterized by release, renewal, and reorganization. Berkes and Folke (2002) propose that traditional resource-use practices can be complementary to conventional resource management science by monitoring and management through qualitative measures and indicators during the frontloop and by building capacity to deal with disruptive change during the backloop. These are aspects of management that have previously received little attention in science. Berkes and Folke further suggest that local and traditional management practices can provide both long-term local observations and an institutional memory for understanding ecosystem change.

Traditional ecological knowledge is defined as a cumulative body of knowledge, practices, and beliefs about the relationships of living beings, including humans, to one another and to the environment (Gadgil et al. 1993). This body of knowledge evolves by adaptive processes and is handed down through generations by cultural transmission. Here, we use the concept of local ecological knowledge to refer to the knowledge held by a specific group of people about their local ecosystems (Olsson and Folke 2001). This definition recognizes that ecological knowledge used in local resource management can also be generated by and reside in communities that lack historical and cultural continuity. Local ecological knowledge is a blend of knowledge generated locally through practice and experience plus knowledge incorporated from other sources, such as scientific knowledge (Fig. 1).

Fig. 1. A model of local knowledge as a mix of local and external knowledge that forms the basis for the applied management practices.



In this paper, we investigate and compare local management practices for dealing with uncertainty and change in two cases of low-input farming systems, including one from northeast Tanzania and one from east-central Sweden. Our rationale for focusing on management practices is based on the assertion that studying what people do can reveal insights into the nature of the tacit or experience-based knowledge used in resource and ecosystem management (Berkes and Folke 1998, Scott 1998). Practices for agroecosystem management in the Tanzanian case were mapped in an earlier study where a multitude of practices that enhance the functioning of key ecological processes were identified (Tengö and Hammer 2003). A comparison with Swedish farmers was triggered by the interest among smallholder farmers in Roslagen, 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 cultural and biophysical conditions. To our knowledge, no comparative assessment of management practices for coping with ecosystem change between agroecosystems in a high-income and a low-income country has previously been carried out. Our interest lies primarily in how local farmers respond to and learn about ecosystem dynamics. Although we are aware that socioeconomic disturbance and change are also critically important to farm management decisions (e.g., Lambin et al. 2003), it is not the focus here.

The paper starts with an introduction to the two cases and a description of the methods we applied. The next section combines results and discussion, starting with a comparison of the practices identified in the Tanzanian and Swedish cases, respectively. The practices are discussed according to how they (1) build insurance capital during the frontloop through multispecies management and a qualitative understanding of ecological processes and interactions and (2) build capacity to dampen the effect of disturbance and make reorganization possible. We conclude that it is possible to identify local ecological knowledge and practices relevant for flexible and adaptive agroecosystem management in low-input agriculture in both Sweden and Tanzania and that general mechanisms can exist across cultural settings and geographical scales. We propose that such practices and the iterative processes that generate them enhance the capacity of farmers to deal with uncertainty and change. This capacity is especially important today when we face increasing levels of human impact on ecosystem processes at all scales (Folke et al. 2004).

STUDY SITES AND METHODS

The two case studies were located in the Mbulu highlands of Tanzania and Roslagen, Sweden. These sites were selected based on the authors' previous knowledge of the areas and the recognition that, in each case, local ecological knowledge was an important factor in farm management (Tengö and Hammer 2003; K. Belfrage, J. Björklund, and L. Salomonsson, *unpublished manuscript*). In both cases, farms have small-scale monetary flows, integrated livestock and crop production, and limited use of chemical fertilizers and pesticides. The two areas have a long, continuous history of agricultural production and are located in regions that are economically marginalized in their respective countries. In Tanzania, similar farming systems can be found in other areas of the country, which still has a high percentage of smallholder farmers. However, the kind of comparatively intensive production system found in the Mbulu highlands has been historically rare in East Africa (Börjeson 2004). In Sweden, a dramatic transition from smallholder farm units to large-scale, mechanized, specialized farms has occurred during the past 50 yr (Ihse 1995, Björklund et al. 1999). However, in areas of Sweden with mixed agriculture and forestry, such as Roslagen, smallholder farmers have found a niche in low-input agriculture, producing high-quality and organic products.

Some characteristics of the farms in Tanzania and Sweden are shown in Table 1. The Tanzanian case study was located in the Mbulu highlands just above the Rift Valley Escarpment in the Mbulu region and Arusha district of northeastern Tanzania. The topography, with numerous hills and valleys, and the limited soil fertility were important constraints on farming (National Soil Service 1994). The variability and unpredictability of the onset, duration, and amount of precipitation strongly affected agricultural production. The East African region suffers from drought conditions on an irregular but recurrent basis, and El Niño Southern Oscillation events occasionally trigger extreme amounts of precipitation in East Africa, as happened in 1997–1998 (McGregor and Nieuwolt 1998, Ngecu and Mathu 1999). Pests and diseases that affect crops and livestock were another source of disturbance for crop production.

