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Resilience assessment desktop case studies in Thailand and Niger

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Case studies to accompany a discussion paper for the Scientific and Technical Advisory Panel of the Global Environment Facility

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About STAP

The Scientific and Technical Advisory Panel comprises seven expert advisors supported by a Secretariat, which are together responsible for connecting the Global Environment Facility to the most up to date, authoritative and globally representative science.

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1 Overview

This report is an accompaniment to a main report that describes a Resilience, Adaptation and Transformation Assessment (RATA) Framework (O'Connell et al., 2015), hereafter referred to as the RATA Framework Report. The case studies tested and contributed to the development of assessment methods and indicators proposed in the RATA Framework Report by applying them to assess the resilience of two contrasting agroecosystems. One is the intensive production of irrigated rice in tropical Thailand, the other an extensive semi-arid agro-pastoral system in Niger. We selected these contrasting systems so as to span a range across three critical dimensions of agroecosystems: soil moisture, which depends on rainfall; naturally occurring soil nutrients; and level of external fertilizer and agrochemical inputs (Figure 1). These characteristics can be described for any agroecosystem. Interactions among these variables are relevant to the Rio conventions on desertification and degradation, climate change and biodiversity, and so hold the potential to inform indicators relevant to all three conventions. They have profound implications for resilience because they are related to key controlling variables as we describe next:

- plant growth in dryland agroecosystems is limited mainly by water availability (Maasai pastoral system), nutrient availability (Sahel agropastoral and shifting agricultural systems), or both (Kenya highland mixed farming system) (Frost et al., 1986)
- farmers motivated by the need for food or cash reduce these constraints with fertilizers, irrigation, or both. This favours crops as well as weeds and pests, so industrial fertilizer, herbicide and pesticide dependence are all increased
- low input systems depend on ecosystem functions such as soil fauna that maintains soil moisture storage capacity and predators that control pests, but those functions are partly substituted by irrigation, fertilizers and agrochemicals in high input systems
- external inputs tend to degrade ecosystem functions and reduce resilience through, for example, their effects on soil fauna and soil acidity, predators of crop pests and crop pollinators; they also pollute aquatic systems and affect fisheries, humans and other species.

Without climatic change the needs for food and money drives increased dependence on external inputs, declines in free, self-organising ecosystem services, and consequent loss of resilience. Climatic change, and global change more generally, is likely to destabilize agroecosystems in some regions and increase the risk of degradation by shifting the relative scarcities of soil water and soil nutrients, thus affecting plant production and cover. These changes would also shift relative levels of dependence on external inputs versus ecosystem services, with consequences for agrochemical pollution and biodiversity. These descriptions describe biophysical characteristics of agroecosystems. In the RATA Framework Report we emphasize that an agroecosystem is a social-ecological system and our assessment of these case studies necessarily includes social characteristics relevant to each system.

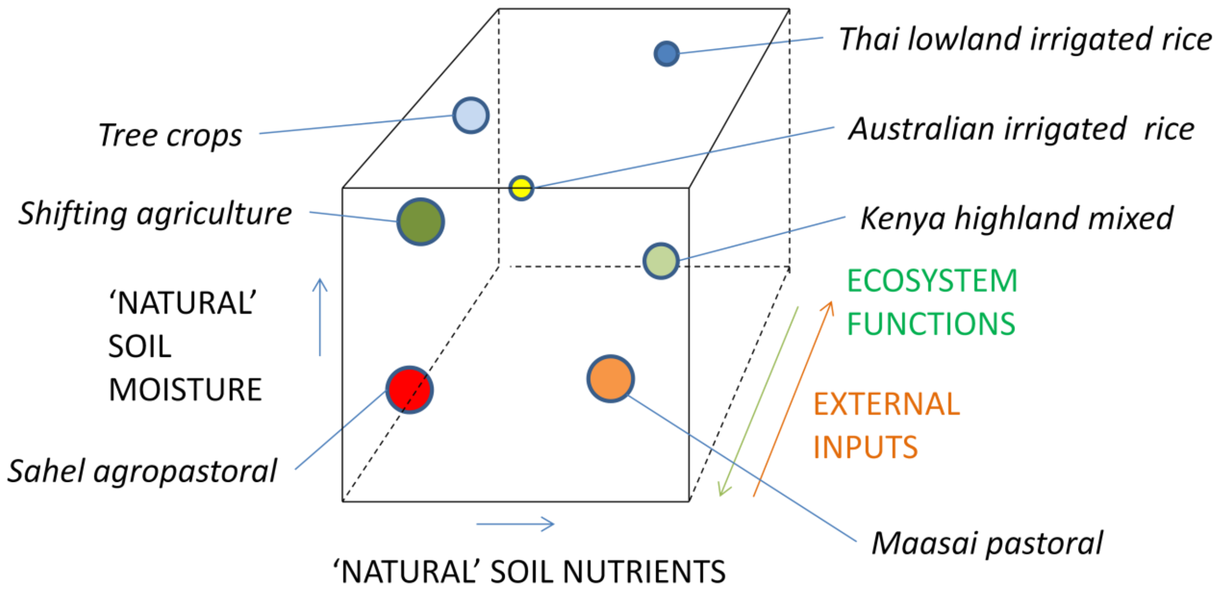


Figure 1 Soil moisture, soil nutrients, external inputs and ecosystem functions.

'Natural' soil nutrients refers to the nutrients available to plants in the absence of fertilizers or manure. 'Natural' soil moisture is the moisture available to plants without irrigation. External inputs are commercial fertilizers, herbicides, fungicides and pesticides. Ecosystem functions are processes such as predation on pests and maintenance of soil water infiltration rates that are performed by biota. They tend to decline with increasing external inputs because of toxins and other chemical changes.

Our Sahel and Thailand examples were rapid desktop studies by two researchers unfamiliar with these agroecosystems. As such the cases do not have sufficient rigour or depth of knowledge, nor did they use the participatory assessment methods we would advocate for an assessment used to guide actual agroecosystem policy and management. The case studies were, however, critically important tests of the methods and indicators we proposed in the RATA Framework Report.

The case studies follow the assessment process described in the RATA Framework Report, and the headings 'Element A.1, A.2' etc. are steps summarized in Figure 8 of that report.

2 Case study: the Lowland Irrigated Rice Agroecosystem on the Central Plain of Thailand

2.1 Element A. System Description

2.1.1 ELEMENT A.1 SCOPE OF THE RESILIENCE ASSESSMENT

The irrigated lowland rice agroecosystem occupies around 35,000 km^2 on Thailand's Central Plain, which lies within the basin containing the Chao Praya river and its tributaries (Figure 2). The scale at which we assess the resilience of this agroecosystem (the focal scale) is the 158,000km^2 of the basin (FAO, 2010). Within it are upland catchments upon which irrigated lowland rice production depends for water. They contain dryland cropping and upland paddy rice agroecosystems, which are different categories of agroecosystem (Dixon et al., 2001) so their resilience indicators would be estimated and reported separately. We do, however, analyse their interactions with the lowland rice agroecosystem on the Central Plain, and the consequences of this for its resilience.

Figure 2 Focal area – the Chao Praya River Basin, Thailand. (Source – Wikipedia)

Central to the resilience of the agroecosystem is a climatic regime in which between 1200 and 1800 mm of annual rainfall yield a mean annual runoff of 33,000 GL (UNEP, 2010, FAO, 2010).

Issues that have informed our resilience assessment include (FAO, 2010, UNEP, 2010, Perret et al., 2010, Soitong and Gummert, 2010, Wiengweera and Gummert, 2010):

- climatic change, water becoming scarcer and competition for it increasing;
- wet season flooding coupled with subsidence due to groundwater abstraction in Bangkok
- saltwater intrusion into the over-used aquifers under Bangkok
- navigability of rivers, a crucial part of the transport network, impeded alternatively by floods or by low water levels as water is abstracted for irrigation

- forest clearance for agriculture in the upper catchments affecting stream flow, water quality and dam capacity
- water pollution and greenhouse gas emissions from rice production.

These issues are discussed more in Section 2.1.3 ('Resilience of what, to what').

2.1.2 METHODS

There are many ways to assess resilience (Section 4, RATA Framework Report). Options for this case study were limited by time and resources, so it shows one way of assessing resilience in such circumstances. We reviewed literature on Thailand and the focal area for information needed in Elements A and B of Figure 8 of the RATA Framework Report. We used the simulation software Vensim to build an influence diagram, adding new variables and linkages as we found them in the literature. In Figure 3, I is an input variable. If it increases or decreases, the + sign means that variable A responds in unison, as does variable D. Variable C is part of a stabilising, or negative feedback loop: as B increases so does C, but the negative sign between C and A means that as C increases, A decreases, and vice versa, so the variation in output variable O1 is dampened. By the same logic, variable F is part of a reinforcing, or positive feedback loop which destabilizes output variable O2. The resulting influence diagram for the agroecosystem is summarized in Figure 4.

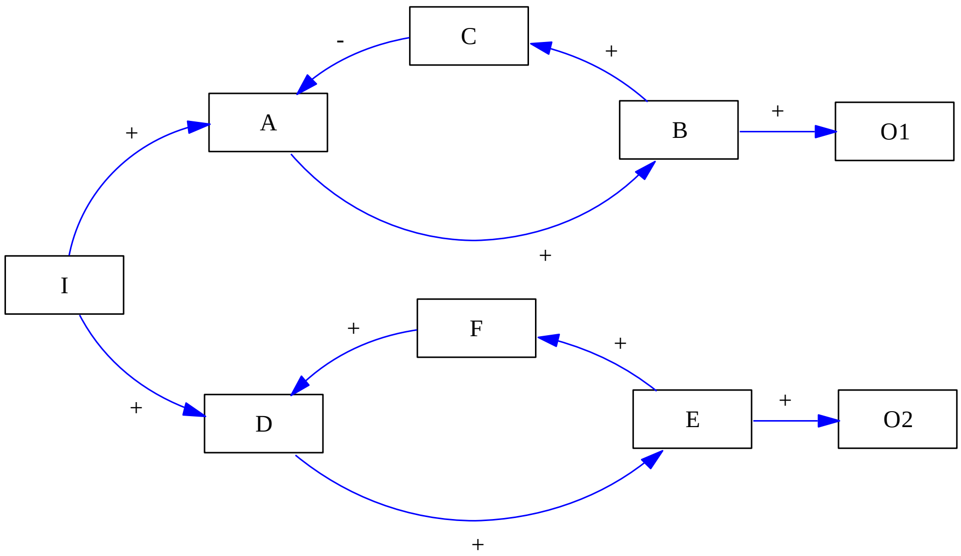


Figure 3 Influence diagram with feedback loops.

2.1.3 ELEMENT A.2 RESILIENCE OF WHAT TO WHAT?

Resilience of what?

Our desktop study assesses the ability of the lowland rice agroecosystem of the Central Plain to continue to contribute to future human wellbeing by providing for their food, water, income and quality of life needs despite economic and environmental shocks and trends. In 2003 about 82% of households in the region (excluding Bangkok) were above a poverty line set then at Baht 20,000/household/y (Simarak et al., 2005), with the majority of poorer people living in dryland areas (FAO, 2010).

The case study is human-centred – the consequences of rice production are judged only in terms of their direct or indirect impacts on human values. Indirect impacts result from loss of ecosystem functions, such as unintended eradication by pesticides of predators that could control crop pests. Values include use and non-use values. Some use values such as marketed rice or fish are monetary, others are not – rice eaten by farming households or fish caught in paddies for direct household consumption, for example. Non-use values include the intrinsic and existence values of ecosystems and their biota, such as the rich birdlife, and the unquantifiable values of the options that the system retains for potential use if the system transforms, such as land, water and biotic resources that could be put to other uses.

