Risks, vulnerabilities and resilience in a context of climate change

Vincent Gitz and Alexandre Meybeck
Agriculture and Consumer Protection Department, FAO, Rome

Agricultural activities are by nature prone to risks and uncertainties of various nature, both biophysical, abiotic, climatic, environmental, biotic (pests, diseases) and economic. Many of these risks have a climatic component and most of them will be affected by climate change, either in intensity, scope or frequency.

The aim of this paper is not to review the increasing literature on risks, on vulnerability[1] and on resilience.[2] It is to articulate these broad notions in such a way that they can be of use to frame an approach applicable to concrete issues in the agricultural and food systems.

The impact of a risk depends on the shock itself and on the system to which it is applied. Depending on its vulnerability, the system will be more or less affected by the same shock. Depending on its resilience, it will recover more or less easily.

Climate change is expected to modify risks, vulnerabilities and the conditions that shape the resilience of agriculture systems. Climate change is also introducing new uncertainties.

Could building resilience to known risks be a way to build resilience to changing risks and to adapt to climate change? How to build strategies and policies for resilience of agriculture and related systems in the context of climate change?

To consider these questions, one has first to clarify how these notions of risk, vulnerability and resilience are connected, how they apply to systems, and to interlinked systems, and how environmental (biophysical), economic and social perspectives can interact.

Therefore, this paper aims towards a better understanding of "what adaptation means" and towards strategies to build resilience in making the following points:

1. Risks operate on **systems** and first one must have a good understanding of the systems to be considered.
2. Climatic risks and changes operate in the **middle of all other risks**, superpose with them and change them.
3. Before we come to "what we mean by resilience", we must explain the notion of **vulnerability.** To consider risks as they impact systems leads us to consider vulnerabilities. We will try to define what this notion covers and its dimensions.
4. **Building resilience** starts with reducing vulnerabilities: a system is more resilient if it is less vulnerable. But this is not enough. Resilience adds two dimensions: the

[1] For a review on the notion of vulnerability, see Adger (2006) and Fellmann (2012).
[2] For a review on resilience from an operational point of view, see Martin-Breen. and Anderies (2011).

dimension of time and the need to deal with uncertainties. This is where **adaptive capacity** is key.

5. Finally we will draw some lessons for **strategies to build resilience** in the context of climate change.

SOME DEFINITIONS AND PERSPECTIVES

Definitions

"Risk" is used here to designate the potential of shocks and stresses to affect, in different ways, the state of systems, communities, households or individuals. Probability, uncertainty (when probabilities of occurrence or even nature of impacts are unknown), severity, economic scale, time scales and direct and indirect costs should be taken into account.

"Vulnerability" is the propensity or predisposition to be adversely affected (IPCC, 2012). It is a dynamic concept, varying across temporal and spatial scales and depends on economic, social, geographic, demographic, cultural, institutional, governance and environmental factors. Measuring vulnerability is complex as it needs to be considered across various dimensions.

"Resilience" is the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (IPCC, 2012).

"Adaptive capacity", the capacity of a system to adapt in order to be less vulnerable, is a dynamic notion. It is shaped by the interaction of environmental, social, cultural, political and economic forces that determine vulnerability through exposures and sensitivities, and the way the system's components are internally reacting to shocks. In fact, it has two dimensions: adaptive capacity to shocks (coping ability) and adaptive capacity to change. The first dimension is related to the coping ability (absorption of the shock), the second dimension is related to time (adaptability, management capacity). Adaptations are manifestations of adaptive capacity (Smit and Wandel, 2006).

Characterization of systems

Importantly, these notions of vulnerability and resilience are applied to systems[3], which means that first the system(s) to be considered (its components, their boundaries and delineation) has to be clarified in order to assess its vulnerability and/or resilience.

Systems can be embedded into one another, meaning that one system can be a component of a major system.

Systems can be delineated according to various perspectives (including expected functions), environmental, economic or social (including political and institutional), even though they are linked.

Food systems are by nature ecological, economic and social (Ericksen, 2008; Füssel and Klein, 2006). Each dimension has its own organization and interacts with the others. They

[3] A system is a set of interacting and independent components that form an integrated whole, in interaction with the environment and other systems.

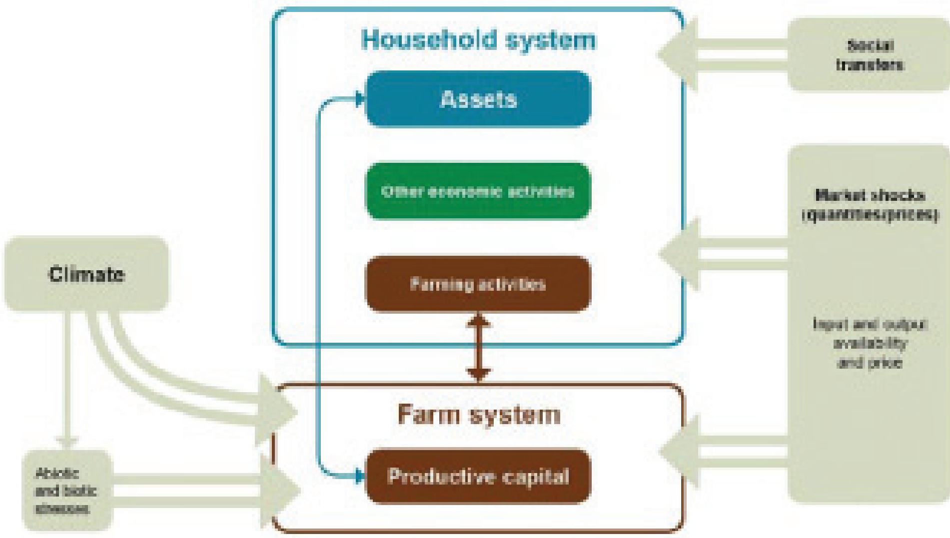

Figure 1. Household and farm systems

can be described and analysed in each of their dimensions. There are also theories attempting to understand and describe "complex systems" (Holling, 2001; Gunderson and Holling, 2001) particularly to better seize the concept of sustainability.