The Swedish case study was located in Roslagen, in the municipality of Norrtälje in east-central Sweden, approximately 80 km north of Stockholm. The main constraints affecting farming were the short cropping season and cold winters. Relatively poor and stony soils and recurrent local dry spells in early spring affected crop production success. Diseases were a problem, especially for potatoes and vegetables. Late frosts in spring and early frosts in autumn were other sources of uncertainty for farmers.

Table 1. Characteristics of the farms studied in Roslagen, Sweden, and the Mbulu highlands, Tanzania.

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

Management practices in the two case studies were mapped using a qualitative research approach (Kvale 1996, Chambers 1997). In Tanzania, 18 households were selected on the basis of access to a common pool resource, a pasture area (Table 2). The households were also grouped together in three neighborhood units characterized by collaboration and mutual aid. At least one representative in each household was interviewed at least once, including both men and women, during two fieldwork periods in 1998 and 2000. Interviews were semistructured using checklists of 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 techniques such as transect mapping and seasonal calendars (Scoones and Thompson 1994, Mikkelsen 1995). A local interpreter translated to English during all interviews.

In the Swedish case study, the participants were part of a loosely defined but distinct informal network of smallholder farmers. The farmers in the network all managed their farms in a similar way that required low external input, and they frequently collaborated in agricultural tasks. The network included a village senior who was identified as a potential repository of local ecological knowledge. All 12 farmers in the network were interviewed (Table 2). Participatory observation (Kvale 1996) was a central method. It was combined with deep interviews and informal discussions, individually and in groups (Yin 2003), that were carried out on several occasions in 2002 and 2003.

The management practices identified in the Mbulu highlands, Tanzania, 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, Sweden. The farmers recognized that they used many of the same practices listed and found similarities with their own methods of farm management. We decided, in agreement with the participating farmers, to carry out a similar mapping of management practices in Sweden, based on the results from the Tanzanian study.

After the mapping, we developed a joint table for both case studies (Table 3). We found many similarities in how the farmers dealt with uncertainty and variability in the agroecosystems of both cases. Because the capacity to manage change has been a neglected aspect of natural resource management (Berkes et al. 2003), we decided to focus our comparison on this. In both case studies, socioeconomic factors such as changes in market prices, political regulations, subsidies, or extension campaigns were also recognized as important sources of uncertainty for farm management. This study, however, focuses on biophysical variables.

The mapping of farm management practices in the Swedish case was based on the list of practices identified in Tanzania. As a result, additional and more detailed practices were identified in Roslagen, Sweden, than in the Tanzanian case. It should be noted the comparison of practices is a qualitative analysis. Further, we 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.

Table 2. The farmers interviewed in the Mbulu highlands, Tanzania, and Roslagen, Sweden, with details about area farm operations.

A. Mbulu highlands, Tanzania

Farm code	Age of the head of household	Gender of the head of household	Cash crop production	Livestock
1	60	M	Coffee, tobacco	Chickens
2	60	M	Coffee, bananas, tobacco	Cattle, goats, pigs, chickens
3	35	M	Coffee	Cattle, chickens
4	45	M	Coffee, tobacco	Cattle, goats, sheep, pigs, chickens
5	75	M	Coffee, bananas, fruit	Cattle, goats, sheep, chickens
6	60	M	Tobacco	Cattle, pigs, chickens
7	50	M	Tobacco	Cattle, goats, sheep, pigs, chickens
8	40	M	Coffee, tobacco	Cattle, goats, sheep, chickens
9	65	M	Coffee, fruit	Cattle, goats, pigs, chickens
10	55	M	Coffee, fruit, pyrethrum	Pigs, chickens
11	70	M	Coffee, tobacco	Cattle, goats, sheep, chickens
12	40	M	...	Cattle, chickens
13	45	M	Coffee, tobacco	Cattle, goats, sheep, pigs, chickens
14	75	M	Tobacco	Goats, chickens
15	60	M	Coffee, tobacco	Cattle, goats, pigs, chickens
16	40	F	Coffee, soy beans, bananas, fruit	Cattle, goats, sheep, pigs, chickens
17	40	M	Coffee, bananas, fruit, tobacco	Cattle, goats, sheep, chickens
18	65	M	Coffee, bananas, tobacco	Cattle, chickens

B. Roslagen, Sweden

Farm-code	Age of farmer	Gender of farmer	Full- or part-time	Use of pesticides	Use of artificial fertilizers	Main product	Livestock
1	28	F	Part	No	No	Horse raising	Horses, calves
2	39	F	Part	No	No	Meat	Cattle, sheep, horses
3	40	M	Full	No	No	Milk	Cattle, chickens
4	45	F	Part	No	No	Horse raising	Horses
5	45	M	Full	No	No	Vegetables	Sheep, chickens
6	48	M	Part	No	No	Meat	Cattle, sheep
7	50	M	Full	No	No	Meat	Pigs, sheep
8	52	F	Full	No	No	Milk	Cattle, chickens
9	60	M	Full	No	No	Milk	Cattle, chickens
10	63	M	Full	No	Yes	Grain, timber	Cattle, horses
11	75	M	Retired	No	No	Grain	Cattle
12	83	F	Retired	No	No	Timber	Cattle†

†Held on release for milk producer.