Resilience to what?

Drivers and shocks

National governance and international research and development programs are more or less responsive to feedbacks from changes in farmers' behaviours and rice production levels, their use of water and agrochemicals, and the consequences of production for water quality and human health. In contrast, drivers of the irrigated rice agroecosystem are defined as variables that cause the system to change but are unresponsive to feedback from system to the driver. We define shocks as drivers that impact on a system and then subside. We identified the drivers and shocks below.

Climate

The South East Asian Region's climate is changing as greenhouse gas emissions increase (World Bank, 2013). Average SE Asian summer temperature is projected to rise at a rate that depends on the success or otherwise of attempts to reduce global emissions. The frequency of extreme heat events is projected to increase. Thailand has been identified among the countries where temperature rise is expected to constrain rice production, because the dry season temperatures are already at the upper threshold of tolerance for current rice varieties (Wassmann et al., 2009). Trends in precipitation are unclear - predictions of whether annual averages will increase or decrease depend on which model is used (World Bank, 2013). The models generally agree, however, that the magnitude and frequency of extreme rainfall events will rise, perhaps contributing up to half of annual rainfall variability, even as the duration of dry periods increases. Potential impacts on rice production are flood damage to crops and infrastructure, and further yield reduction because drought is thought to enhance temperature sensitivity (Wassmann et al., 2009).

Sea levels will continue to rise so that saltwater will intrude further into coastal groundwater. The area of land permanently inundated will grow and the storm surge limit will continue to spread inland for as long as the sea level keeps rising. The landward extent of storm surges is predicted to be enhanced by the increased intensity of tropical cyclones. Coastal agriculture will necessarily retreat from the sea, but the future of Bangkok itself, which has subsided because of groundwater extraction (FAO, 2010), will depend on the defensive and adaptation strategies chosen, and their effectiveness.

Markets

Demands from urban and international markets have already influenced a shift of some land from irrigated rice production to the growing of vegetables, fruit and other commercial crops. The commercialization of production, including the use of contract farming by 'outsiders' is said to be weakening long established collective water management institutions, in particular around urban areas or near the busier roads, where market demand is strong (Bastakoti et al., 2010).

Changes in input markets could also drive changes in the agroecosystem. The prices of fossil fuels and agrochemicals are the most obvious – we discuss their use and its consequences below – but commercial development of genetically modified crops with associated patent rights may also affect seed prices.

Population change

National rate of population growth was slowing in 2004, the age structure shifting towards a higher proportion of economically active 15-65 year-olds. Despite this the proportion working in agriculture continues to decline – it fell from 79% to 66% between 1970 and 1990 (Simarak et al., 2005) - and labour scarcity currently increases agricultural labour costs. Migration into the upper catchments by those seeking land drives deforestation that affects lowland irrigation (discussed below).

Crop diseases and pests

A wide range of bacterial, viral and fungal diseases affect yields and post-harvest storage (IRRI Rice Knowledge Bank, www.knowledgebank.irri.org). The organisms evolve along with crop breeding and management, so that new strains can arise unexpectedly. Insects, rodents, snails and nematodes are among the pests. Disease, pest and weed threats drive levels of use of agrochemicals, which we identify below as a controlling variable.

2.1.4 ELEMENT A.3 GOVERNANCE

The resilience of this agroecosystem can be enhanced or diminished by national laws, policies and investments. The large area irrigated is the result of past public investments in infrastructure, while current policies aim to reduce irrigated rice production from five crops in two years to two crops a year so as to reduce the use of scarce dry season water, manage pest risks, maintain soil quality and reduce rates of agrochemical use. Inducements to comply include improved market access, and subsidies for high quality seeds, green manure use, and crop diversification. The Thai Government also administers an income risk insurance program, from which farmers not responding to the other policies could be excluded (UNEP, 2010). National scale governance also determines land tenure and water use rights, the construction and maintenance of public irrigation infrastructure, and levels of acceptability of water quality. In addition it sets national rice pricing, education and research policies as well as funding extension programs for farmers. More broadly, national scale governance negotiates trade agreements that affect rice export levels, and negotiates internationally acceptable levels of greenhouse gas emissions.

International research organizations, the International Rice Research Institute (IRRI) in particular, aim to influence the productivity of the lowland rice system through their research on genetic improvement, land and water management and pest and disease control. Its focus is aligned with that of the government – the efficiency of resource use and value of the crop, rather than the resilience of the agroecosystem.

2.1.5 ELEMENT A.4 HOW THE LOWLAND RICE AGROECOSYSTEM FUNCTIONS

We used the influence diagram to identify the main variables and how they interact dynamically under the influences of governance, drivers and shocks. With this tentative understanding we then identified focal scale controlling variables in preparation for the resilience assessment (Figure 4). Buff coloured boxes are potential controlling variables. We used judgement to nominate these as controlling variables. We chose them from among the other variables in the diagram because they are relatively stable, they influence many of the variables that people value and that contribute to wellbeing, and because wellbeing is likely to change suddenly if the level of the potential controlling variable crosses a threshold. Controlling variables maintain a regime through stabilising feedback loops.

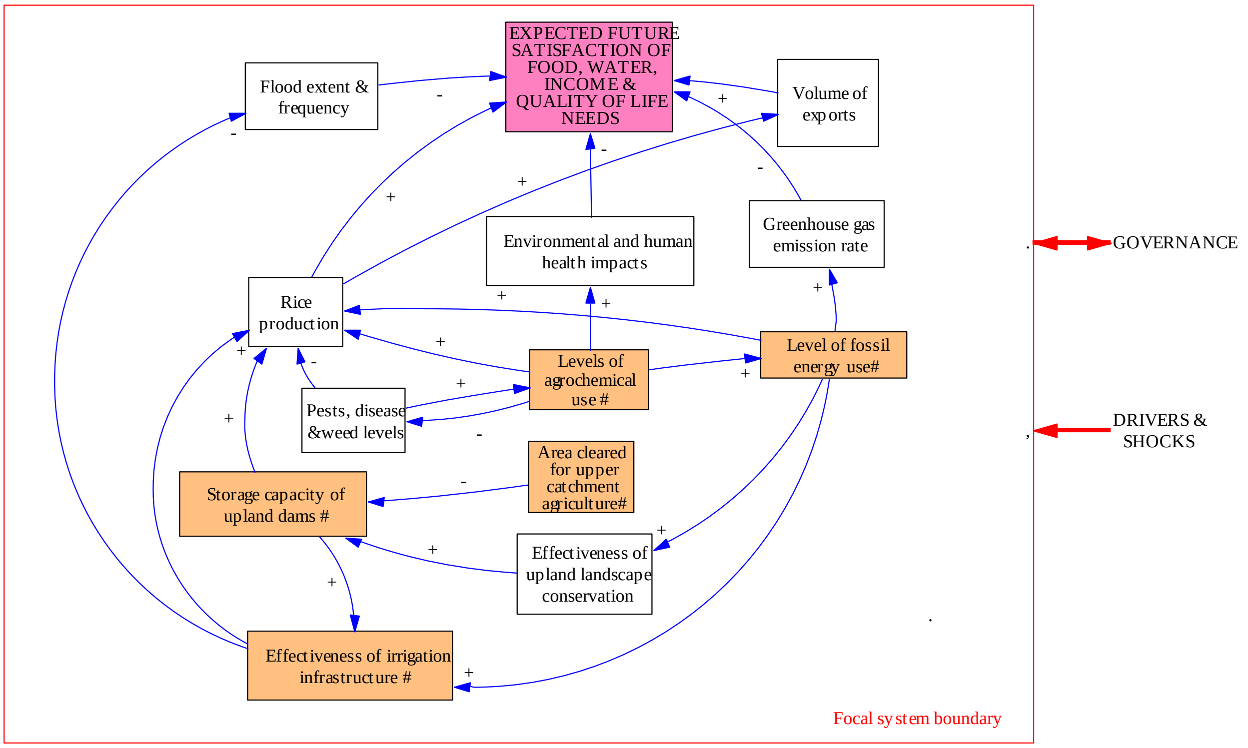


Figure 4 Summary of the main interactions that generate wellbeing and affect resilience in the lowland rice agroecosystem. Controlling variables are brown.

Stakeholders and roles

Stakeholders were identified and their interactions analysed by Soitong and Gummert (2010), and this section is based entirely on their report.

Farmers organize themselves into informal groups, or formal cooperatives, or larger groupings concerned with the dissemination of knowledge, better seeds and new technologies. The Thai Rice Farmers' Association aims to influence government policies as well as providing market and production advice to farmers. Agricultural labourers are also actors - the opportunity of higher wages working in urban jobs makes them scarce and costly to rice farmers. Rice traders, exporters and rice seed producers could benefit from trading more premium quality rice sold at a high price, suggesting the potential for a reduction in the area under irrigation by supplying this market. There is a potential for machinery manufacturers to benefit from making and selling more fuel-efficient machinery as pressures to reduce fossil fuel consumption build. Financial service providers could benefit from supplying credit to new types of enterprise if the traditional rice market shrinks. Input suppliers, however, would gain no benefit from reduced agrochemical use.

Water users form into groups to manage tertiary level canals, and these are further aggregated to manage canals at the secondary level, with primary level canals presumably being government-controlled (not confirmed). Fifty such communal irrigation systems, 31 of them lowland, and six of these within our focal area, were evaluated by Bastakoti and Shivakoti (2009) against Ostrom's (1990) set of attributes that characterize persistent irrigation systems. They concluded that rules about spatial boundaries of the systems, and membership of the collective were clear and accepted. The remaining attributes were only satisfied in part because:

- there was some lack of congruence between rules relating water use by individuals, and their contributions to the system of labour, materials and money on the one hand, and the prevailing economic and hydrological conditions on the other
- individuals affected by collective rules could not always participate fully in modifying them
- monitoring of individuals' water use by the group was not always adequate
- penalties for repeated abuse of rules did not always become increasingly severe

- arenas for resolving conflicts within the group or with officials were not always effective
- the group's right to self organize and make their own rules was at times challenged by government
- groups were not always nested within broader scale groups with similar attributes.

Based on those findings we would rate these water governance arrangements as fairly resilient, but Bastakoti et al. (2010) found that many water user groups failed once government support ended. One reason is that as urban areas grow and road networks spread, the greater individual benefits from growing cash crops compared with rice lead to the adoption of individualized irrigation systems, such as private wells, which have much lower transaction costs than communal systems.

Controlling variables

Level of fossil energy use and greenhouse gas emissions

The level of fossil energy use is proposed as a controlling variable because of its central role in production and distribution of rice, and the impacts of greenhouse gas emissions on climate. Fossil fuel energy use for the mechanized activities of irrigated rice production is estimated at 4760 MJ/ha/y, and for manufacturing, storage, distribution and related activities 3062 MJ/ha/y. Human labour contributes 24.1 MJ/ha/y. Decreasing family size, and competition for labour from nearby Bangkok reduce labour availability, drive up wages and increase the use of machinery. Draft animals are little-used in this agroecosystem (Simarak et al., 2005). However Singleton (pers. comm.) points out that in Myanmar after the devastation of cyclone Nargis buffalo were preferred over two wheeled tractors because they did not need spares or fuel, neither of which were readily available. Buffalo are resilient, though both tractors and buffalo emit greenhouse gases.