From a food production perspective, the smallest system would be the farm, integrated in a farming system and at the same time in a food chain, or food chains according to each production.

From a food security perspective, the smallest system would be the household (composed of individuals), which can be linked to a farm or farming activities (Figure 1), integrated in a social community and with other links, economic and social.

From a biophysical perspective, the farm has to be considered as part of a landscape, with different delineations according to various issues (water, biodiversity, etc.).

The food production systems and the food security systems, as well as the biophysical/ environmental systems, are interlinked, and sometimes share some subcomponents.

For the three ranges of systems above, stemming from three different perspectives, we can define more local or elementary sets of systems (such as farms, households), and higher level systems that would be national, regional and global (Table 1 and Figure 2). In Table 1 and Figure 2, to simplify, we have considered a five-scale imbrication of systems.

Table 1: Systems across dimensions and scales

	1	2	3	4	5
Food production	Farms	Farming systems and food chain(s)	National	Regional	Global
Food security	Households	Communities	National	Regional	Global
Biophysical	Farms	Landscapes	National	Regional	Global

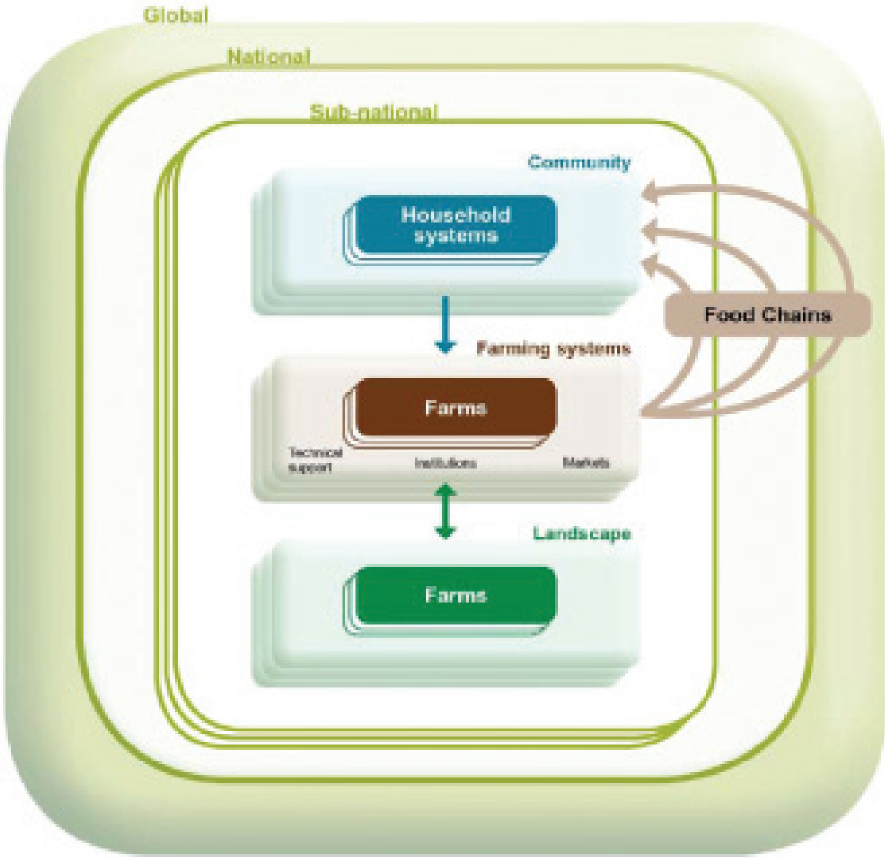

Figure 2. Imbrication of different systems across scales

RISKS AFFECTING AGRICULTURE

Various risks

Agricultural production is submitted to risks of various types: political instability, economic and price-related risks, climatic, environmental, pests and diseases, at different scales. Risks affecting yield in main staple crops are particularly important for smallholders, who tend to consume a large part of their own production. Farmers are also exposed to economic risks including land tenure insecurity, variations in access to inputs (fertilizers, seeds, pesticides, feed) in quantity and quality, and variations in access to markets.

Often risks of various types, when superposed, exacerbate their effects, as for example in the case where livestock that are already weakened by a lack of feed owing to a drought would be more prone to becoming infected by a disease. Also, after a poor harvest, seeds could be lacking for the next growing season.

Risks faced by producers not only compromise food security directly but also indirectly as they constraint agricultural development by preventing investment and access to credit.

Table 2: Types of risks and potential impacts on farmers

Types of risk	Potentially influenced by climatic factors	Potential economic consequences on farmers	Potential long-term consequences
Input price increase	Yes (feed)	Yes, reduced income for farmers	When it affects investment (seeds, breeding stock)
Output price decrease	Yes	Yes, reduced income for farmers	Reduce incentive for investment
Weather shocks	Yes	Yes	Depending on type of shocks and productions
Plant pests	Yes	Yes, reduced yield	Yes. Pest could last. Loss of productive capital (trees). Potential trade barriers.
Animal diseases	Yes	Yes, reduced production. Loss of livestock. Potential trade barriers	Yes. Disease could last. Loss of productive capital. Potential trade barriers.

Reducing the producers' vulnerability and strengthening their resilience to shocks is an essential part of any agricultural development policy.

Risks affecting agricultural activities are generally categorized according to the nature of the associated shocks: biophysical, economic, etc. (Eldin and Milleville, 1989; Holden, Hazell and Pritchard, 1991; Cordier, 2008; OECD, 2009). They are also often classified according to the intensity, frequency and predictability (degree of uncertainty) of the associated shocks. They can also be categorized according to their impacts: nature, but also importance, scope both in space and time (INEA, 2011).

All of these parameters not only characterize the risks and their potential impacts. Their apprehension is also necessary to shape the level and type of intervention needed to reduce them and/or to avoid that they have long-term consequences.