RESULTS AND DISCUSSION

A comparison of the farm management practices for Roslagen, Sweden, and the Mbulu highlands, Tanzania, is presented in Table 3 and clustered according to the ecological services with which they interact. Almost half of the practices (45%) were found to be similar in both case studies. Most of the identified practices concerned ecosystem services of nutrient recirculation and biological control of weeds and pests. Differences in practices were found regarding the management of water as an agent of disturbance. In both cases, we found practices related to both “the frontloop” and “the backloop” in Holling's model of ecosystem dynamics (Holling 1986). These practices built insurance against disturbance, monitored and circumscribed uncertainty, and enhanced conditions for ecological functioning and recovery.

Frontloop practices during exploitation and conservation

Ecological processes particularly relevant during periods of exploitation and conservation are plant production, the mobilization and recycling of nutrients, and pollination. Based on the list of management practices, we identified two areas that enhanced efficiency and built insurance capital to buffer disturbances during the frontloop: multiple species management and the use of qualitative indicators in land-use planning with respect to time and space (Berkes and Folke 2002). In this section, practices related to these two areas is analyzed and discussed.

Table 3. A summary of the mapped farm management practices clustered according to the ecosystem service with which they interact. The final column lists references that investigated the potential impact of these practices. **Bold** = practices identified in both Roslagen, Sweden, and the Mbulu highlands, Tanzania. Normal = practices found only in Roslagen, Sweden. *Italics* = practices found only in the Mbulu highlands, Tanzania

Ecosystem services	Management practices	Examples	References
Plant production	Polyculture, local variety improvement	**Mixed grains, cereals intercropped with leguminous plants, crop rotation,** diverse perennial leys in crop rotation, *seed selection*	Lampkin (1990) Brown (1991) Naeem et al. (1994) Granstedt (1994) Granstedt (1995) Jackson (1997) Drinkwater et al. (1998) Isselstein et al. (2001) Mäder et al. (2002)
Biological control	Weed control management	**Hoeing (manual weeding), crop rotation and intercropping within fields, undersown crops and catch crops to deter weeds**, black fallows (Table 4), weed harrowing, delayed sowing after harrowing of annual weeds, geese as weed consumers, flame treatment on newly sown vegetable fields	Lampkin (1990) Ghersa et al. (1994) Rydberg and Milberg (2000)
	Pest control management	**Social protection of pest-controlling species (Table 5), enhancing/creating habitat for pest-controlling species (Table 5), 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 crops, preparation with steam to kill pathogens, *overplanting, fallowing, burning of tick-infested areas*	Brown (1991) Altieri (1994) Jackson (1997) Holland and Thomas (1997) Kromp (1999) Zhu et al. (2000) Wolfe (2000) Dimander (2003)
Nutrient recirculation	Nutrient supply	**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 nitrogen-fixing crops, timing of manure application to maximize 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*	Magdoff (1992) Parton and Rasmussen (1994) Granstedt (1994) Granstedt (1995) Paul et al. (1997) Giller et al. (1997) Matson et al. (1998) Kling and Jakobsen (1998) Paoletti (1999) Mäder et al. (2002)

Buffering climate variability	Diversification	**Crop diversification among fields, intercropping and crop rotation within fields, landscape diversification, multiple sowing dates**	Tilman and Downing (1994) Altieri (1999) Brookfield (2001)
	Moisture conservation	**Nurse crops or trees as shade,** early spring harrowing to prevent capillary rise and evaporation, *mulching, keeping continuous land cover (by crops, weeds, or mulch), shading trees*	Reijntjes et al. (1992)
	Water harvesting	Dams for irrigation of vegetables, *field structures to enhance infiltration*	Reij et al. (1996), Rockström (2000)
	Groundwater regulation	**Forest or tree protection,** protection of water sources	
Pollination	Protection and enhancement of pollinators	**Enhancement of species habitats, social taboos on pollinator species, beehives,** protection of early flowering species	Feber et al. (1997) Allen-Wardell et al. (1998) Weibull et al. (2000)
Information services	Biological indicators (Table 5B)	**Indicators for timing of planting and harvest, indicators to predict weather, indicators of field conditions**	Scott (1998)
Erosion control	Soil retention and water regulation	*Contour planting, leveled fields, planting on tied ridges, mulching, keeping continuous land cover (by crops, weeds, or mulch), perennial crops along contours and field edges, cut-off drains and sluices*	Reijntjes et al. (1992) Reij et al. (1996) Scoones (2001)

When addressing biodiversity in agroecosystems, the concept of agrobiodiversity is commonly used to mean the diversity of useful plants in managed ecosystems, including crops, semidomesticated plants, and wild species (Brookfield 2001). In our consideration of organisms in multispecies management, we also include fauna that play a direct or indirect role in generating and securing services essential for agricultural production, such as pollinating insects and birds that contribute to pest control.