Even ignoring the almost 1000MJ/ha/y in the agrochemicals used, the system is over 99% dependent on fossil fuels to manage the current area irrigated (UNEP, 2010). Renewable energy use is growing, but cannot as yet be used for mechanical power. Fertilizers increase the emissions of nitrous oxide, to which are added substantial methane emissions from the anaerobic fermentation of soil organic matter in inundated paddies. Worldwide, lowland irrigated rice farming was estimated to produce 5-10% of global emissions of methane (UNEP, 2010). Farmers might be pressured to reduce emissions if Thailand caps its greenhouse emissions and perhaps introduces a carbon tax or trading scheme. Methane emissions can be reduced to an extent by water management (UNEP, 2010), but there is nevertheless a potential threshold on rate of fossil fuel use.

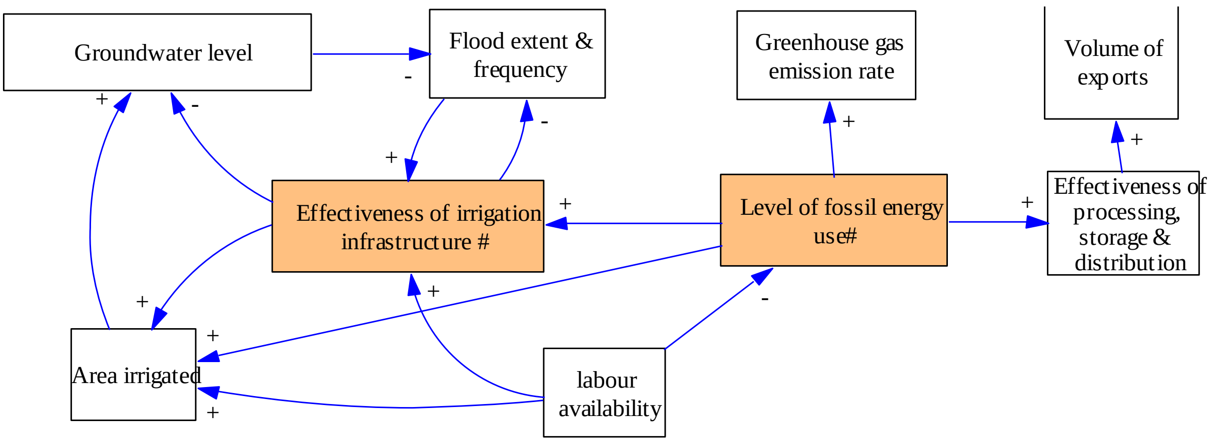


Figure 5 Level of fossil fuel use as a potential controlling variable

Possible indicators for level of fossil energy use:

i. trend in fossil energy use in the focal area
ii. level of dependence on fossil energy
iii. trend in national greenhouse gas emissions
iv. proximity of national greenhouse gas emission rate to internationally negotiated target.

Levels of agrochemical use

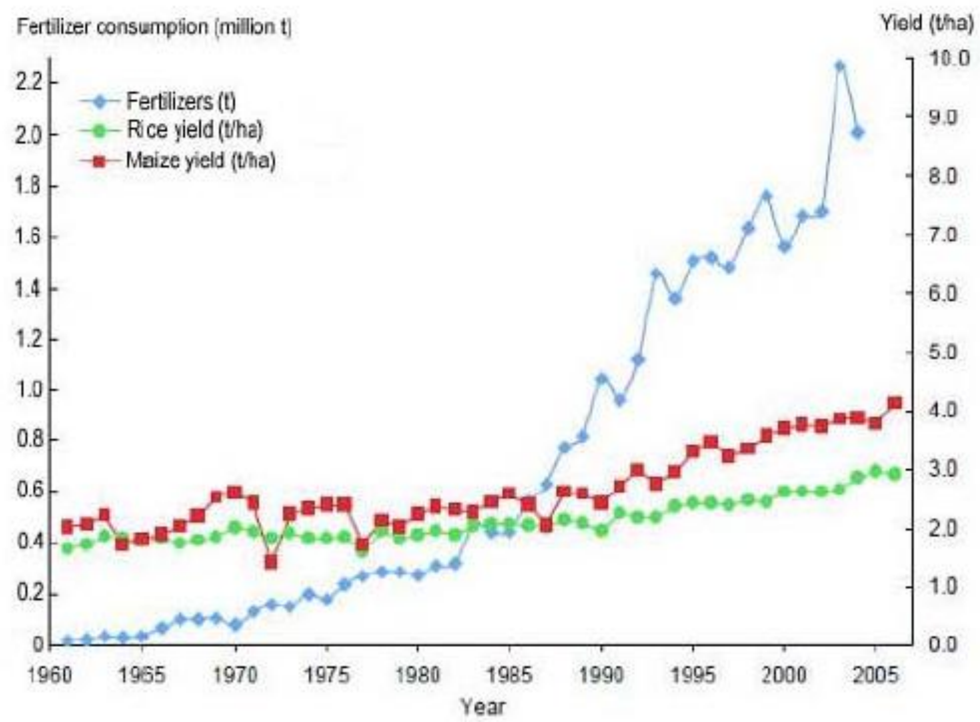


Figure 6 Fertilizer consumption and crop yields in Thailand. Source: copied from UNEP (2010).

We use 'agrochemical to include fertilizers, pesticides, fungicides and herbicides. The strong upward trends in agrochemical use are not matched by yield increases (Figure 6). We propose there is a potential upper threshold on agrochemical use because of their environmental and health impacts (Figure 7).

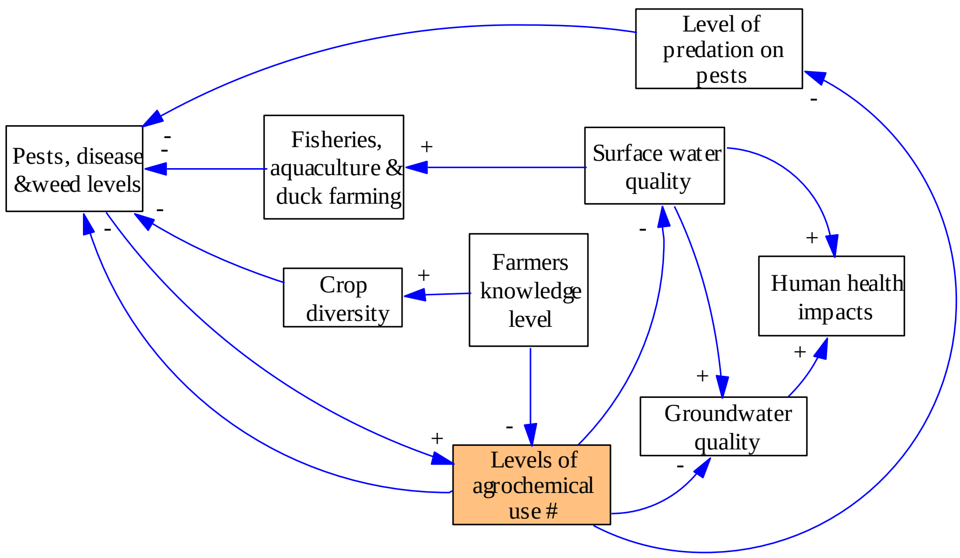


Figure 7 Levels of agrochemical use as a potential controlling variable

Most agricultural pesticides used in Thailand are imported (Figure 8). There is a positive feedback loop involving the prophylactic use of pesticides on crops, thus predisposing them to pests by killing predators. Farmers are advised mainly by retailers, who sell them chemicals with a high physical kill rate, that are relatively cheap, and extremely toxic to beneficial predators on pests. That leaves crops highly vulnerable to rapid increases in crop pests, which is thought to be exacerbated by over-use of nitrogenous fertilizers.

The Brown Planthopper outbreak of 2009/10 is an example. This pest also carries rice virus diseases (UNEP, 2010).

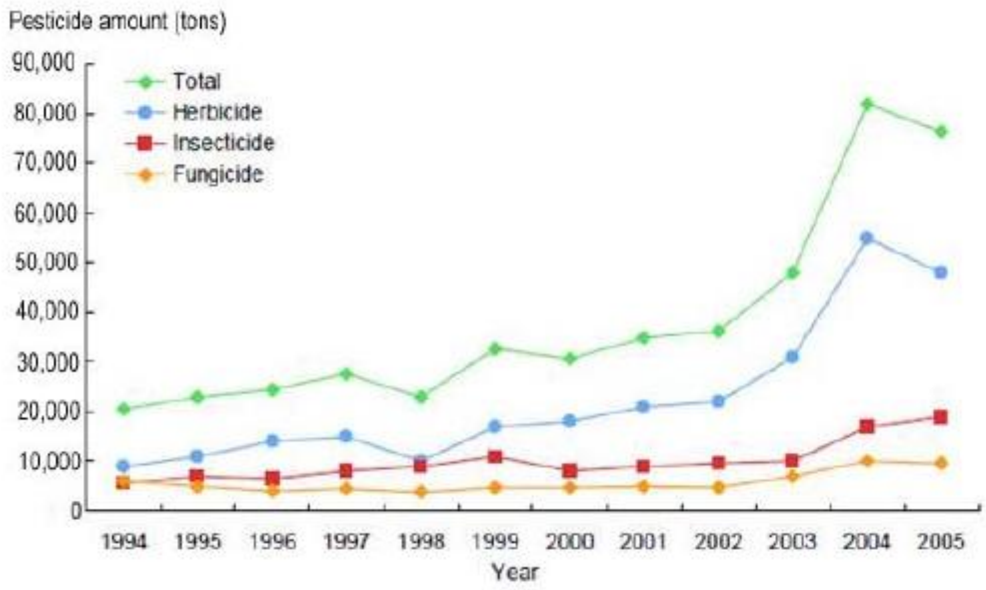


Figure 8 Pesticide imports to Thailand. Source: copied from UNEP (2010).

Fertilizer, pesticides and herbicides in drainage and runoff water from paddies pollute surface and groundwater where it affects human health, fisheries, and other biota (Figure 7). Nationally, 40% of Thailand's surface water resources are rated "poor", or "very poor". Some 75% of national domestic water consumption is from groundwater, and that resource is becoming increasingly polluted. Agricultural pollutants are causing algal blooms in reservoirs and the Gulf of Thailand (UNEP, 2010).

Possible indicators for levels of fertilizer use

i. trends in use
ii. threshold for tolerable water quality level. The impact reaches into the Gulf of Thailand where we assume it affects marine ecosystems.

Possible indicators for levels of pesticide, herbicide and fungicide use

i. trends in use
ii. threshold of tolerable pollution level. This indicator is speculative. It is outside our expertise, but it is likely to be difficult and costly to measure because new products are introduced with new and different pollution risks, molecules from different products interact in the environment to produce new chemicals, because the health consequences of pollutants are hard to assess, and for other reasons best sought from environmental chemists.

Effectiveness of irrigation infrastructure

The effectiveness of irrigation infrastructure is proposed as a controlling variable because of its role in production of rice (Figure 9). Water storages and the extensive rice paddies mitigate wet season flooding, benefitting rural and urban dwellers, including those in flood-prone Bangkok (World Bank, 2013). Climate change is expected to increase the recurrence of extreme rainfall, which is likely to test the capacity of levees, storage and control structures. There may be an upper threshold on this capacity which if exceeded could result in loss of life, property and crops and damage to transport and communications network during floods. The latter is already affected during the dry season by the drop in river flows caused by diversion of water for irrigation. This is said to have reduced river traffic fivefold between 1978 and 1990 (FAO, 2010).