Based on a review of the literature, OECD identifies crop yield, output price and, to a lesser extent, input price as the major risks for crop producers (OECD, 2009). Livestock grazing systems are subject to much the same type of risks. Livestock systems that rely heavily on external feed are particularly subject to input price risk (OECD, 2009).

Weather is in itself a major cause of risk. It also has a major influence on most of the other production risks.

Climate changes will change the determinants of the risks that agricultural systems are facing. For example, it can manifest itself by changing the degree of uncertainty and predictability of previously existing risks.

The South Asian summer monsoon is critical to agriculture in Bangladesh, India, Nepal and Pakistan. Climate change could influence monsoon dynamics, a change of precipitation and delays in the start of monsoon season, with important impacts on agriculture, even for slight deviations from the normal monsoon pattern. Even if modelling studies are improving to assess how monsoon patterns might be affected by climate change, it remains that climate change adds here an important layer of uncertainty to previously existing risks (start of the monsoon, amount and pattern of precipitation).

Often, there can be very different perceptions of a risk depending on the angle of analysis, or depending on the point of view from which it is appraised or considered (risks bearer, impact bearer, vulnerability bearer, external actor, etc). One good example in that regard is

Box 1: Drought terminology (from IPCC)

In general terms, drought is a "prolonged absence or marked deficiency of precipitation", a "deficiency of precipitation that results in water shortage for some activity or for some group" or a "period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance" (Heim, 2002). Drought has been defined in a number of ways. "Agricultural drought" relates to moisture deficits in the topmost one metre or so of soil (the root zone) that impact crops, "meteorological drought" is mainly a prolonged deficit of precipitation, and "hydrologic drought" is related to below-normal streamflow, lake and groundwater levels. (IPCC, 2007a).

The socio-economic impacts of droughts may arise from the interaction between natural conditions and human factors, such as changes in land use and land cover, water demand and use. Excessive water withdrawals can exacerbate the impact of drought. (IPCC, 2007b).

the definition of "extreme events". A meteorological event can be described as "extreme" because of its intensity or because of its infrequency. Most often it is because of both. Moreover, intensity can be perceived and assessed as the intensity of the event/shock itself or by the importance of its effects, which depend on the vulnerability of the affected area and/or activity. In that respect agriculture is very specific because of its greater vulnerability to even slight changes in temperature or rain patterns, which can have devastating effects on crops, grasslands or forests. Changes in short-term temperature extremes can be critical, particularly at key stages of plant development (Gornall *et al.,* 2010). Therefore, describing the risk (intensity, frequency, probability, uncertainty) is not enough – one has to look at its transmission into the system considered, starting with impacts.

Various impacts

A single stress/shock can have various impacts, of diverse nature and time scale, even considering a single simple farming system.

For instance, a drought in livestock grazing systems (see Figure 3) reduces the availability of water and grass – both directly and indirectly because, as the watering points are reduced, some pastures are no longer accessible – and so increases demand for feed at the very moment when there is less feed available. These drive a feed price increase, which forces livestock owners to sell their cattle. Massive sales while there is a reduced demand push cattle prices down, forcing to sell even more to buy feed. These effects on prices reduce farm and household income and assets. Moreover, they reduce the value of assets (livestock) and the productive capital for the future. Prolonged or repeated drought also has long lasting degrading effects on land: a combination of drought and overgrazing, particularly near watering points, destroys the vegetal cover, increasing soil erosion.

Assessing potential im-pacts of a stress on a system requires not only evaluating potential impact on each of the components of the system but also how it will change the relationships between the components of the system. It is particularly difficult for complex systems involving biophysical factors, as these cannot be totally reduced to a single dimension.