In both case studies, farmers practiced polyculture, which involved mixing crops in the same field space (i.e., intercropping) and growing them at different times (i.e., crop rotation). In Tanzania, one example of polyculture was the common intercropping of maize (*Zea mays*) and beans (*Vicia faba*) often in combination with pumpkins (*Cucurbita* spp.). In Sweden, intercropping of cash crops was not practiced because purchasers would not accept mixed products. Intercropping was nevertheless commonly applied to the production of fodder used on the farm, such as oats (*Avena sativa*) and peas (*Pisum sativa*), and grain mixtures. Organic farming in Europe uses crop rotation to revitalize soils and prevent pest infestations (Lampkin 1990, International Federation of Organic Agriculture Movements 1998). However, the practice of crop rotation has a long history in Roslagen that precedes the conversion to organic farming by some individual farmers. A typical crop rotation in Roslagen, which included perennial leys with nitrogen-fixating species, is shown in Table 4. On each farm, several rotations occured at the same time. Timing and crop sequencing were adjusted according to soil type and current field conditions. The improvement of leys with a blend of nitrogen-fixing species was a practice for nutrient supply that was lacking in the Mbulu highlands. However, the rules we identified for crop sequencing in the Mbulu highlands included leguminous crops such as beans or peas. The sequence of crops in the Tanzanian case was continuously adjusted based on factors such as soil type, soil fertility, manure availability, and family needs.

Table 4. An example of a crop rotation in Roslagen, Sweden.

Year	Crop	Time	Practice and comments
1	Black fallow[†]	April-June	Repeated harrowing and plowing to deter weeds, especially couch grass (*Elymus repens*), thistles, and other vegetatively propagated weeds.
		August	Manure is 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.
		August	Harvest of cereals, plowing, and sowing of multidiverse 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.
		August	Plowing of ley, sowing of autumn cereal. The autumn cereal absorbs the nutrients released from the ley.
6	Autumn cereal	August	Harvest of cereal.
		November	Plowing.
7	Oats	May	Sowing of oats. The oat crop is less demanding and is able to absorb the remaining nutrients.
		September	Harvest of oats.

[†]Black fallow is not compatible with the rules for European Union subsidies.

The advantages of intercropping identified by the Roslagen farmers during interviews are listed in Appendix 1. The list indicates an awareness of enhanced production, pest control, and risk spreading to avoid crop failure. Practices of polyculture are receiving increasing academic interest, and recent studies confirm advantages similar to those recognized 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 enhances 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 practices identified in both of our case studies have been shown to enhance the diversity of flora and fauna in and above soil (McLaughlin and Mineau 1995, Altieri 1999, Mäder et al. 2002). It has been argued that the internal regulation of function in agroecosystems strongly depends on the amount of plant and animal biodiversity present (Altieri 1999).

The practices of the interviewed farmers also recognized that farm animals, noncultivated plants, birds, and soil flora and fauna are important components in agroecosystems. In both case studies, the management of farm animals emphasized the multiple roles animals play apart from their role in farm production. For example, cows and sheep were used to convert nutrients from areas not suitable for cultivation. In Roslagen, geese were used to control weeds in gardens, and hens were used to control livestock parasites. In both the Swedish and Tanzanian case studies, noncultivated plants were used as primary producers, as shade plants, as temporary stores of nutrients, and as ecosystem feedback indicators (see Table 5). For example, in the Mbulu highlands, weeds that do not propagate vegetatively were important for mulching and were also often used as vegetables and medicinal plants. Studies of agrobiodiversity have shown that this type of associated diversity in agroecosystems can be closely related to production success (Swift et al. 1996, Altieri 1999, Brookfield 2001).

Table 5. Examples of wild species and their role in relation to farming practices in Roslagen, Sweden, and the Mbulu highlands, Tanzania. This is not an exhaustive list of the species used in management practices. More details were identified in the Swedish case study, which was carried out in response to the findings in Tanzania.

Wild species considered by the farmers as agents in agroecosystem.

A.1. Mbulu highlands

Species		Use/Functional role
Scientific name	Local name	
Commelina sp.	Nii	“Good weeds,” nitrogen fixation, nutrient storage, shade
Solanum nakurense	Mnafu	
Kedrostis hirtella	Tangi	
Physalis peruviana	Maandu	
Desmodium sp.	Tsamu	
Fabaceae	Several species	
Poaceae	Fongi	
Asteracea	Lilaway	
Brassicaceae	Mangananaati	

A.2. Roslagen

Species		Use/Functional role
Scientific name	Local/English name	
Plantago major	Groblad/Greater plantain	“Good weeds,” nitrogen fixation, nutrient storage, shade
Centaurea cyanus	Blåklint/Cornflower	
Bromus secalinus	Råglosta/Rye brome	
Medicago lupulina	Humlelucern/Lucerne	
Matricaria chamomilla	Kamomill/Chamomile	
Lotus corniculatis	Käringtand/Common Bird's foot-trefoil	Sown in leys to prevent growth of visceral parasites (high content of condensed tannins)
Cichorium intybus	Cikoria/Chickory	
Plantago lanceolata	Svartkämpe/Ribwort plantain	
Urtica dioica	Brännässla/Stinging nettle	Strengthening plants to avoid pest infestation