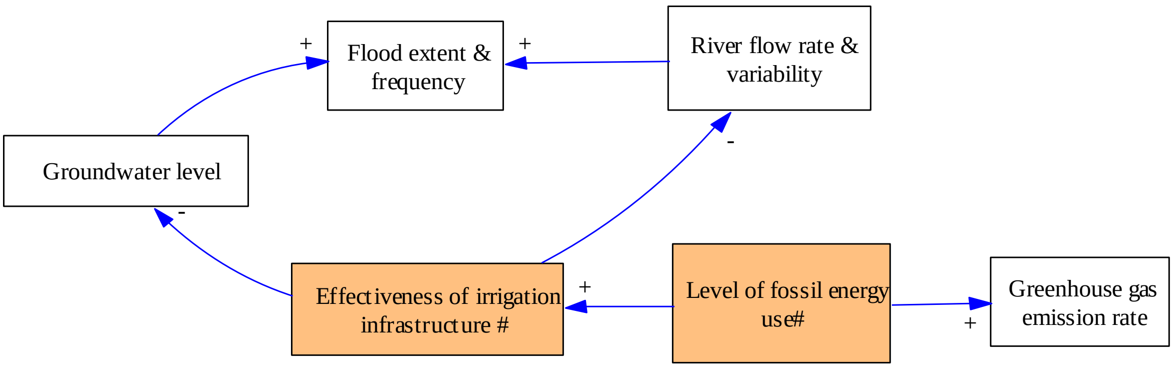


Figure 9 Effectiveness of irrigation infrastructure as a potential controlling variable

Potential indicators for effectiveness of irrigation infrastructure:

i. Modularity: shows the ability of the system as a whole to remain functional when parts of it are damaged. The many paddies, and the multiple lowland water storages are examples of modular sub-systems, but the few large upland dams are much less modular, and the loss of one would have a severe impact.
ii. Functional diversity: estimates the extent to which the functions of one damaged system component can be replaced by a different component. A hypothetical example is the effects of damage to flood control infrastructure around a city being mitigated by the use of irrigation infrastructure to divert floods.
iii. Reserves: measures the amount of spare capacity in a system under extreme conditions. Water resources are already at full capacity, and scarcity limits production during the dry season, with the potential for that scarcity to accumulate if a series of drought years alternates with lower wet season rainfall.
iv. The capacity of water management groups at different levels and locations in the system to coordinate their decisions.
v. Existence of convincing and rehearsed emergency strategies.

Developing these indicators would benefit from hydrological modelling and climatic scenarios spanning extremes of drought and rainfall to reveal weak points in the system.

Upland controlling variables

Irrigation water availability constrains production during the dry season (UNEP, 2010). The capacity of upland dams supplying this agroecosystem decreases as sediment accumulates, carried from steep slopes cleared for agriculture by erosive rain and runoff. Although clearing was illegal, one upland forest catchment was being cleared at 1.1%/y (Wannasai and Shrestha, 2008), another at 1.4%/y. The latter lost 15% of its forest cover from 1995 to 2006 and dam storage volume fell by 6.6% (Thothong et al., 2011).

We identify dam capacity as a controlling variable with a potential threshold because regional climate change is expected to increase the frequency of extreme rainfall events as well as the duration of dry periods – there will be more water to store, and more reason to store it.

Soil loss rates are least from forest, faster from the fallow stage of shifting agriculture and planted perennial crops (Figure 1), and greatest from annual arable cropland (Valentin et al., 2008). Farmers seeking land in protected forests tend to plant perennial rather than annual crops because it strengthens their chance of securing sanctioned tenure. However, if population pressure persists this encourages the clearance of more forest and the planting of more perennial crops in order to secure more land. While perennial crops yield less sediment and are also preferred by most farmers, they need to plant on average 15% of their land under annual crops with high sediment yields to meet their subsistence needs (Wannasai and Shrestha, 2008). If extreme rainfall events become more frequent, the erosivity of rainfall would increase too – nearly 48% of the sediment accumulated in a dam during a twelve year study came from a single event (Thothong et al., 2011). Clearance exposes soils to erosive rainfall until a crop is established. It is driven by population increase and the need for food and incomes, so as cleared land degrades, more is needed, with further consequences for dam storage capacity. We therefore propose the area cleared for upper catchment agriculture as a second controlling variable with an upper threshold. Landscape soil conservation can retain the soil, water and nutrients necessary for production, and can counter the effect of clearing to an extent (Valentin et al., 2008). Provided the population is not growing, this measure would decrease future demand for cropland.

Dam storage capacity is proposed as the third controlling variables in the upland set. Relationships in this sub-system are in Figure 10. Proposed controlling variables are identified by buff coloured boxes, and potential indicators for these are below.

Potential indicators of area cleared for upper catchment agriculture:

i. Ten year trends in area cleared in catchments for all upland dams in the focal area. If trends are similar they can be aggregated, otherwise trends would need to be reported as separate classes.
ii. The area of annual crop above which runoff rate in extreme rainfall events is deemed unacceptable. Soil loss modelling would be needed. Again, if minimal cover thresholds vary significantly between catchments they would need to be reported separately
iii. Proximity to ii.

Potential indicators of storage capacity of upland dams

i. Trend in storage capacity
ii. Acceptable threshold of storage capacity under modelled rainfall scenarios with longer droughts and more extreme events than are experienced under the current climate. We propose the use of rainfall scenarios rather than actual data because time would be needed to change storage capacity and to implement landscape conservation projects
iii. Proximity of storage capacity to ii.

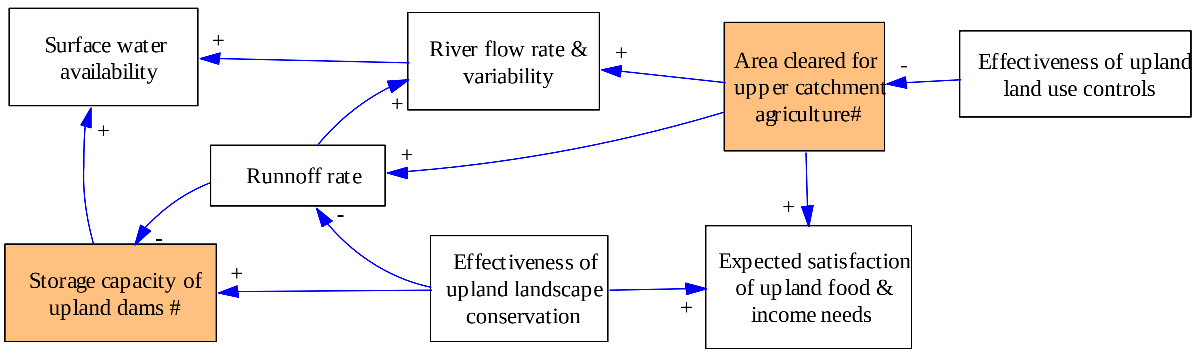


Figure 10 Potential controlling variables in the upper catchments

A summary of the controlling variables and suggested indicators are in Table 1.

Table 1 Summary of controlling variables and indicators for specified resilience of irrigated rice

Indicator	Rationale & assumptions
Levels of fossil energy use and greenhouse gas emissions	• trend in fossil energy use in the focal area • level of dependence on fossil energy • trend in national greenhouse gas emissions • proximity of national greenhouse gas emission rate to internationally negotiated target
Levels of agrochemical use	Fertilizers: • trends in use • threshold for tolerable water quality level. The impact reaches into the Gulf of Thailand where we assume it affects marine ecosystems Pesticide, herbicide, fungicides: • trends in use • threshold of tolerable pollution level
Effectiveness of irrigation infrastructure	• Modularity: shows the ability of the system as a whole to remain functional when parts of it are damaged. The many paddies, and the multiple lowland water storages are examples of modular subsystems, but the few large upland dams are much less modular, and the loss of one would have a severe impact. • Redundancy: estimates the extent to which the functions of one damaged system component can be replaced by a different component. A hypothetical example is the effects of damage to flood control infrastructure around a city being mitigated by the use of irrigation infrastructure to divert floods. • Reserves: measures the amount of spare capacity in a system under extreme conditions. Water resources are already at full capacity, and scarcity limits production during the dry season, with the potential for that scarcity to accumulate if a series of drought years alternates with lower wet season rainfall. • The capacity of water management groups at different levels and locations in the system to coordinate their decisions. • Existence of convincing and rehearsed emergency strategies
Area cleared for upper catchment agriculture	• ten year trends in area cleared in catchments for all upland dams in the focal area. If trends are similar they can be aggregated, otherwise trends would need to be reported as separate classes. • the area of annual crop above which run-off rate in extreme rainfall events is deemed unacceptable. Soil loss modelling would be needed. Again, if minimal cover thresholds vary significantly between catchments they would need to be reported separately • proximity to above area.
Storage capacity of upland dams	• trend in storage capacity • acceptable threshold of storage capacity under modelled rainfall scenarios with longer droughts and more extreme events than are experienced under the current climate. We propose the use of rainfall scenarios rather than actual data because time would be needed to change storage capacity and to implement landscape conservation projects • proximity of storage capacity to above threshold.

2.2 Element B. Assessing the resilience of the agroecosystem

2.2.1 ELEMENT B.2 GENERAL RESILIENCE

Thus far we have identified the drivers we expect to impact the system and explored their potential effects, but if investment in building resilience is focussed only on the expected impacts, the system may become more vulnerable to unexpected shocks (Carpenter et al., 2012). General resilience is the capacity of a system to persist through all kinds of shocks, including an unexpected shock or systemic change, such as the new crop diseases and social disruptions climatic change might bring. Our lack of knowledge prevents us assessing these attributes but we list some preliminary suggestions of indicators to illustrate the direction in which an assessment might proceed (Table 2).

Table 2 Potential indicators of general resilience – current levels and trends

Indicator	Rationale & assumptions	Potential sources of information on levels and trends
Public trust in the integrity of governance	Intentional regime shifts and responses to crises will require sufficient levels of public trust in judicial, political and administrative processes	Existing social surveys; published international indices e.g. Transparency International
Ability to change laws when new circumstances require it	Significant adaptations and regime shifts would probably require changes in, for example resource access laws	Commissioned work to assess the flexibility of legislation
Openness to criticism and new ideas	When circumstances change and conventional solutions no longer work, leaders should accept criticism and be open to new ideas	Commissioned work to compare Thailand with other nations
De-centralization of power and the resources to govern	It is an assumption in resilience thinking that decentralized governance is more adaptable than a hierarchical system because monitoring, actions and resources are located close to the origin of problems	Commissioned work to assess the current governance structure
School educational levels	A sound education is assumed to make societies more adaptable	Published international indices, e.g. World Bank 2012
Numbers of university graduates	As above	Published international indices
National research capability	Finding long term solutions to declining resilience requires innovative thinking and the ability to generate useful information at the right scale for exploring and implementing options.	Commissioned work to assess capability
Integration of scientific and local knowledge	Local knowledge can be informative about local problems, while scientific knowledge is more widely applicable; integration can enhance both	Commissioned work to assess the integration
Indicators well defined and linked to theory	See RATA Framework report sections 2 - 4.	Quick desk study
Indicators at time and spatial scales suited to system behaviour	As above	As above
Strong feedback to research, governance and management	Researchers, policy makers, resource users and managers need to learn about the system from the way it responds to drivers, shocks and previous interventions so that their activities are well focussed.	Commissioned work to assess the effectiveness of linkages
Long term funding for data collection and analysis	Effective monitoring requires long term commitment of sufficient funds to realize and communicate the value in the data	Size of budget relative to tasks, and duration of commitment

Indicator	Rationale & assumptions	Potential sources of information on levels and trends
land uses	A heterogeneous land use pattern reduces the likelihood of a livestock or plant disease or pest spreading.	Develop an index of land use diversity. Satellite imagery would produce data rapidly.
Input markets	Dependence on a few markets makes farmers vulnerable to risks outside their control	Data will probably be held by the Thai Government.
Output markets	As above	As above
Gender roles	A mix of genders makes for better quality decisions	Statistics probably available
Cultures	Cultural diversity is assumed to generate a similar diversity of ideas about the causes of problems and potential interventions	As above
Money	Savings at national or household levels can be used to recover from shocks or to enable transformation. National trust funds are best established soon because they are likely to be useful as climatic changes develop.	Statistics probably available
Energy	Reserves of fossil fuel would reduce the risks to imports from international crises.	As above

2.2.2 ELEMENT B.3 SPECIFIED RESILIENCE

The current level of specified resilience depends on trends in levels of controlling variables, and their proximity to thresholds.