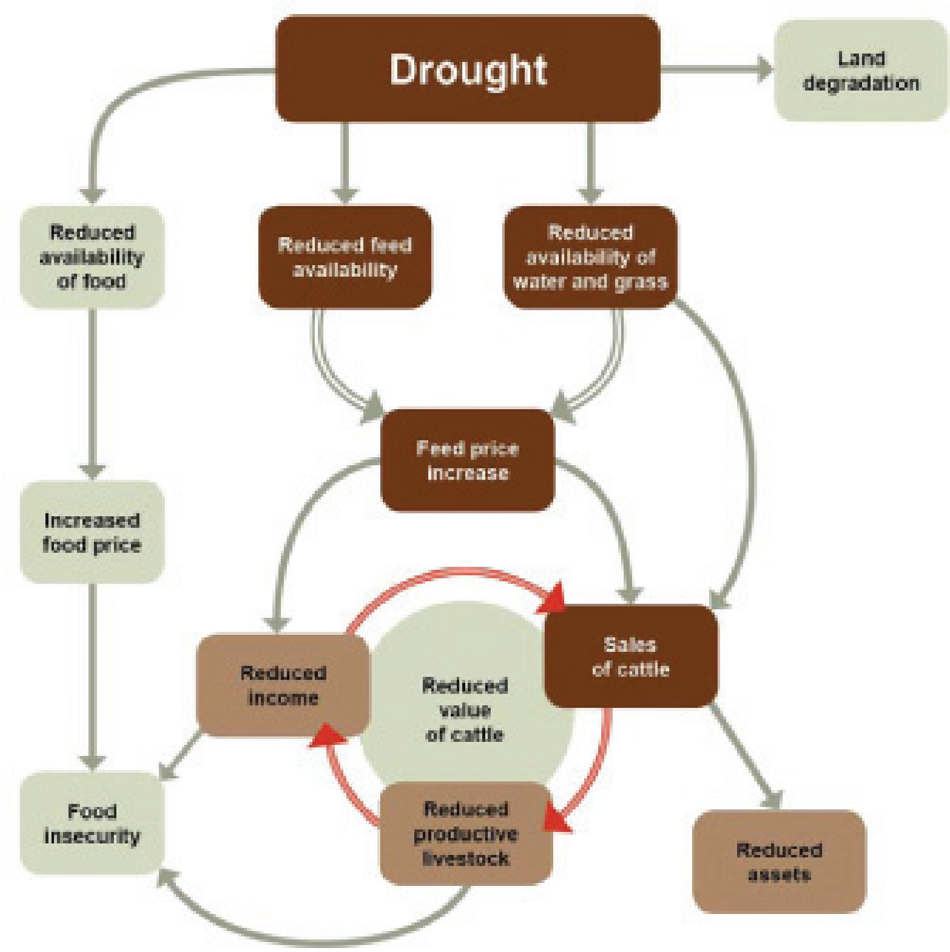

Figure 3. Impacts of a drought on grazing systems

Climate changes will have an effect on various components of each ecosystem, and on internal feedback loops (Figure 4). Some of these effects begin to be better understood and can be simulated, like effects on a single species, as the effect of higher average temperature on major crops, for instance. But effects on the whole system are much more difficult to predict. For instance, effects on pests and on their predators are much less known. And thus effects on their interrelationships, which drive the impact on crops, cannot be integrated in projections. Seemingly, climate change will affect both pollinators and the plants with which they interact (Kjøhl, Nielsen and Stenseth, 2011). Any disruption on their synchronicity could have a major effect on their relationships and thus on both of them. Therefore, the real effect of climate change on yields is not as known as the results from modelling crop reactions to climate change would make believe.

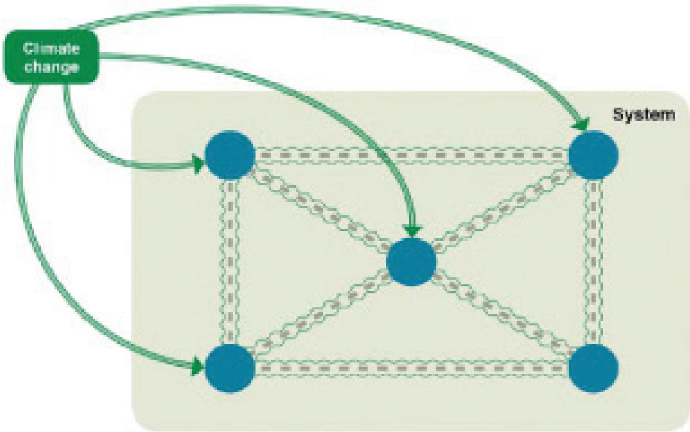

Figure 4. Impacts of climate change on the components of a system and their interrelationships

Risk management

Risk management can involve various levels of systems and/or various dimensions. Solidarity at community level can help poorer households to support the effects and to recover (for instance, cattle lending practices in pastoral societies).

Some risks, such as plant pests and animal diseases, can spread from one farm or territory to another. Here risk management strategies, involving prevention, monitoring, early warning and early action can prevent the shock from spreading and having catastrophic effects. The **FAO Emergency Prevention System (**EMPRES) programme on locust in West Africa successfully avoids catastrophic crises such as the one of 2003–2005 for a cost of less than 0.6 percent of the value of the crops lost in 2003–2005 (Cossée, Lazar and Hassane, 2009).

Finally, in a given system, production shocks are transmitted in the economic and social dimensions. This transmission can be linear, amplified or reduced, depending on the policies and institutions that are in place.

VULNERABILITIES

Vulnerabilities and vulnerability

The net impact of a shock, ultimately depends not only on the intensity of the shock itself but also on the vulnerability of the system to this particular type of shock.

Vulnerability, as defined in the introduction of this paper, is a complex concept that needs to be considered across scales and across various dimensions. It can be defined as vulnerability of "what" to "what" (Carpenter *et al.,* 2001). But it is in fact more complex. The first "what" encompasses two dimensions: (i) the identification of the *system and components* that at the end "bear the vulnerability"; and (ii) the measure of the potential impact qualities/dimensions/units that characterize the entry, through a threshold, of the system/component into a degraded/impacted state: it can range from health to nutrition, injuries, revenue, assets, including social variables. This defines the "domains" of the vulnerability. The second "what" is either a single risk, or a set of risks, or a change in the context that shape existing risks.

Measuring and assessing vulnerability is a growing field of research, and goes outside the scope of this paper. The vulnerability of a system has to be contemplated given the whole set of risks (and related specific vulnerabilities) that affects it and that may have compensative, cumulative or amplifying effects. It also encompasses several dimensions: productive, economic, social. Therefore, there is potentially a wide range of metrics to assess vulnerability.

Means to be used to reduce the impact of a shock can either compensate for vulnerability (for instance, provide feed from another area in case of a localized drought) or reduce it in the long run, for instance by investing in more water points or in irrigation.

The degree of "specific" vulnerability of a system to a particular type of risk can be analysed as exposure and sensitivity to the potential shock that relates to this risk, and also depends on the "adaptive capacity" of the system to cope with the impact of the shock. The adaptive capacity itself can also be impacted by an external shock.

In a given system, shocks in one dimension can spread into another dimension: production shocks are transmitted in the economic and social domains. This transmission can be linear, amplified or reduced, depending on the policies and institutions that are in place.

For instance, a climatic shock, reducing yield in one area, can, at household level, be compensated for by trade, provided that trade is not impeded, and provided that households have the means to buy that food, using other sources of income, their own assets, or social transfers (safety nets).

In many cases, there can be amplifying or positive correlations between effects of shocks of diverse nature. In such cases, and conversely, reducing vulnerability to one kind of shock can also help to reduce (specific) vulnerability to another kind of shock. Vulnerability is also impacted by the various shocks; a drought increases vulnerability to the next drought. By decreasing the strength of the cattle, it also increases their vulnerability to diseases. By reducing assets of households, it also increases their vulnerability to any kind of shock.

Obviously, some characteristics of a system make it more or less vulnerable to a set of risks. A farm relying on a single crop is particularly vulnerable to a pest affecting this single crop or to a price drop of that crop. On the contrary, a much diversified system is less vulnerable to both pests and price fluctuations affecting specifically one type of production.