B. Species embraced by social protection and their ecological function.
B.1. Mbulu highlands

Species or species groups		Prohibition against harming	Functional role
Scientific name	Local/English name		
Apis spp.	Honeybees	Yes	Pollinates
Dendroaspis polylepsis	Tlawqati/black mamba	Yes	Regulates pest species
Dendroaspis angusticeps	Amaposi/green mamba	Yes	Regulates pest species
Buphagus erythrorhynchus	oxpecker	Yes	Regulates ticks on livestock
	Earthworms	Yes	Promotes nutrient recirculation and soil formation
Single large trees in the landscape, for example		Yes	Conserves water and biodiversity[†]
Ficus sp.	Antsi	Yes	...
Acacia sp.	Gaermo	Yes	...
Erythrina abyssinica	Tiita	Yes	...
	Guami, Har-i, Taewi, Sonkaramo	Yes	...

[†]Colding and Folke (2001).

B.2. Roslagen

Species or species groups		Social protection	Functional role
Scientific name	Local/English name		
Bombus spp.	Humla/bumblebee	Prohibition against harming, habitat enhancement	Pollinates
Salix caprea	Sälg/great sallow	Cutting restrictions	Provides early season food for pollinators
Coccenellidae	Nyckelpigor/ladybugs	Prohibition against harming	Regulates pest species
Araneidae	Spindlar/spiders	Prohibition against harming	Regulates pest species
	Earthworms	Prohibition against	Promotes nutrient recirculation and

		harming	soil formation
Sturnus vulgaris	Stare/starling	Improve nesting habitats	Regulates insect populations
	Mesar/titmice	Improve nesting habitats	Regulates insect populations
	Svalor/swallows	Improve nesting habitats	Regulates insect populations
	Ugglor/owls	Prohibition against harming, improve nesting habitats	Regulates pests such as mice
"Underjordingar"/"subsurface creatures," i.e., earthworms and mycorrhiza-forming species		Management recommendations	Promotes nutrient recirculation and soil formation

C. Wild species used as agroecosystem indicators.
C.1. Mbulu highlands

Species		Monitored feature	Indicates
Scientific name	Local name		
Pteridium aquilinium	Tslarhama	Presence	Infertile soils
Species with shallow roots and broad leaves		Presence and density	Fertile soils

C.2. Roslagen

Species		Monitored feature	Indicates
Scientific name	Local/english name		
Betula sp.	Björk/birch	Leaf size	Time for sowing
Jynx torquilla	Göktyta/Eurasian wryneck	Song (in spring)	Time for sowing
Dryocopus martius	Spillkråka/black woodpecker	Song	Approaching rain
	Svalor/swallows	Flying	Approaching rain
	Myror/ants	Low flight	Approaching rain
Rhinanthus serotinus	Höskallra/greater yellow-rattle	Seed capsule maturity	Time for hay harvest
Urticaria dioca	Nässlor/stinging nettles	Presence	Fertile soil
Chenopodium sp.	Målla/goose-foot	Presence	Fertile soil
Centaurea cyanus	Blåklint/cornflower	Presence	Silty soils poor in nutrients

Papaver rhoeas	Kornvallmo/common poppy	Presence	Silty soils poor in nutrients
Equisetum arvense	Åkerfräken/common horsetail	Presence	Silty soils poor in nutrients
Persicaria sp.	Pilört/red shank	Presence	Humid organic soils
Ranunculus repens	Revsmörblomma/creeping buttercup	Presence	Humid organic soils
Tussilago farfara	Tussilago/coltsfoot	Presence	Clay soils
Sonchus arvensis	Åkermolke/corn thistle	Presence	Clay soils
Pinguicula vulgaris	Tärört/butterwort	Presence	Insufficiently drained soils
Juncus effusus	Veketåg/soft-rush	Presence	Insufficiently drained soils
Bryophyta	Mossor/mosses	Presence	Compacted soils
Elymus repens	Kvivkrot/crouch grass	Presence	Well aerated soils
	Måsar/gulls	High abundance during soil preparation	Active soil biota

In both case studies, we found that multispecies management included social protection of some wild animals and plants. The protection included prohibitions on harming species and/or management recommendations. Table 5B gives examples of species that were afforded social protection and indicates their ecological functions. For example, the farmers in Roslagen, Sweden, recognized bumblebees as important pollinators for garden and field production. Bumblebees were afforded social protection, and tree cutting was restricted for tree species that flower in early spring when other pollen- and nectar-producing plants are rare. These protections enhanced the preconditions for successful pollination. In the Mbulu highlands of Tanzania, there was a general agreement that bees and beehives should not be disturbed. In both the Swedish and Tanzanian case studies, pollinator presence was further enhanced by the making of beehives and the management of field boundaries and mixed land that provides suitable insect habitat (cf Weibull and Östman 2003). In both case studies, species important for nutrient recirculation and soil formation such as earthworms and mycorrhiza were also protected (cf Hendrix et al. 1990, Kling and Jakobsen 1998, Paoletti 1999). In Roslagen, "subsurface creatures" were protected through several informal recommended practices regarding soil preparation and management, such as the avoidance of certain tools considered harmful to soil life. The protection of species involved in pest control is discussed below in the backloop section.