The level of fossil fuel dependence is high and growing. The most likely threshold that usage rates will meet is a greenhouse gas emissions cap, but threat of that may cause use to shift towards renewable sources proactively. Government may already be exploring an energy transition but we have not sought this information.

Levels of agrochemical use are also high and growing. Their water pollution impacts are acknowledged, but we have not detected any sense of crisis from our desks, nor do we have evidence of any intention to cap usage.

We speculate that intolerance of floods in general, and of Bangkok in particular because of extreme river flows interacting with a rising sea may reveal thresholds in the capacity of the infrastructure to store and divert water and manage flows. We do not speculate on when this might occur, but it is likely to reduce the effectiveness of transport networks as roads and bridges are cut.

The capacity of large dams in the uplands affects seasonal water availability for rice as well as unintentional flooding of rural and urban lands. Their capacity will matter more in future because both dry spells and flow volumes are projected to increase (World Bank, 2013), but meanwhile sedimentation due to forest clearance for agriculture is reducing capacity even as the erosivity of rainfall is expected to increase sediment yields under climatic change.

We conclude from the information we have that this agroecosystem is becoming more vulnerable to economic and climatic shocks because it is trending towards potential thresholds on all controlling variables). Meanwhile policy and research emphases are upon increased resource use efficiency rather than on building resilience for growing uncertainties. Our concern is that this agroecosystem may enter a time of unprecedented turbulence configured efficiently for circumstances that no longer exist.

In Table 3 we assess the likelihood of thresholds being transgressed within the next 25 years.

Table 3 Subjective assessment of likelihood that a threshold on a controlling variable will be exceeded in the next 5, 10 or 25 years

Subjective likelihood	Fossil energy use level	Agrochemical use level	Infrastructure effectiveness	Upland area cleared	Dam storage capacity
Very unlikely					10
Unlikely	5	5	5	5	
Possible	10	10	10		25
Likely				10	
Very likely	25	25	25	25	

2.2.3 ELEMENTS B.1 AND B.4 ASSESSING THE LIKELIHOOD OF A REGIME SHIFT OR NEED FOR TRANSFORMATION

We propose that the likelihood of an unwanted regime shift or transformation depends on the number of controlling variables that are likely to cross thresholds around the same time. That depends in part on how tightly connected the controlling variables are, because crossing one threshold can potentially drive other controlling variables across thresholds if linkages among them are strong. In this agroecosystem, Fossil Energy Use Level, Agrochemical Use Level and Infrastructure Effectiveness are tightly linked, the other two controlling variables much less so. An unwanted regime shift or transformation could, according to resilience theory, be countered by general resilience if that is sufficiently effective. We did not assess general resilience, but assuming it is moderately effective, we judged the likelihood of an unwanted regime shift or transformation to be unlikely within the next five years, possible within the next ten, and very likely within the next 25 years.

This agroecosystem could conceivably be transformed unintentionally into a different system by major changes in the monsoon system, but the possibility of this climatic shift was not explored by the World Bank (2013), which was more concerned with the likelihood of greater extremes of dry and wet, and the inevitability of sea level rise. Depending on the magnitude and seasonality of dry and wet extremes, water scarcity and flooding – of Bangkok in particular - could drive a transition towards a technologically advanced regime using multiple sensors linked to computerized water storage and flow controls and much lower levels of water use. Water pricing could speed the process. Current concerns with pollution from agrochemicals may precede a comparable shift towards a farming system in which precise amounts of agrochemicals are placed robotically in the right place at the right time. This shift could be facilitated by the capping of greenhouse gas emissions which might drive irrigators away from paddy production with its high methane emissions, perhaps towards other crops. An emissions cap would also encourage a shift to renewable energy – solar, wind or biofuels. Demand for biofuels could see some land put to that use.

These changes could in theory see the integration of all these technologies into a new high technology agroecosystem. We speculate that it would be more efficient than the current human-controlled system, but also less resilient. However, from our desks we found it hard to envisage a uniform regime shift or transformation across the whole of this extensive and somewhat heterogeneous agroecosystem. Areas near busy roads and urban centres are already being transformed by the decisions of individual farmers to move out of communal paddy production by inundation and into individualistic cash crop production from their private wells, and this may be the beginning of a transition towards greater heterogeneity of land uses. Added to this, sea level rise and saline intrusions of groundwater are likely to transform the agroecosystem near the coast where production is unlikely to continue, so our speculations about potential regime shifts need to be tempered by the knowledge that Bangkok City depends for the management of floods and salt water intrusion from the coast on water management within the agroecosystem. With sea level projected to rise more than 50cm above current levels by 2060, and by over a metre by 2090, some rice production may be sacrificed for the wellbeing of Bangkok's residents – 6.6 million of them currently and the population still growing. But unintentional regime shifts or transformations could also occur locally. Sea level rise is expected to drive people off floodplains in the South and South East Asian Regions (World Bank, 2013), and the arrival of climatic change refugees may trigger unintentional transformation of the agroecosystem in ways we do not presume to explore. Investing in general resilience should increase the capacity to adapt to such shocks.

2.3 Conclusions from rapid resilience assessment of lowland irrigated rice

We were not able to assess the general resilience of the agroecosystem in the time and with the resources we had, but our assessment of specified resilience suggests that in anticipation of climatic change and its associated impacts, it would be wise to shift policy and investment emphases towards general resilience and away from the current focus on production and resource use efficiency gains. Given our limited knowledge of the system we did not presume to explore a planned regime shift or transformational change, but now is a good time for Thai people to be exploring possibilities, options and transitional pathways.

3 Agro-pastoral millet/sorghum agroecosystems in south-west Niger

3.1 Element A System Description

3.1.1 ELEMENT A.1 SCOPE AND OVERVIEW

In this case study we consider agro-pastoral millet/sorghum agroecosystems in Niger (Dixon et al., 2001). It provides an example of subsistence agro-pastoral farming systems in the Sahel, which are central to the livelihoods of approximately 90 million people (Garrity et al., 2012). Agriculture employs over 80% of the work force in semi-arid regions of West Africa (Djaby, 2010). The region is of particular relevance to the UNCCD due to land degradation risks, and decades of research have been invested in the area with a view to understanding and alleviating these risks. We cannot be comprehensive in our approach to covering previous work in this case study, and instead we focus on a selection of published research findings that are amenable to our resilience assessment framework in order to test the utility and applicability of the approach we are proposing.

Resilience assessments require consideration of multiple spatial scales, and in this case study the finest scale considered is individuals in villages in the Fakara canton, which is part of the Kollo Department in the Tillaberi administrative region of Niger (Figure 11).

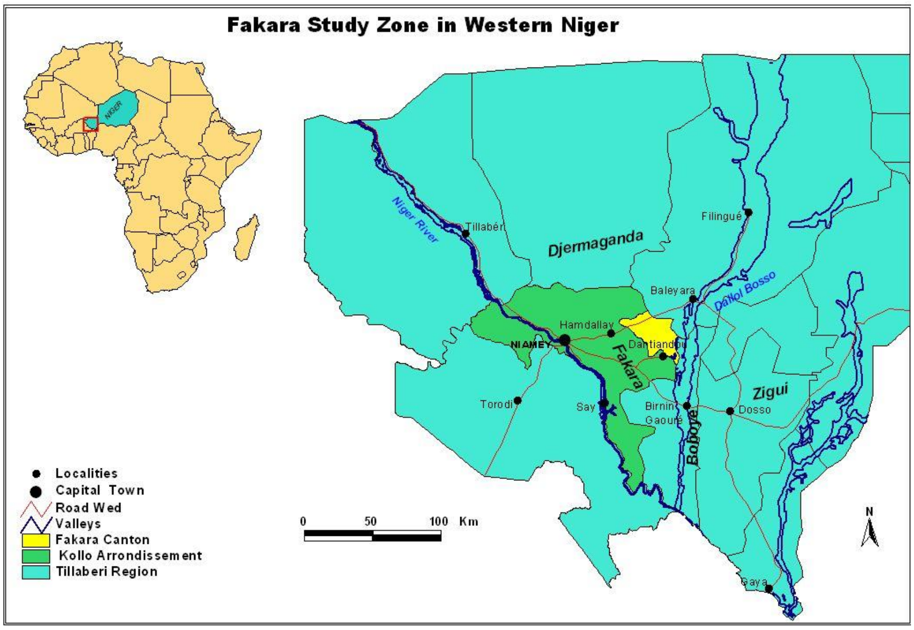


Figure 11 The Fakara, Niger (Hiernaux and Ayantunde, 2004)

Dynamics of agroecosystems in the Sahel have been of strong interest in the research community in recent decades, and several conceptual models have been published along with critical assessments of different conceptual models. More broadly, the dynamics of forage production and livestock in semi-arid and arid rangelands have been the subject of much study and several conceptual models have been developed that are relevant when assessing resilience in agroecosystems in West Africa. We have selected examples from this large body of literature to illustrate the use of our resilience assessment framework. The following descriptions of the system are drawn from Fernandez et al. (2002), Hiernaux and Ayantunde (2004), Saqalli (2008), Malik (2014) and Hiernaux and Turner (2002).

Climate, soils, hydrology and vegetation

The region falls in the central Sahel bio-climatic zone. Average annual rainfall is approximately 500mm on a steep North-South gradient, with rainfall reducing to the North. The climate is semi-arid tropical, with summer rainfall over a rainy season of 4 to 5 months (and shorter rain season to the North). Seasonal pattern of monsoonal rains is regular and predictable, but the actual spatial and temporal distribution is erratic and unpredictable from year to year.

The soils of the region are characterized by low soil fertility, weak structure and low organic matter content. Cation exchange capacity is usually low and unsaturated. Acidic topsoils low in nitrogen and phosphorus. Soil nutrient deficiency is a limiting factor in determining rangeland and crop productivity. Surface water from monsoonal rains is largely retained in local (often small) catchments and is subject to high evaporation rates.

The vegetation comprises mostly annual grasses and scattered small trees and shrubs. The conditions select against perennial grasses, with annual grasses better adapted to severe, long dry seasons and poor fertility soils. Spatial and temporal heterogeneity in water and nutrient availability, fire and seasonal herbivory make for patchiness in the vegetation, as do the land use practices (e.g. grazing pressure, clearing, cropping, fallowing, manuring). The vegetation dynamics are highly adapted to droughts.

Agriculture

There are predominantly two agrarian cultures: village household (mostly Jerma people) crop-farmers and camp household (mostly Fulani people) pastoralists. Both cultures have been coevolving towards sedentary crop-livestock systems and exclusively pastoral households are rare (or no longer exist). We group the two ethnic groups and mixed farming and pastoral systems under the one FAO agropastoral category, recognising their interdependence in managing land, crops and livestock. It is a region of subsistence agriculture based on millet and sorghum staples, with secondary legume crops (cowpea, bambara nut, ground nut) and cash crops (sesame, sorrel). Mostly no-till practices mean that labour availability for low-efficiency manual weeding is often limiting crop productivity. Traditionally, fallow practices have been used in response to low soil fertility. Fallowing periods are changing, however, from long (15 to 30 years) to short (3 years) or none at all if fertilizer inputs are being used. The amount of land cropped per household varies, and is influenced by history (Jermas have more access to cropland than Fulanis), access rights, family status, gender, age, marital status and labour availability.