Finally, vulnerability can evolve in time as a system's adaptive capacity to a set of risks and shocks evolves in time, and also as its exposure and sensitivity to shocks can evolve with time. This is especially key in the context of climate change, which drives changes in the vulnerability of systems in two ways: (i) by introducing new risks; (ii) by changing the context and systems' responses to previously existing risks (including climate-related ones).

Vulnerability at scales

Systems can be defined at various scales. As we have seen, an upper scale system is generally composed of different systems defined at lower scales (for instance, from a biophysical perspective, landscape systems are composed of farms).

The vulnerability of an upper scale system depends on the vulnerability of the subsystems that it includes. It also depends on how other systems, to which it is linked, including systems of a higher scale, will be vulnerable or insensitive to the shocks.

For example, the vulnerability of a farm to a certain risk is compounded of its own vulnerability and of the one of the landscape in which it is situated, and whose vulnerability is in turn compounded of its own, of the vulnerabilities of the various farms situated in it, and of the one of the system of higher level (e.g. the territory) in which it is situated.

A corn farm is more vulnerable to corn rootworm when corn is cultivated yearly on the same parcels; even more if it is close to other corn farms; even more if one of these farms is close to an airport; even more if this airport has flights arriving from a country where rootworm is common. In turn, a territory where a lot of farms, close to each other, cultivate corn, is more vulnerable to corn rootworm.

Seemingly, the adaptive capacity of a territory is compounded of the adaptive capacity of the farms that it encompasses, and of the systems that encompasses it (Figure 5).

A territory devoid of any system for monitoring animal diseases and for early action is more vulnerable to animal diseases. It makes all livestock producing farms of this territory more vulnerable to animal diseases.

From one level to another, vulnerabilities can either:

- add themselves;
- compensate each other;
- amplify each other.

A household relying on agricultural production is vulnerable to agricultural production shocks. A country relying on agricultural production is vulnerable to agricultural production shocks. Which makes households relying on agricultural production situated in countries relying on agricultural production even more vulnerable, because at the time of a major shock it is more difficult for the country to compensate.

Therefore, one way to reduce vulnerability can be to act on the transmission from one level to another. This is why, for instance, monitoring of diseases and plant pests, and early action to avoid their spread, is an essential way to reduce vulnerability at different levels.

Figure 5 is a schematic representation of the state of vulnerability of production systems: vulnerability of the farms, of the farming landscape (group of farms) and of the farming region/territory, for example the vulnerability at different scales to an animal

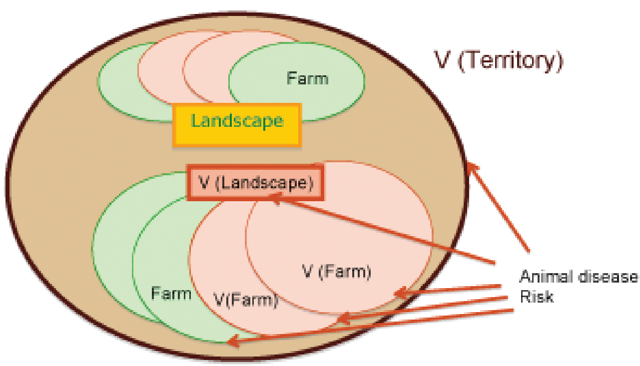

Figure 5. Vulnerability and vulnerabilities at different scales

disease. Towards the darker grey are more vulnerable units. Towards the light grey are less vulnerable units. The vulnerability of the landscape of farms depends of the vulnerability of each farm it contains and of the upper-scale vulnerability of the territory.

RESILIENCE

Resilience can be described as the capacity of systems, communities, households or individuals to prevent, mitigate or cope with risk, and recover from shocks. At first approximation, resilience is the contrary of vulnerability, but importantly it adds a time dimension to the concept: a system is resilient when it is less vulnerable to shocks *across time*, and can recover from them.

We have seen that adaptive capacity encompasses two dimensions: recovery from shocks and response to changes. These two dimensions play an essential role towards resilience, both to recover from shocks and to adapt to change. Therefore, it ensures the "plasticity" of the system. For example, the organization of proper seed systems enables farmers having lost a crop to have seeds for the next season. It also enables them to have access to seeds adapted to new conditions.

We have seen that adaptive capacity can be impacted by shocks. Shocks hurting, directly or indirectly, an adaptive capacity have a long-term effect and are therefore one of the first concerns to ensure resilience.

For instance, after a severe drought, pastoralists are more vulnerable to a new drought, because they have less productive cattle. They have also less adaptive capacity, less capacity to recover to shocks and eventually to change because they have lost assets (Figure 4). They are less resilient.

As for vulnerability, resilience can be specified as "resilience of what to what" (Carpenter *et al.*, 2001). However, focusing on specified resilience may cause the system to