In both case studies, wild flora and fauna were also used as indicators for interpreting and responding to ecosystem variability and change (see Table 5C). Farmers observed the development of wild plants and the development and behavior of wild animals, and used this information to plan and adjust land management. Although this was performed in both the Swedish and Tanzanian case studies, more detailed practices were identified in the Swedish case. In variable environments, the timing of planting or harvesting is critical, for example, to avoid late nighttime frosts or to take advantage of erratic rainfall. In Roslagen, Sweden, wild species indicators such as the size of birch leaves were used to decide when to sow, and the maturity of höskallra (*Rhinanthus serotinus*) was used to help decide when to start harvesting hay. Such indicators captured information about multiple parameters such as day length, air temperature, soil temperature, and moisture content. Scott (1998) describes a similar indicator, the size of oak leaves, which was used by indigenous North Americans to decide when to sow in New England. He suggests that this type of indicator relies on the recognition of an orderly succession of events. Although the timing of these events might be earlier or later in a given year and 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. This type of rule of thumb in ecosystem management can provide valuable site-specific information about, for example, when to start sowing on an individual field (cf Gadgil et al. 1993). At the same time, it can be used as a rule or principle to apply to a wider geographical setting.

Table 5C lists multiple indicators used for predicting local climate in the Swedish case study (e.g., the behavior of several bird and insect species). Taken together, the set of qualitative indicators improved a farmer's capacity for successful planning when climatic conditions were otherwise difficult to predict. We also found a number of qualitative indicators of soil properties, such as the presence or absence of certain species. These indicators may reveal information about the direction or trend of change in the soil and, hence, allow for a flexible response in field management (see Berkes and Folke 2002).

The collective body of indicators in Table 5C suggests a qualitative understanding of ecosystem processes and their interconnectedness. Berkes and Folke (2002) propose that qualitative indicators of local ecosystem dynamics can provide an important complement to scientific indicators that frequently focus on the quantitative monitoring of environmental variables.

The practices discussed above, classified as frontloop practices, may serve multiple functions, such as improving resource use efficiency and building insurance to deal with disturbance. For example, Holt-Gimenez (2002) showed that after Hurricane Mitch struck Central America in 1998, smallholder farmers that practiced intercropping, the application of compost and animal manure, terracing, and integrated pest management, suffered less damage and recovered more quickly than did farmers who relied more heavily on mechanization and agrochemicals. Practices that dampen the effect of variability and disturbance and allow for ecosystem reorganization and recovery are discussed in the next section on backloop practices.

Backloop practices during disturbance, release, and reorganization

Ecosystem services related to the backloop and listed in Table 3 include biological control, buffering of climate variability, and erosion control. Ecological disturbances faced by the agroecosystems of Roslagen, Sweden, and the Mbulu highlands, Tanzania, were generally similar and included pest outbreaks, parasites, and drought. However, the disturbance regimes in the two case studies differed in magnitude, intensity, regularity, and predictability. In spite of this, many mechanisms for dealing with disturbances were similar. In the following section, we analyze and discuss practices for dampening the effect of disturbances such as drought and diseases, starting with the role of diversification. We further identify practices that sustain ecological processes important during the backloop, including social protection of species that perform ecosystem services such as pest control.

In both the Swedish and Tanzanian cases, the diversification of crops within fields in time and space (e.g., crop rotation and intercropping) was applied to reduce the risk of overall crop failure. In Tanzania, crop diversity was higher. Further, farmers there selected their own seeds and used local varieties that were adapted to local conditions, such as those equipped to survive temporary drought. This practice was carried out by only a few of the Swedish farmers, most of whom used hybrid seeds. In the Mbulu highlands, the topography and varying exposure to sun and wind created field types with different microclimates and soil characteristics. The farmers took advantage of the local heterogeneity and arranged cultivations to include a variety of conditions. Thus, these farmers created a diversification in space that improved the likelihood of crop success in at least some of the fields. Similarly, farmers in both case studies used multiple sowing dates for important crops. As the vulnerability of seedlings to temporary drought and pests vary throughout their development, this practice spread the risk of crop failure on all fields.

Redundancy in diversity within ecosystems may act as insurance capital for ecosystem functions (Folke et al.

1996) because seemingly redundant species can help to buffer disturbance and reorganize the ecosystem after a disruption (Peterson et al. 1998, Levin 1999, Elmqvist et al. 2003). In both the Swedish and Tanzanian case studies, diversity was enhanced at the species level for both cultivated and noncultivated species and at the patch and landscape levels.

Precipitation can be a disturbance for farming because of drought, intense rains, and temporary floods in fields. In Tanzania, rainfall was often intense and, because of the sloping fields, erosion control was important to maintain soil fertility. Many farm management practices identified in the Mbulu highlands reduced the effect of erosive runoff, such as contour planting, mulching, and the construction of cutoff drains and sluices (Tengö and Hammer 2003). Such practices were not found in the Swedish case study where the landscape was flatter and rainfall events were less intense.