Livestock (cattle, sheep, goats) is an important form of wealth in the region, and again the wide distribution of livestock holdings reflects social and cultural factors. Livestock husbandry has a strong reliance on seasonal herd mobility, with herds moving North in the wet season. These transhumance practices are being affected by a range of influences, including the reduction and fragmentation of grazing lands, access to communal resources such as livestock tracks and political unrest, resulting in the decrease of long-distance transhumances.

Vegetable gardening is a dry season activity that is only possible where there is access to groundwater (e.g. via wells, marshes, valleys). Gardening is a female activity, and limited to married women with spare household labour capacity (e.g. daughters-in-law or unmarried daughters).

Population

Niger has the highest total fertility rate (approximately 7.6 infants per woman), the lowest Human Development Index value (HDI of 0.337), one of the highest gender inequality index values and one of the lowest levels of income per capita (2011 PPP $873 per capita) of all nations. The Fakara canton has a population of approximately 31700 (2008 Census). The population has grown dramatically since independence in 1960, and many of the villages have formed since this time. The population is far from stable, and population demographics are a key driver of the evolution of agroecosystems in this region, as village population increases see expansion of fields and livestock holdings.

As mentioned above, livestock is an important form of wealth and a means of production, but many families have no livestock and instead have other forms of wealth, such as rights to land, equipment (e.g. vehicles and pumps) and granaries.

3.1.2 ELEMENT A.3 GOVERNANCE AND SOCIAL INTERACTIONS

Historical accounts make clear that in just over 100 years the social-economic context has evolved substantially, and in particular the inheritance hierarchies and conditions for accessing land, livestock and other wealth continue to evolve. Village households have primary rights to cropping land (primary usufruct rights for descendants of village founders) and camp households need to enter into agreements (secondary usufruct rights) with village households to be able to use cropping land. Within village households, gender and social rank are key determinants of access to all social and economic activities, as are seasonal changes.

The dominant inheritance tradition at the beginning of the 20th century saw land transferred to the highest-ranking male heir (e.g. eldest son), and others were left to find new land elsewhere. In recent decades inheritance practices have been evolving towards a local version of a Muslim inheritance system, which sees land and livestock are transferred equally to heirs (gender-specifically, e.g. only female-owned livestock passes to female heirs). In practice most women do not own land; where they have inherited land there are social pressures that see brothers given management of the land. Inheritance arrangements are thus complex, changing and carry religious sensitivities due to the gap between formal Muslim law and observed local practices.

During the dry season a large proportion (70%-90%) of adult men, depending on age and level of responsibilities, migrate to countries bordering the Gulf of Guinea to find jobs. The seasonal migration reduces the number of people needing to live on the stored millet, so provides more food for those who remain at home, and also provides off-farm income to village families. In this way it is difficult to define the spatial domain of the agroecosystem given the reliance of households on migration (whether for livestock transhumance or seasonal employment in other countries).

The importance of marriage and other social practices cannot be overstated. Saqalli (2008) cited reports that approximately 40% of family expenses are on marriage and religious feasts, which is close to the proportion spent on food (48%) and much more than investments in farm inputs (5%). Marriage status is a key determinant of social rank, which in turn affects access to various assets and activities. For example, married men can inherit land or appropriate new land parcels, have access to child labour and prestige associated with marriage and children. Married women with children have higher social rank than unmarried women, providing access to gardening and children-related prestige.

There are strong cultural values of mutual aid and institutions to enable access to common, shared resources, such as pastoral resources, however other pressures are putting these under strain and such access is unequally distributed.

3.1.3 ELEMENT A.2 RESILIENCE OF WHAT AND TO WHAT

Our focus is on the resilience of this agroecosystems' capacity to meet the health, wellbeing and livelihood needs of the populations dependent on them, now and into the future. When considering what these systems will need to be resilient to, there are several drivers and pressures contributing to both internal and external stresses and disturbances. Broadly, these include population demographics, climate variability (which results in climate shocks), climate change (a trend in both average levels of rainfall and temperature and in the pattern of climate shocks), ecological constraints, health, governance (especially regarding access to resources) and social-economic conditions. These are expanded upon in more detail in the following section describing conceptual models. Resilience to land degradation risks is of particular interest.

3.1.4 ELEMENT A.4 HOW THE AGROECOSYSTEM FUNCTIONS

Overview

Conceptual models of the system have been informed by detailed field observations and measurements, remote sensing data and ecological theory. Conceptual models include: narrative descriptions of the key dynamics at play in the system (Hiernaux and Turner, 2002, Hiernaux and Ayantunde, 2004), influence or causal loop diagrams, identification of significant positive and negative feedback loops, statistical trends (Hiernaux and Ayantunde, 2004, Djaby, 2010) and process-based simulation models (Saqalli, 2008, Saqalli et al., 2010a, Saqalli et al., 2010b, Saqalli et al., 2011). The identification of positive and negative feedback loops in particular is helpful in any resilience assessment as these inform both alternative system states and potential drivers and controlling variables for shifts between different states.

Critiques of conceptual models have drawn attention to broader issues to do with researchers from developed nations attempting to analyse and solve developing world problems. Viewing a system with too narrow a perspective limits the options identified as possible for the region, and can overlook powerful influences on system dynamics. For example, Hiernaux and Turner (2002) referred to the shortcomings of descriptive work that assumes a static equilibrium system and fails to include knowledge of dynamic biophysical processes:

> *Researchers' understanding of the human and ecological complexity of this region has been constrained by the dominance of descriptive (including remote sensing) over process-oriented research traditions, the short-term nature of most research and static equilibrium-based concepts and methods brought to the social and ecological study of this area.*

Saqalli et al. (2010a) highlighted limitations of too heavy a focus on the biophysical dynamics, and sought to strengthen the social dimensions of coupled social-ecological models of the region.

More broadly over time there has been an evolution of conceptual models. For example, work since the 1970s saw a focus on ascertaining whether human, biotic or abiotic drivers are the most important factors causing land degradation and desertification. Attempts to address that question led to an appreciation that such either/or approaches are not as helpful as those recognising coupled social-ecological dynamics; neither social nor biophysical factors are more important, and it is more helpful to identify reinforcing and dampening interactions (feedback loops) between them. In this way, debates in the literature over whether problems of drought, famine and poverty are the result of climate or human activities were replaced with conceptual models that emphasized the interactions between climate, vegetation, fire, soils, animals and human activities, stressing that it is unhelpful to seek to attribute outcomes solely to biophysical or human processes.

In studying these social-ecological interactions there has been a strong focus on biophysical understanding of these systems (climate, hydrology, soil, crops and natural vegetation), with human decisions recognized as important factors mediating observed biophysical changes. In other words, the social-ecological interactions were included, but primarily as a lens through which to understand observed dynamics in biophysical conditions (soil characteristics, nutrient and water availability, crop yields, quantity and quality of forage production, livestock populations). Given the purpose of such research is often not to improve agricultural yields, per se, but to contribute to improved livelihoods, health and wellbeing outcomes for growing populations, Saqalli et al. (2010a) emphasized the importance of recognising that "farming systems cannot be understood without making reference to a 'system of activities' where agricultural productions are part of a palette of activities, spread out along the year and gender specific".

Existing conceptual models

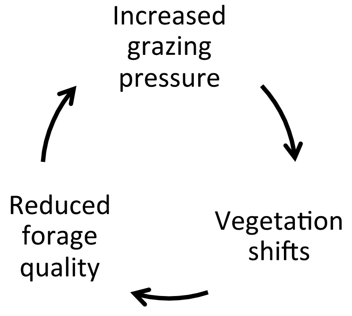
The purpose of this case study is to demonstrate the application of the framework presented in the RATA Framework Report. This particular case illustrates a situation that can arise in any rapid, desktop assessment process like this one: the existence of multiple conceptual models. In the face of this situation, the challenge is not to seek the 'correct' conceptual model, but turn the plurality to an advantage. In particular, multiple conceptual models can inform which system components are well understood and robust to any conceptualization, and where there is there some uncertainty and room for further exploration and learning. We can go further and point out that the existence of multiple conceptual models derived from many different perspectives itself contributes to general resilience. In this rapid assessment we don't fully explore all conceptual models that are relevant to this system, but we make sure that we draw on a subset to demonstrate the benefits of including multiple conceptual models in the assessment.

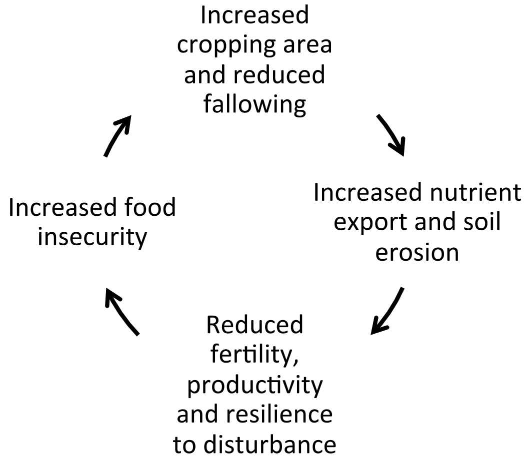
Fernandez et al. (2002) and Hiernaux and Ayantunde (2004) have already conceptualized this system within a resilience framework, recognising that 'desertification is a multi-dimensional problem with many conceivable causes and a network of consequences that encompass a wide range of spatial and temporal scales' and that 'degradation and restoration of landscape are two sides of the same problem, involving both natural and social forces'.

Abiotic conditions are key drivers of the system, and Hiernaux and Ayantunde (2004) described the ways in which the climate and soil conditions have selected for a flora and fauna that is extremely resilient to droughts, floods and fire. With increasing population and grazing pressures in recent decades, however, they identified interacting processes leading to a 'downward spiral of desertification'. These include:

- Unprecedented increase in population has changed land use practices.
- Croplands have expanded and livestock populations have grown.
- Cropland expansion has led to a shortage of quality grazing resources for livestock in the late dry and early wet season, which has severely increased the grazing pressure on the ranges during the growing season when livestock are excluded from croplands.
- Increased grazing pressure during the wet season (when livestock are not allowed to access cropped land) triggers changes in vegetation composition either to the benefit of short-cycle, less productive annuals or to highly productive but poorly palatable species. Both these changes result in reduced grazing resources.
- Increased cropping and reduced fallow duration:
    - Increases risk of fragmentation and biodiversity losses.
    - Decreases soil fertility by enhancing nutrient exports and aggravating soil erosion.
    - Increases albedo and increases soil crusting
- Decline in soil fertility through reduced fallow periods affects vegetation productivity and efficient use of water and sunlight.
- Livestock mobility can mitigate some of the grazing pressure on the rangelands, however barriers to that mobility are increasing, and transhumance practices depend on ongoing access to communal resources such as water points and cattle paths.

Positive (i.e., reinforcing) feedback loops identified in this conceptualization include:





In the absence of any other system considerations, these positive feedback loops alone would lead to (a) ongoing agroecosystem shifts and (b) increased food insecurity due to lower crop and livestock productivity. This is an example of a system dynamic that creates a system state that is both undesirable and resilient (recognizing that this situation is transient because as conditions for people worsen the people do everything in their power to change it, including leaving the system - e.g., migration to towns). These dynamics have their strongest effect during the rainy season as this is when labour shortages are high, grazing resources are limited and the vegetation and soil are most sensitive to pressures.