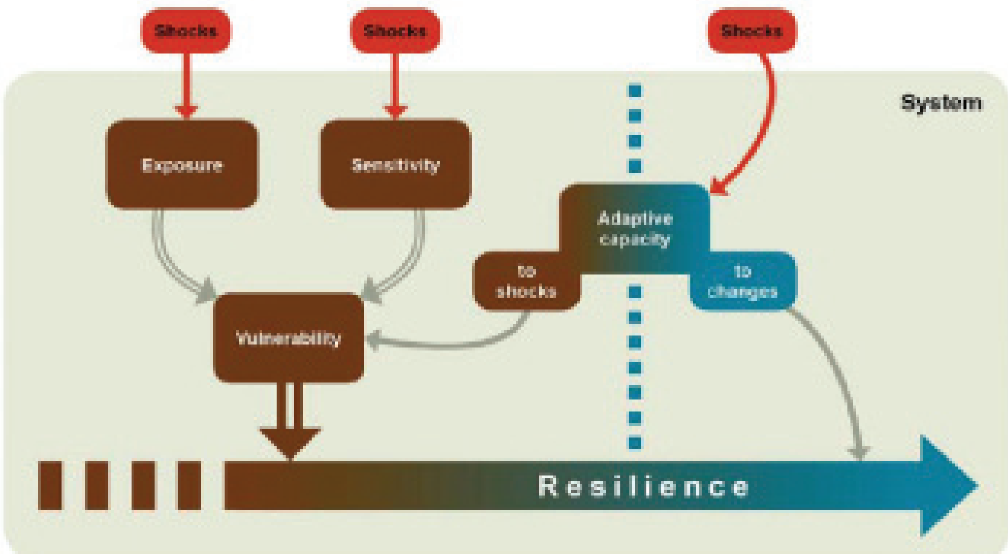

Figure 6. Vulnerability and resilience

lose resilience in other ways (Cifdaloz *et al*., 2010). This is why general resilience can be described as being "about coping with uncertainty in all ways" (Folke *et al*., 2010).

As for vulnerability, resilience can be considered in various dimensions – biophysical, economic and social and at various scales. And as for vulnerability, the way the various dimensions and scales interact is crucial, precisely because of the importance of general resilience to cope with uncertainty. For instance, Karfakis *et al*. (2011) shows that increasing the level of education of farmers can be an efficient mean for reducing farmers' households vulnerability to climate change.

Resilience puts a greater emphasis on the capacity of a system to recover and transform itself in the long term, to adapt to its changing environment, in a dynamic perspective. It therefore implies that it is not only shocks that have to be considered, as a change relative to an average, but also the change of the average itself, ultimately the question being until what point a system can adapt before changing to another type of system.

BUILDING RESILIENCE

To a great extent, increasing resilience can be achieved by reducing vulnerabilities and increasing adaptive capacity. This can be achieved by reducing exposure, reducing sensitivity and increasing adaptive capacity, for every type of risk. It can act in each domain, either biophysical, economic and social. One way to achieve better resilience is to reduce transmission of shocks between types of risks, between scales and between domains and to organize compensation between scales (for instance transport of feed) or between domains (for instance safety nets) to avoid cumulative and long-term effects.

In this section we make an attempt to describe the bricks that can be used to build strategies for resilience.

Three ways to build resilience

In a first approximation we can identify the following three ways to build resilience:

1. Reduce exposure. There is a fundamental difference between climatic and non-climatic shocks in this regard because most of the shocks on-farm can be reduced at the source, or limited in their extension, contrary to climatic shocks. Here the best example is probably the eradication of rinderpest, which has totally suppressed a major risk for livestock and those depending on it.
2. Reduce the sensitivity of systems to shocks. Sensitivity to drought can, for instance, be reduced by using drought-resistant varieties or keeping stocks of hay.
3. Increase adaptive capacity. This includes considering the modifications of a system taking into account all the potential shocks and changes altogether (to take into account compensating, cumulative or exacerbating effects).

But all of this is not enough. To ensure resilience, the three ways of actions above have to be considered *through time*, and given *uncertainties*.

Building resilience through time.

First, there is the need to build adaptive capacity not only to existing risks and shocks (coping capacity), but also *to changes, in an evolving context* (Figure 5).

Second, there is the need to consider that strengthening resilience, in real life, has to be done *at the same time as the shock occurs, since they occur all the time*. This is where we can separate between *ex-ante* (A), during shock (B), and *ex-post* (C) actions to build resilience:

1. *Before the shock*, by increasing, *ex ante*, the resilience of productive or livelihood systems to existing or emerging risks: for example, through putting in place systems for the early detection of emerging risks, or through the reduction or elimination of a specific risk.
2. *During the shock*, ensuring that affected agents (farmers, communities, small-scale food processors, poor consumers) can benefit from continuing access to food and adequate diets, and keep their asset levels and means of livelihood, including by safety nets.
3. *After the shock*, helping systems to recover and build adaptive capacity. Actions can be pursued that progressively reduce the effect of the previous shock, reduce the exposure and sensitivity to future ones, and/or that increase the adaptive capacity of a system to future shocks in a changing context (*adaptive capacity to changes*). Restoration measures such as grassland restoration measures are a good example of this.

Addressing uncertainties: a condition to build resilience

Finally, we have to take into account that occurrence of shocks is not certain: either their own nature, or the nature or size of the impacts, can be uncertain, or their occurrence in time is generally not known. Therefore building resilience goes with the need to *anticipate* within uncertainty, within the system, or across scales.

In that sense, specific risk monitoring not only reduces vulnerability but also increases resilience as it allows anticipating risks and their change.

A good example of actions to build resilience in the face of uncertainties owing to climate change is in the domain of genetic resources. If climate changes, farmers might need to rely on different genetic resources, some that are already used elsewhere, or some other species or varieties that were considered minor but that could appear to be more adapted. To do so, there is the need to be able to rely on the largest pool of genetic resources. Genetic resources, which are also threatened by climate change, are indispensable for adaptation. We need to keep very diverse genetic material, including traditional and improved crop varieties and their wild relatives. They are adapted to specific conditions, have been selected for different uses, and constitute the reservoir from which varieties can be developed to cope with the effects of climate change such as drought, shortening of the growing season and increased incidence of pests and diseases. Preserving genetic resources increases the resilience potential of the whole system. To make this potential effective, genetic resources have to be accessible to farmers where they are needed: it is not enough to have the appropriate genetic resources in a gene bank or a research centre. They have to be multiplied and distributed, which require plant breeders, seed enterprises and the proper legal system to certify their quality and the accuracy of the genetic information. All these actors and elements constitute “seed systems” that enable farmers to have the seeds they need. Regional harmonization of seed rules and regulations is also essential, particularly as crops will move, to adapt to climate change.

Box 2. Risks and adaptation measures: the role of amplifying effects

Let us call R the risk, S the shocks (materialization of the risk), V the Vulnerability, I the net total impact on the system of the sum of shocks (materialization of the vulnerability).