To improve the capacity to deal with temporary periods of drought at the field level, farmers in both case studies adopted some similar practices for conserving soil moisture, such as the use of cover crops that enhance seedling survival (cf Reijntjes et al. 1992). In the Mbulu highlands, mulching was a widespread practice that helped conserve moisture as well as provide other functions (cf Lal 2000). However, mulching was not common in Roslagen. A practice for preserving soil moisture in Roslagen was the harrowing of fields in early spring to disrupt soil pores and thus preventing capillary rise and evaporation. An interesting difference between the two case studies was the rationale for protecting trees in the landscape. In the Mbulu highlands, single large trees such as *Ficus* spp. were protected, in part because they were considered to conserve water and protect water sources. In Roslagen, villages protected groups of alder trees (*Alnus glutinosa*) and birch (*Betula* spp.) in swamps and wetlands in the belief that they regulate water levels and thus protect nearby fields from flooding.

In both case studies, weeds and pests were controlled through manual or mechanized removal (e.g., by hoeing or harrowing), crop rotation, intercropping (cf Liebman 1995), using plants as antagonists, relying on wild or domesticated animals to consume unwanted species (cf Altieri 1999), and rotational grazing to prevent infestation and contagion (Tables 3 and 5B). These practices did not prevent pest outbreaks, but limited their impact and the resulting loss of production. Crop combinations, including species whose chemistry and smell deter pests and parasites, were used in vegetable gardens and leys in the Swedish case (Table 5A). For example, species that contain condensed tannins, such as *Lotus corniculata*, prevented the growth of visceral parasites (Niezen et al. 1993).

Some of the practices identified may have improved the capacity of the agroecosystem to perform ecosystem functions after disturbance and allowed for ecosystem renewal. In both case studies, small-scale agriculture created a patchy landscape with fields and woodlots interspersed with pastures and tree-rich home gardens. Together with the practice of leaving strips of natural vegetation between fields, this created and enhanced habitat that supported populations of pollinators and natural enemies of pests (cf Reijntjes et al. 1992, McLaughlin and Mineau 1995). We also found that predators of pest species were supported by social protection (Table 5B). For example, the oxpecker (*Buphagus erythrorhynchus*), which feeds on livestock ticks, was a protected species in the Mbulu highlands, Tanzania (Lawi 1999). Similarly, in Roslagen, Sweden, some known predators of crop and livestock pests, such as owls, starlings, titmice, swallows, spiders, and ladybugs, were not harmed by the farmers, and bird habitats were enhanced by providing nesting space in barns and constructed nesting boxes (Table 5B).

Rules that guide the behavior of people through informal sanctions are often referred to as taboos. According to Colding and Folke (2001), informal institutions such as taboos create an invisible system of local ecosystem management that, in many cases, is important for resource conservation and for maintaining ecosystem function. Colding and Folke (1997) found several examples of taboos that deal with ecological keystone species. Taboos involving species and habitats can also function to nurture renewal following disturbance by providing seeds, seedlings, or larvae that can recolonize a disturbed area and by maintaining key ecological functions (Berkes and Folke 2002, Colding et al. 2003). In both case studies, we found taboos concerning species that perform ecosystem services such as pest control, pollination, and decomposition. The taboos included protection of the species themselves and recommendations for habitat improvement. Thus, taboos may have played a role in preserving agroecosystem function in the two case studies. Furthermore, when social mechanisms such as taboos are transferred among generations, they may also contribute to maintaining farmers' knowledge of the role of these species in ecological processes.

Dynamics of local ecological knowledge

In our analysis of management practices in two cases, it became clear the body of practices in use was not static. We found examples of revitalization of old practices in response to, for example, climate change and new diseases as well as the incorporation of recent findings in agricultural science into farm management. We also identified the role of local networks for transmission of knowledge.

In the Swedish case study, a series of mild winters during the 1990s increased the intensity and severity of pest outbreaks, especially the fungal infestation of crops. This led to experimentation not only with new crop varieties but also with old varieties to test their pest resistance. Further, the farmers in Roslagen also recognized that the multiple-species leys common in the past could produce a more reliable harvest during varying climatic conditions. However, the seeds for many of the old ley species are difficult to come by today. Another example involved the severe potato blight fungus (*Phytophtora infestans*). For a few years, this fungus made cultivation of the most common and the most popular potato variety, the King Edward, impossible without the heavy use of fungicides. As an alternative, the Swedish farmers experimented with spraying the potato with an infusion of stinging nettles (*Urticaria dioica*). Stinging nettles have long been known to enhance the resistance of livestock and vegetables against diseases. When applied to the King Edward potato, the farmers found that the nettle also improved the survival of the potato crop. By transmitting old knowledge to deal with a new problem, the farmers were able to continue to cultivate the desired potato variety. This case shows how local management practices served as a reservoir of adaptations that enhanced resilience by increasing the capacity to reorganize and respond adaptively to change (Folke et al. 1998).