Djaby (2010) concentrated on improving the understanding of nutrient availability and fluxes in the region, and in particular the consequences of various crop-livestock interactions for nutrient flows, forage quality and crop yields. Djaby's work recognized that nutrient flows cannot be understood at the farm scale without taking into account forage uptake, manure deposits and seasonal dynamics across larger spatial scales. Here the conceptual model is one of fluxes within and between various nutrient stores in primary production components (soils, crops, feeds & fertilizers), homestead components (food, humans, garbage heap) and secondary production components (feed, animals, manure). This model was used to interpret detailed measurements from 461 farms to derive nutrient balances. The inclusion of livestock activities was critical in deriving accurate nutrient balances. The nutrient balances formed the basis of risk indicators for soil fertility depletion. Based on these assessments Djaby (2010) identified the attributes of households that maintain a minimal biophysical configuration for a neutral or positive nutrient balance, without which soil condition will degrade (e.g. proportion of land fallow and cropped, and number of livestock per capita). Livestock mobility and land tenure arrangements were identified as critical aspects that enable these minimal conditions. These findings point to important thresholds that exist within the system.

The conceptual models so far have included human social dimensions in only a limited way. The inclusion of more social considerations brings more feedback loops that lock in current trends, but also more options for adapting and transforming the system.

Fernandez et al. (2002) and Hiernaux and Ayantunde (2004) identified three slow, controlling variables (two biophysical and one socioeconomic) and thresholds for these variables beyond which the system risks changing state. The variables are:

- An index of sustainability with regard to soil fertility that is defined by fallowing practices and has a threshold such that a household with no access to manure can maintain soil fertility only if it fallows at least 3/8 of the arable land it manages. (Note that including livestock and associated manuring of fields eases this threshold.)
- An index of herbage intake, with a threshold for sustainability being that total herbage intake by resident livestock can be no more than a third of the mass of palatable herbage at the end of the growing season.
- An index of economic sustainability, defined by the ratio of basic needs of the household to the aggregated agricultural production, with a threshold for unsustainability when household needs exceed production.

The first and third indices are plotted in Figure 12. The indices are defined so that threshold values are at 100, with lower values being more desirable. The lower left quadrant of the diagram represents a sustainable regime where at least 3/8 of the land is fallowing and households produce enough to meet household needs. The diagram points to three groupings:

i) village farmers who are operating in an economically unsustainable way,

ii) village mixed farmers and camp agropastoralists who are meeting both biophysical and economic sustainability criteria, and

iii) all farms within the village of Kodey (the most populated) which have unsustainable fertility practices. It indicates that livestock ownership enables economic sustainability, but increased livestock ownership also increases grazing pressure during the wet season, which risks taking farmers into the biophysically unsustainable bottom-right quadrant.

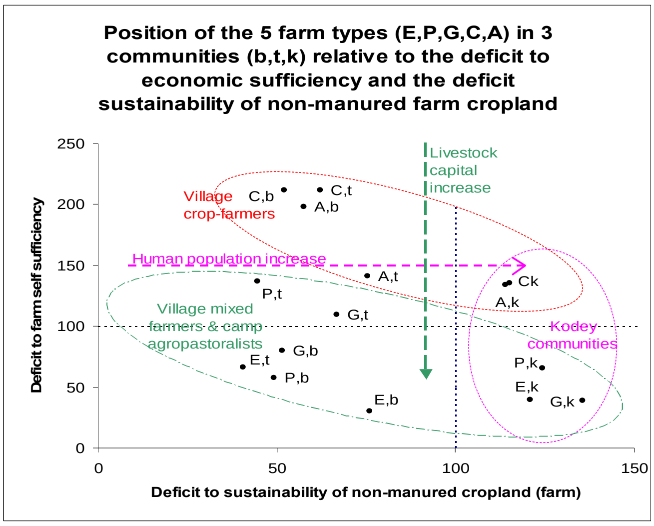


Figure 12 Position of five farm types (E, P, G, C, A) in three communities (b, t, k) relative to index of farm self-sufficiency and index of sustainability (Hiernaux and Ayantunde, 2004)

This conceptual framework allowed Fernandez et al. (2002) to highlight cross-scale linkages to other scales, including:

- Community rangelands mean that the amount and quality of forage for livestock per household depends on community livestock density and type.
- Access to wet-season forage is strongly dependent on amount of fallow land made available by neighbours.
- Access to cross-border rangelands is critical to transhumance activities, and so affects household production and wellbeing.

The analysis highlights the heterogeneity in the system. Any attempt to place the agroecosystem as a whole into one of these quadrants would mask the variation across villages. Similarly, there is much variation between households and individuals within a village and between pastoralist and village communities. Such heterogeneity suggests caution is needed in presenting any aggregate summary of the system, and there is much to be learned from the diversity in the system.

Saqalli and colleagues' work (Saqalli, 2008, Saqalli et al., 2010a, Saqalli et al., 2010b, Saqalli et al., 2011) built on knowledge of the Fakara farming systems to include a stronger emphasis on social dynamics, and to highlight cross-scale linkages to the individual scale (whereas until now the analysis unit has been the household or farm with cross-linkages to larger scales). The hypothesis is that "small individual temporally-based social constraints and assets may have huge effects at the collective level." They considered the different individuals and factors that affect the living conditions for Jerma people. For example, a man cannot access land unless he is married. Marriage requires a payment of a dowry to the bride's family, and if a dowry is not available (e.g. via the man's father) then the man needs to earn enough to provide a dowry. He can earn money by seasonal migration activities. To have access to that opportunity at the very least he needs to be able to buy a bus ticket and associated expenses, and there is the risk of a spiral of debt in pursuing these opportunities. Women cannot own land and can only access land for gardening when married. These are examples of some of the social conditions and constraints under which the agroecosystem dynamics play out, and there is a strong seasonal influence on what activities do and don't take place.

Saqalli and colleagues using an agent-based model, named SimSahel to explore the social conditions, the seasonal variation in social activities and their impacts on the broader agroecosystem. In this way conceptual models of the agroecosystem system were integrated and developed into a quantitative simulation model that has proved useful for including important social-ecological dynamics when assessing possible development trajectories and interventions. In particular, the adoption of potential development interventions is significantly limited by individual circumstances within the societal context, which adds layer of conditions and constraints, especially concerning marriage, family structure, inheritance modes, access to assets and activities, and migratory options.

3.2 Element B Assessing the system

3.2.1 ELEMENT B.1 ALTERNATIVE REGIMES

The conceptual models discussed above point to different ways of defining the system so that alternative states and transitions are highlighted.

Djaby (2010) used a nutrient balance approach, suggesting that a neutral or positive nutrient balance is a minimal threshold for sustainable soil management. Once fertility has crossed that threshold and is decline, it becomes increasingly difficult to recover a sustainable nutrient balance (so ensuring any recovery will require longer or more external inputs). The 3/8 fallow period referred to above is an example of a useful heuristic that helps keep the system away from this threshold for nutrient decline.

As illustrated in Figure 12, Fernandez et al. (2002) and Hiernaux and Ayantunde (2004) identified two alternative states, and transition pathways between them. The first is a biophysically sustainable and productive regime in which household/farm production exceeds the needs of the household. Crossing either the biophysical or economic threshold sees the system undergo a shift to an undesirable regime of decreasing agricultural productivity and socioeconomic security. Once this regime shift has occurred the pathways back are highly hysteretic and are likely to require higher scale interventions to occur.

Traditionally separate practices of transhumant animal husbandry and sedentary cropping have co-evolved into mixed crop-livestock systems. This change could also represent a regime shift, especially as below a critical threshold of animals pastoralists can no longer afford to live a mobile existence and must settle to secure enough food for their family. Once settled there are systemic barriers to building up a large enough herd to return to a mobile existence. The reverse is also possible: in some circumstances successful cash crops create the potential to invest in livestock and accumulate capital.

Saqalli et al. (2010b) identified similar alternative states, showing that other controlling variables at play involve social change processes (e.g. changing inheritance structures) interacting with other demographic drivers and ecological conditions to lead to divergent strategies in different villages: (a) no intensification, exporting wealth through off-territory cattle (transhumance activities) effectively allowing ‘off-shore savings’; (b) strong agricultural intensification via better livestock-crop integration and more gardening.

These identified alternative states and associated thresholds suggest the following indicators:

- nutrient balance indicating whether farms are depleting their soil fertility
- distribution of household economic self-sufficiency index
- distribution of the index of sustainability with respect to fallowing
- distribution of the index of sustainability with respect to herbage intake
- effective governance of communal resources needed for seasonal herd migration
- farmer empowerment of natural resource management.

Note that other alternative states are likely in this system, in particular those related to the viability of livestock herds (Hiernaux, pers. comm.).

3.2.2 ELEMENT B.2 GENERAL RESILIENCE

Drawing on published general resilience attributes (Walker and Salt, 2012, Walker et al., 2014) we suggest looking to the following for indicators of general resilience of desirable system properties:

- **Ecological diversity and variability.** The native vegetation has been found to be highly resilient not only to abiotic stresses (droughts, floods, fire), but also to more general stresses including pest invasions and heavy grazing. According to Hiernaux and Ayantunde (2004), the "ecosystem remained very variable but resilient as long as the agricultural system remained extensive."

- **Connectivity** is key in this system in at least two ways:
    - Connectivity enables livestock mobility at critical times of the year. Fragmentation is leading to loss of that connectivity, so decreasing livestock productivity and so general resilience.
    - Ongoing access to seasonal migration activities builds options for off-farm income, and so contributes to general resilience for families (e.g. increased access to income, health and education services), but with uncertain implications for ecosystem resilience.
- **Shared understanding of conceptual models.** There are multiple conceptual models of the system, and active attempts to share and understand different conceptual models. It is less clear the extent to which the key stakeholders in the system have developed and shared such conceptual models.
- **Innovation, learning and experimentation.** Research and development programs have invested in learning about the system and conducting field experiments. Hiernaux and Ayantunde (2004) concluded that a key issue now is farmer empowerment, so indicators of trends in farmer-led institutions would be a useful indicator
- **Reserves**. The primary form of wealth, and wealth reserves, are in land access, livestock and labour force. These are vulnerable in times of drought and when land scarcity pressures build, suggesting that other forms of wealth would be beneficial for building general resilience. Human and social capital reserves are vital, yet access to education, health and communication services is mixed and unequal.
- **History of shocks.** Droughts, fires and floods are inevitable, as is high spatial and temporal variability of important influences such as rainfall. The long history of shocks like these in the region has built general resilience, since what currently exists in the system has already had to come through them, thereby developing the adaptive capacity to cope with them.
- **Social capital and cohesion.** Social norms, particularly those around family structure, inheritance mode, marriage and religious celebrations, shape the conditions under which men and women have access to resources and activities. These norms are changing rapidly, and that adaptability contributes to general resilience. Good health, access to education and opportunities underpin these aspects of general resilience, yet HDI and gender inequality indices are amongst the worst in the world (Malik, 2014); trends in these indicators would be instructive for informing this dimension of general resilience.
- **Governance.** Governance of crop-livestock interactions at multiple scales, and in particular the governance instruments for ensuring access to communal resources that enable herd mobility (e.g. water points, livestock paths).
- **Humility.** A shift in the literature is apparent. Bold declarations in past decades asserting what needs to happen to bring improvements to sub-Sarahan agroecosystems have been replaced in more recent decades by more nuanced and humble acknowledgments that the social-ecological dynamics are complex, changing rapidly, and respond in unexpected ways to interventions. This greater humility in the research and development community is an interesting development, but it is speculative whether such changes will lead to improved general resilience.