Let us assume for the sake of simplification that there are climatic risks and shocks (Rc and Sc) and non-climatic risks and shocks (Rn and Sn)

We can write I = f (Sc, Sn)

and V = g (Rc, Rn)

where f and g are functions characteristic of the system that take into account its exposure, sensitivity and degree of adaptive capacity to risks and shocks.

An adaptation measure is a transformation of the system towards functions fa and ga whereby in principle impacts of climatic shocks are lower, and vulnerability is reduced, *everything else being equal.*

Ia = fa (Sc, Sn)

Va = ga (Rc, Rn)

where Ia (Sc, Sn) < I (Sc, Sn) and Va (Rc, Rn) < V (Rc, Rn) for all Sn and Rn

Now let us suppose that in first approximation we can write:

F(Sc, Sn) = alphac Sc + alphan Sn + beta Sc Sn

Then a climate change adaptation measure could be a measure that either acts to reduce alphac, or to reduce beta.

Comprehensive strategies to build resilience through scales and dimensions

a) Reduce, or take account of, amplification effects

When there are amplifications effects across risks and different kinds of shocks (economic, climatic, etc.), a reduction of non-climatic risks that act as a multiplier of climatic shocks can be a way to reduce the impact of climate change and therefore is an adaptation measure (Box 2).

b) Organize compensation

The exposure, sensitivity and adaptive capacity of a system are often the (complex) result of the way internal components of a system interact. Internal components of the system can be organized, or interventions can be applied to key components of the systems or to their interplay, to put in place compensation mechanisms that make the overall system less exposed, less sensitive and/or with more capacity to adapt.

To take an easy example, a household whose main activity is farming is less vulnerable to drought if it has non-farming income or assets that are outside farming activities.

As we have seen, the vulnerability of a system is also dependent of its relationships with subsystems, to other similar systems at the same level, or to systems at a higher level. Therefore, resilience can also be increased by organizing compensation across scales and with other systems.

Trade could compensate for a shock on production in a given area, provided that there are no barriers to it and that poor consumers can afford to buy traded products at the time when their income is lower and prices higher.

Box 3. Enhancing resilience in pastoral systems
Improved grazing management could lead to greater forage production, more efficient use of land resources, and enhanced profitability and rehabilitation of degraded lands and restoration of ecosystem services. Grazing practices can be used to: stimulate diverse grasses, improve nutrient cycling and plant productivity and the development of healthy root systems; feed both livestock and soil biota; maintain plant cover at all times; and promote natural soil-forming processes.

Hardiness of local cattle is essential for their very survival, especially considering potential degradation of climate conditions (increased risk of drought). In particular, capacity to walk long distances in order to find grass far from water points is essential. Improving the efficiency of local cattle by selection on productivity in the breed and better health and feeding conditions rather than by cross-breeding could preserve the genetic specificities that are essential to the resilience of grazing systems in arid conditions.

This is where safety nets can play an essential role.

Finally, sustainable management of forests (Braatz, 2012) and sustainable management of fisheries (De Young, 2012) are also good examples where the actions towards resilience in one domain of vulnerability, starting by the biophysical domain, have also positive effects on the resilience and vulnerability in other domains (social/economic).

c) From risks and vulnerabilities to policies and tools

While the reverse approach (from tools and policies to their impact on vulnerabilities) is often the major one followed, it results from the above that, in the climate change context, the identification and proper understanding of all the risks, impacts, vulnerabilities, over systems, in various dimensions, and how climate change might act on them, is rather a necessary precursor to consideration of tools and instruments, policies and their targets, and integration in a comprehensive approach towards resilience

Strategies for resilience should combine a set of specific policies targeted to address specific agents or components of systems, categories of risks, domains of vulnerability, and ways of action of the tools.

To ensure their proper use within a comprehensive strategy, there is an immense value added in clarifying, for each policy/tool, the ways of action of the tools and policies, and primarily the agents affected.

Policies targeted at farmers can include measures aiming at building economic resilience at farm level either by increasing income, by promoting diversification (especially if the risks affecting each activity are not correlated) or by insurance (in certain cases). They also include measures to reduce or eliminate specific risks, such as plant pests and animal diseases, including advanced observation networks for quick response. Other measures either prevent the loss of productive assets, such as feed banks for livestock during droughts, or enable quick recovery, such as availability of seeds.

Policies should also address risks along the food chain (including for small-scale food producers), including storage, post-harvest losses and food safety risks. Prevention of food

Box 4. Change of system: from slash and burn to agroforestry in Central America

Since 2000, FAO has initiated special programmes for food security with the Governments of Guatemala, Honduras, Nicaragua and El Salvador. These programmes worked together, sharing practices, experiences and results, to improve and develop agroforestry systems in the subregion.

Agroforestry systems are promoted to substitute traditional slash and burn systems, particularly on slopes. They are at the same time more efficient and resilient.

In traditional slash and burn systems, a family needs close to 6 hectares to maintain itself on a diet of maize and beans: it exploits the parcel for two years, and then sets it aside for 14 years.

In agroforestry systems, a parcel is exploited for ten years, producing, along with maize and beans, a variety of other products, often including also livestock, then is set aside for only five years. A family thus needs 1.4 hectares to sustain itself, and with a much more varied and balanced diet. Land is therefore almost four times more efficient.

This is also because, in agroforestry systems, yields (which are comparable the first year) do not decline over time as they do very rapidly in slash and burn systems. In fact, they can even slightly increase over time in agroforestry systems. Productivity of labour and of capital are also higher in agroforestry systems.

Costs are reduced, especially in fertilizers, thanks to more organic matter in the soil and better use of nutrients by the plants.

At community level, diversification of production triggers the development of local markets.

So agroforestry systems are very efficient: for food security, for the environment, in terms of resource use.