The Swedish farmers mentioned several examples of recent findings in agricultural research that has been incorporated in management and adjusted to local conditions, e.g. the use of catch crops, undersown crops, green manure, and different methods for parasite control such as rotational and alternating grazing. Two recently adopted practices were mentioned by the farmers as being particularly useful: the preparation of seeds using steam to kill pathogens and flaming, which was used as a method of weed control in vegetable cultivations. In the Mbulu highlands, some farmers experimented with new crop varieties that mature quickly in the relatively cool climate. We also found that soil and water conservation practices were improved by information spread through extension projects.

In both the case studies, local networks within and between villages appeared to function as a bridge for the transmission of both old and new farming practices between groups and to new generations. This transmission of information was a precondition for keeping local ecological knowledge vital and dynamic. Several of the Swedish farmers in our study were also active in non-governmental organizations such as Ekologiska Lantbrukarna (The Swedish Ecological Farmers Association), Svenska Naturskyddsföreningen (the Swedish Society for Nature Conservation), and Förbundet Sveriges Småbrukare (the Association for Swedish Smallholder Farmers). The farmers considered these to be important sources of new knowledge and practices to improve smallholder farming. Local networks were also considered crucial for dealing with social disturbances such as new political regulations, European Union subsidies, and lobbying by chemical and plant breeding companies who were encouraging a transition toward intense, large-scale agriculture.

The system of farm management practices based on local ecological knowledge identified in the case studies was equipped to deal with and adjust to a dynamic environment. The practices were not aimed to block out disturbance, an approach that is common in conventional agricultural practices (Holling and Meffe 1996). On the contrary, the farm practices in our case studies evolved through long-term interactions between people and their environment, and farmers appeared to have an ecosystem perspective on farm management. The identified practices that dealt with the backloop period were based on an understanding of ecosystem dynamics and the role of disturbance in ecosystem behavior and management (Berkes and Folke 1998). The farmers in our case studies are aware that individual seasons, climate irregularities, and pest outbreaks will affect crop production. By diversifying and adjusting their ecosystem management practices, farmers minimize the adverse impact of these disturbances on their livelihoods. Such knowledge about how to deal with and interpret environmental change makes locally developed management practices an integral component in the development of sustainable agriculture, in both high- and low-income countries. We argue that comparisons of farmers' management practices in different environments can reveal insights into how to sustain the capacity of ecosystems to generate essential services.

CONCLUSIONS

Human alteration of ecological processes at different scales calls for an increased awareness of unexpected ecological events and the need to strengthen our capacity to cope with them. This requires a complex systems approach to natural resource management that acknowledges the nonlinearity and unpredictability of ecosystem behavior. We found that the farmers in Roslagen, Sweden, and the Mbulu highlands, Tanzania, recognized the dynamic behavior of the ecosystems they interacted with. They developed management practices that increased their capacity to deal with recurrent disturbances such as pests and climate variability. In both case studies, we found a multitude of management practices that worked in synergy with ecosystem processes, that promoted biological diversity, and that could adapt to local ecosystem dynamics. The body of knowledge underlying these practices was not static but incorporated new knowledge both from farmer experience and from agricultural research. When comparing the case studies, we also found many similarities among local farm management practices across cultural settings and geographical scales. Some of these practices may be applicable as general mechanisms over a wide geographical scale for adjusting and responding to ecological dynamics and for enhancing the capacity to deal with uncertainty and change.

The iterative processes of farm management provide learning mechanisms for experimentation and the reevaluation of practices in response to ecosystem feedback. We suggest that the spatial scale of farm management should be adjusted to ensure that feedback signals from the ecosystem can be easily perceived and that experience with local dynamics can be accumulated and used to guide farm management. Losing the capacity for adaptive response makes farmers more vulnerable to change and to disturbances such as climate change or the scarcity of fossil fuel.

Several studies have looked at human organization around natural resources (e.g., Ostrom 1990, Baland and Platteau 1996), but few have explored the interactions between social and ecological dynamics, such as how social and ecological systems coevolve and how this affects sustainability (Berkes et al. 2003). In this paper, we examined farm management practices as a link between social and ecological systems. By comparing and analyzing how people organize farm management practices based on ecosystem feedback, our results contribute to an improved understanding of social-ecological interactions and the capacity to build resilient agriculture. To secure food production for the future, scientific understanding of agricultural production and ecological processes needs to be combined with the dynamic and site-specific ecological knowledge of local producers, both in developed and developing countries.

Responses to this article can be read online at: http://www.ecologyandsociety.org/vol9/iss3/art4/responses/index.html

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APPENDIX 1

Advantages of intercropping identified by farmers in Roslagen, Sweden

1. Increases production
2. Enhances the supply of nutrients, especially nitrogen
3. Attractss insects and birds that control pests and diseases
4. Protects the crop against fungi by naturally occurring chemical compounds
5. Repels harmful insects by fragrance
6. Increases taste and aroma in the crop
7. Increases the content of ethereal oils in herbs
8. Increases crop quality in vegetables
9. Buffers for crop failure during climate irregularities

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