These considerations have informed a preliminary set of indicators listed in Table 4. The table does not specify the scale at which to track these indicators, but in general it is unwise to be limited to only one scale. Furthermore, our earlier caution on reporting summary statistics from a highly heterogeneous system applies here. There are large inequalities in endowments and access to opportunities within the system, and so the system may foster resilience for some and not for others. The inequalities lead to rather different resilience assessments depending on how that heterogeneity is handled. One approach is to err on the side of caution and assume the whole system is a resilient as its least resilient components. In practice this can be difficult to characterize. For example, in a rapidly changing system, individuals who are not resilient may simply leave the system without trace and be rendered effectively invisible in indicator statistics.

Table 4 Potential indicators of general resilience at the focal scale – current levels and trends

Indicator	Rationale and assumptions	Potential sources of information on levels and trends
Ecosystem diversity and productivity of native vegetation rangelands	Natural ecosystem enhances this agroecosystem's general resilience, and degradation trends are eroding that general resilience	Remote sensing, field measurements
Connectivity of transhumance routes	Loss of options for seasonal transhumance places more pressure on rangelands in the wet season, so reducing quality forage productivity and so general resilience	Household surveys, land use maps
Seasonal migration opportunities	Options to for dry-season migration relieve pressure on household food stores and bring in additional household income	Household surveys
Participation in farmer-led institutions	Farmer empowerment (for men and women) is a key way to strengthen the sharing of conceptual models (between farmers, and between farmers, researchers and development agencies), learning and experimentation, so building general resilience.	Household and institutional surveys, statistics on membership of associations and political parties
Human Development Indicators and Gender Inequality Indices	These indicators are extremely poor at present, and improvements would indicate some lifting of human and social capital, which is a necessary underpinning for general resilience	UNDP, access to education, health, communication services
Capital reserves (per capita)	Human, natural, social and built capital reserves all build options, and so general resilience	National accounts, availability of insurance, banking, grain stores, livestock census
Institutions governing access to shared resources	Good stewardship of shared resources increases general resilience	Household surveys, National laws, local policies

3.2.3 ELEMENT B.3 SPECIFIED RESILIENCE

Assessment of specified resilience requires identifying the main shocks anticipated for the system, along with the controlling variables and their threshold levels or indicators. The analysis by Fernandez et al. (2002) and Hiernaux and Ayantunde (2004) is a useful assessment of controlling variables and threshold levels when considering the specified resilience of the agroecosystem to land degradation risks in the face of growing human and livestock populations. Indicators suggested by their analysis are given in Table 5.

Table 5 Example of a set of specified resilience indicators to reflect the regimes shown in Figure 12.

Indicator	Rationale and assumptions
Index of sustainability with respect to fallowing	Evidence that it is a useful indicator of soil fertility, with a well-defined critical threshold (fallowing 3/8 of arable land).
Index of sustainability with respect to herbage intake	Evidence of a critical threshold if resident livestock have more than 1/3 of the mass of palatable herbage by the end of the growing season
Other indicators of farm-scale nutrient balance	If practices other than fallowing are involved for soil fertility, other indicators of farm-scale nutrient balance will be needed.
Distribution of household economic self-sufficiency index	A clear threshold for unsustainability when household needs exceed production

There is much scope for expanding the specified resilience assessment to identify other relevant indicators. In particular, indicators of livestock productivity and the quality of crop-livestock interactions (e.g. recycling through manure, crop residues) could be developed. Other specified resilience indicators could be derived from more detailed analysis of hypothesized alternate regimes and associated controlling variables and thresholds (e.g. resilience of transhumance practices to a sudden drop in connectivity).

Resilience of crop and livestock production to climate change has not been addressed explicitly in this assessment, yet climate change is an obvious candidate for inclusion in any specified resilience assessment. Likely impacts of increased CO_2 concentrations on photosynthesis in this region are uncertain, global climate model projections for rainfall in the region are contradictory and temperature rise impacts on vegetation and crops are also unknown, so any such assessment would need to accommodate these uncertainties.

3.2.4 ELEMENT B.4 NEED FOR ADAPTATION OR TRANSFORMATION

Land degradation risks in these agroecosystems are clear, with unwanted outcomes for both ecosystems and people. Several approaches to building adaptive capacity have been suggested. Using the conceptualization of Fernandez et al. (2002) and Hiernaux and Ayantunde (2004), building adaptive capacity amounts to widening the bottom-left quadrant of Figure 12.

Suggestions made for this system by these authors include:

- Diversification of crop and livestock production, including trade-oriented commodities, dual-purpose legumes, poultry and small ruminants.
- Off-farm input (inorganic fertilizer, pesticides for cash crops, mineral feed supplement and vaccinations) have the potential for “residual and snowball effects” on ecosystem productivity
- Adapting agroforestry activities so they are better integrated with crop and livestock activities to provide ecosystem services such as shade, nutrient recycling.
- Enhancing farmers’ animal husbandry skills, and improving crop-livestock integration (at both farm and higher scales).
- Farmer empowerment (including access to education, health, communication services and infrastructure).

These are just some of the options for building adaptive capacity and many more are possible. An equally important consideration is whether the likelihood of success in building such adaptive capacity is diminishing. If so, resilience theory would suggest it is sensible, perhaps necessary, to be building transformability. In this system, such options would draw on other aspects of these agroecosystems, such as options for off-farm income and other configurations that would emphasize activities that are currently not defining the system identity as conceptualized so far.

3.2.5 ELEMENT B.5 SUMMARY ACTION INDICATORS

The Summary Action Indicators (Section 4.5 RATA Framework Report) provide high-level information to guide decisions towards appropriate actions and priorities. This agroecosystem consists of different household types. Summary Action Indicators would be different for each type, depending on the level of general resilience for the agroecosystem as a whole, on whether that type is in a desirable or an undesirable regime, and on levels of specific resilience and transformability. Attributes such as natural vegetation and pastoral practices well adapted to a long history of shocks of many kinds certainly confer general resilience, as does the wealth of research that has developed multiple conceptual models and other forms of knowledge for the area. It is clear, however, that general resilience is weakening due to:

- pressure due to poor soil fertility, inherent and growing due to unbalanced nutrient fluxes (net export of nitrogen, phosphorus and mineralization of organic matter)
- changing markets (e.g. increased market for meat driven by demographic shifts and urbanization, less extensive market for millet, and irregular cash crop markets fro cowpea, sesame and groundnut)
- rapid changes in landscape connectivity: reduced connectivity for grazing resources such as rangelands and fallow fields; increased connectivity due to the enhancement of gully run-off that increases the filling of ponds and recharging of the water table; increase in area cropped is increasing connectivity between fields with impact on gene pools, weed and pests
- reduced options for adaptation as population, poverty, health, education and other local pressures build (although such pressures can also drive innovations and ventures that seek out new opportunities)
- global scale pressures (e.g. climate change).

Whether this assessment of weakening general resilience is interpreted as ‘low’ or ‘high’ general resilience, and whether that general resilience of the ‘coping capacity’ or ‘lock-in’ kind is again not clear (and depends on the scale of analysis). These distinctions are important for relating resilience assessment findings to priorities for investing or intervening in the system. The lack of clarity suggests that this particular system may be at a knife edge, where arguments can be made for building general resilience and adaptive capacity of desirable regimes (so suggesting investment in general resilience), or declines in general resilience may be judged as inevitable and the only long-term option is for system transformation. Many aspects of the system are transforming extremely rapidly already. Enhancement of soil fertility, for example through better crop-livestock interactions, would build general resilience and be helpful for combating land degradation trends.

Only local people can say whether their regime is desirable or not, and their answer would depend on what else is possible. The same engagement process could assess the capacity to shift regimes or transform. However, to illustrate how the Summary Action Indicator approach might proceed, we will assume for now that groups whose activities are economically or biophysically unsustainable are in an unwanted regime. The procedure in Section 4.5.2. of the RATA Framework Report, would then advocate these general recommendations:

- Build general resilience for the agroecosystem as a whole (e.g. the biophysical, social and institutional requirements to support enhancing nutrient levels and recycling, crop-livestock interactions, agro-forestry).
- For those with biophysically and economically sustainable livelihoods invest in keeping away from identified thresholds.

- For economically or biophysically unsustainable farmers invest in a regime shift or transformation (which can include off-farm activities);
- Invest in education and health to enhance farmers' empowerment.

We have avoided specific interventions that require local engagement and more knowledge than we have. Reviewing attributes of general resilience at the focal scale, we see that the assessment is mixed. The important messages here are:

- A rapid desktop assessment such as this must not be a basis for decisions. It provides some guidance to future iterations to identify controlling variables and indicators, and where further efforts could be invested in improving understanding, information or reporting. The investment priority at this point would be in empowering stakeholders to build their capacity to explore and navigate these uncertain futures, not least by strengthening access to health, education, communication, financial and related supporting services.
- The Resilience-Adaptation-Transformation Framework and its Summary Action Indicators have enabled a clear characterization of uncertainties and trade-offs that would benefit from further exploration. In this case it has also highlighted where the system is dependent on links to geographically distant systems, suggesting revised conceptualization of system boundaries for any resilience assessment could be useful.

3.3 Conclusions

This is a system for which there are already multiple conceptual models amenable to informing a resilience assessment, and in this rapid desktop assessment only a subset of such models has been considered. In common to these models is the recognition of multiple pressures that are driving ecosystem degradation and poverty risks, as well as identification of key system feedbacks, thresholds and alternate systems states. Furthermore, researchers have identified multiple options that can be pursued to increase the resilience of these agroecosystems to multiple pressures.

This detailed knowledge and experience with these systems, and such well identified options for increasing the adaptive and transformational capacity of the system, forms an important component of general resilience and adaptive or transformational capacity in its own right. Furthermore, these studies and conceptual models have been used to explore and recommend new options for the region. And yet, it is not clear from the literature whether these lessons for adaptation and transformation are being implemented and making a difference.

If indeed the impact of research so far has been less than hoped for, it is not for a lack of biophysical knowledge of the system as it has been researched with care and diligence, with robust and informative findings. It would suggest that more work is needed to strengthen conceptualizations of the links between social and ecological dynamics, and to go about that integration in participatory ways so that it is better informed by local knowledge and enables local ownership of conceptual models, options and strategies. This is not to say that there is not need for further biophysical research, as there is much still to be learned about ecosystem degradation processes, crop responses to changing CO_2 and temperature, and improved sustainable livestock production practices.

The Resilience-Adaptation-Transformation Framework provided a lens through which to review existing knowledge of the system and identify system attributes relevant to resilience. The results of the assessment are limited by (and heavily influenced by) the particular subset of literature selected for review, and would be strengthened by the inclusion of a more comprehensive range of knowledge of the system (including non-academic, especially local knowledge). Questions of resilience 'of what, to what' and the identification of alternative regimes and options for transformation are particularly limited by the choice of system boundaries and the knowledge sources used to inform the assessment.

Our assessment suggests that the focal scale as defined would benefit from being reconceptualized. Rather than choosing a geographical area as the focal scale, it would appear that a system definition that reflects the important networks affecting system dynamics would make more sense. In particular, seasonal migration and transhumance destinations (and associated markets) could be included more specifically as important parts of the agroecosystem, despite being geographically distant. There are also ethical dimensions and sensitivities to be alert to when defining system boundaries, and again benefits from being informed by multiple perspectives of diverse stakeholders to reduce risks of excluding or marginalising the concerns of particular groups via an overly narrow system definition.

Assessment outcomes are currently too premature and generic to be implemented. This assessment was carried out to help us develop resilience indicators, not to inform actions and polices in Niger, but what we present here is a useful starting point for iterative improvement guided by stakeholders in the system.

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