Agroforestry systems are also much more resilient:

- Yields are less variable, (also thanks to better humidity retention).
- They provide for more diverse productions: a buffer against both individual crop's yield variability and price volatility.
- They offer diversified sources of income, including through selling wood for various uses (and at various time scales), which can also buffer some economic shocks.
- They protect the soil from erosion, which is a major concern in these areas. Studies have shown that erosion is reduced in agroforestry systems by a factor of more than ten..

safety risks or effectiveness to handle large-scale food safety emergencies will depend on the services available (inspection and analytical capacities, information sharing, health services).

Policies targeted at consumers would use measures specifically designed to address access to food that is nutritionally adequate, safe and culturally appropriate.

The efficiency of any specific risk management policy is largely dependent on the existence of enabling policies, institutions, coordination mechanisms and basic infrastructure. For example, markets and transport have an important role in diluting the impact of a shock over greater areas.

CONCLUSION

Climate change is expected to introduce new risks for agricultural production and to modify existing ones. Climatic models cannot predict future risks with a sufficient precision to enable decision-makers at local level to exactly address them.

The impact of a risk on a system depends on the shock itself and on the vulnerability and resilience of the system. An analysis of the notions of vulnerability and resilience, as applied to agricultural and food systems, in their various dimensions (biophysical, economic and social), taking into consideration the imbrications of systems of various scales (for instance from farm to landscape), shows that the interactions between dimensions and between scales can play a crucial role to reduce vulnerability and increase resilience.

The notion of resilience itself is particularly powerful to bring together measures intervening into very different dimensions, biophysical, economic and social. It also enables clarification of the relationships between "specific" vulnerabilities and resilience and how addressing known risks can enable strategies to be devised to build general resilience in order to cope with uncertainty.

As such, it provides an efficient way for "no regret" adaptation. A crucial element of it could be to better manage known risks, whether climatic or not, to get prepared for future, uncertain risks and changes.

REFERENCES

Adger, W.N. 2006. Vulnerability. *Global Environmental Change*, 16: 268–281.

Braatz, S. 2012. *Building resilience to climate change through sustainable forest management.* This publication.

Carpenter, S.R., Walker, B.H., Anderies, J.M. & Abel, N. 2001. From metaphor to measurement: resilience of what to what? *Ecosystems*, 4: 765–781.

Cifdaloz, O., Regmi, A., Anderies, J.M. & Rodriguez, A.A. 2010. Robustness, vulnerability, and adaptive capacity in small-scale social–ecological systems: the Pumpa Irrigation system in Nepal. *Ecology and Society*, 15(3): 39 (available at http://www.ecologyandsociety.org/vol15/iss3/art39/).

Cordier, J. 2008. La gestion des risques en agriculture. De la théorie à la mise en oeuvre : éléments de réflexion pour l'action publique. *Notes et études économiques* No. 30, March 2008.

Cossée, O., Lazar, M. & Hassane, S. 2009. *Rapport de l'évaluation à mi-parcours du Programme EMPRES composante criquet pèlerin en région occidentale.* Rome, FAO (available at http://www.fao.org/ag/locusts/common/ecg/1740/en/EMPRESWevaluationF.pdf).

De Young, C. 2012. *Building resilience for adaptation to climate change in the fisheries and aquaculture sector.* This publication.

Eldin, M. & Milleville, P., eds. 1989. *Le risque en agriculture*. Paris, ORSTOM. 619 p.

Ericksen, P.J. 2008. Conceptualizing food systems for global environmental change research. *Global Environmental Change*, 18(1): 234–245.

Fellmann, T. 2012. *The assessment of climate change related vulnerability in the agricultural sector: Reviewing conceptual frameworks*. This publication.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T. & Rockström, J. 2010. Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society*, 15(4): 20 (available at http:// www.ecologyandsociety.org/vol15/iss4/art20/).

Füssel, H.-M. & Klein, R.T.J. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change*, 75 (3): 301–329.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K. & Wiltshire, A. 2010. Implications of climate change for agricultural productivity in the early twenty-first century. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, 365: 2973–2989.

Gunderson, L. & Holling, C.S., eds. 2001. *Panarchy: understanding transformations in human and natural systems.* Washington, DC, Island Press.

Heim, R.R. 2002. A review of twentieth-century drought indices used in the United States. *Bull. Am. Meteorol. Soc.*, 83: 1149–1165.

Holden, D., Hazell, P. & Pritchard, A., eds. 1991. *Risk in agriculture*. Proceedings of the Tenth Agriculture Sector Symposium. Washington, DC, World Bank.

Holling, C.S. 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, 4: 390–405.

INEA (Istituto Nazionale di Economia Agraria). 2011. *Prospettive della gestione del rischio in agricoltura. Riflessioni per un sistema integrato per la PAC post 2013.* Quaderno. Rome.

IPCC. 2007a. *Climate change 2007: the physical science basis.* Contribution of Working Group I to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller, eds.. Cambridge, UK, and New York, USA, Cambridge University Press, 996 p.

IPCC. 2007b. *Climate change 2007: impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Glossary, pp. 869–883. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linder, & C.E. Hanson, eds. Cambridge, UK, and New York, USA, Cambridge University Press.

IPCC. 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation (SREX)*. Special Report of the Intergovernmental Panel on Climate Change (IPCC). Geneva, IPCC Secretariat.

Karfakis, P., Knowles, M., Smulders, M. & Capaldo, J. 2011. *Effects of global warming on vulnerability to food insecurity in rural Nicaragua*. Rome, ESA-FAO WP Series No. 11–18.

Kjøhl, M., Nielsen, A. & Stenseth, N.C. 2011. Potential effect of climate change on crop pollination. Rome, FAO (available at http://typo3.fao.org/fileadmin/templates/agphome/documents/Biodiversity-pollination/Climate_Pollination_17_web__2_.pdf).

Martin-Breen, P. & Anderies, J.M. 2011. *Resilience: a literature review.* New York, USA, The Rockefeller Foundation.

OECD. 2009. *Managing risk in agriculture: a holistic approach.* Paris.

Smit, B. & Wandel, J. 2006. Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, 16: 228–292.