CHAPTER ONE

Introducing resilience

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The power of the unexpected

It is a common experience that the best laid plans can be thwarted by unexpected events: events that alter the rate or direction of an expected path of development. Such events may originate from seemingly unrelated sources. Shutting down oil rigs on the US Gulf Coast in the wake of Hurricane Katrina in 2005 drives a spike in Mexican corn prices, which leads in turn to food riots (Zolli & Healy, 2012); a highly 'improbable' event such as the explosion at the Chernobyl nuclear plant changes lamb markets in Wales for over 20 years. Sometimes disruption arises from an apparently insignificant change in a system's internal processes; for example, a change in feed quality triggering financial losses on specialised livestock farms. In highly connected systems, unexpected events can have a range of negative consequences. In the case of agriculture, these consequences can be severe if certain limits or 'thresholds' are crossed.

Modern agriculture is part of a complex, global system of food production that is driven primarily by economic, environmental and socio-cultural forces largely outside of the control of farmers. These external forces have been responsible for most of the events that have triggered recent concerns over food security and the sustainability of current agricultural production systems. Volatility in commodity prices, extreme weather, unexpected policy or political change (e.g. the exit of the UK from the European Union), social unrest (e.g. concerns over immigration) all heighten uncertainty over the viability and future direction of agricultural production, practice and management. Such events can stimulate innovation in production methods, new technologies and products, but can also result in production failure, environmental degradation and land abandonment.

How then can we manage the impacts of the unexpected on agriculture and the wider food production system? Which systems are vulnerable and what can be done to buffer systems against negative outcomes? Such questions are the focus for studies of resilience, a topic that touches many areas of human life and which considers the ability of systems to persist in the face of uncertainty and change. In this book, we examine the concept of resilience with respect to the current and future functioning of agricultural systems.

The evolution of the resilience concept

The term 'resilience' is used in many disciplines including engineering, ecology, economics, psychology, international development and social sciences. It refers to the property of a system or a system state. The resilience concept has developed significantly since the mid-1990s (Folke, 2006), although its definition and interpretation varies between disciplines (Martin-Breen & Anderies, 2011).

Most frequently, a resilient system is described as one that 'returns to its reference state (or dynamic) after a temporary disturbance' (Grimm & Wissel, 1997). This definition, referred to as 'engineering' resilience (Holling & Gunderson, 2002), implies that a resilient system maintains a particular set of characteristics and conditions which together constitute the stable state for that system. If disturbed, the system may be moved away from this stable reference state, but will reliably return to it over time. An example of such a system is a pendulum on a clock, which fluctuates around a single stable equilibrium point. For 'engineering resilience' the time taken for the system to return to its stable reference state is the measure of the system's resilience (Folke, 2006).

The concept of the 'reference state' has prompted researchers to focus on equilibrium-based analyses to identify the conditions under which a system is stable (May, 1974). These analyses use differential or integral equations to determine the rate of system change in response to changing input conditions (Grimm & Calabrese, 2011). Such equilibrium-centred approaches are frequently used to identify the limits within which natural resources – fish, timber, grazing land – can be harvested without risk of significant system change or population collapse.

For ecologists, the concept of a reference state is challenging because ecological systems typically exist in a number of states and orientate around multiple equilibria (Hastings, 2013): for example, lands such as the semi-arid Chaco of western Argentina which consists of a mosaic of grassland, thorny scrub and open hardwood forest. In unmanaged semi-arid Chaco, the balance between these habitats is maintained by periodic wildfires which burn the accumulated biomass of litter and scrub and trigger the regeneration of grassland (Bucher, 1987; Cabido et al., 1994). This succession of grass, scrub and woodland can be viewed as a set of states through which the semi-arid Chaco system transits, the external agent – fire – disrupting the cycle but rejuvenating it by resetting it to an earlier state. Thus, within a specific area, the temporal and spatial pattern of the vegetation will change following a fire, but the overall composition and the relationships that determine system function can continue. There is no single equilibrium state for this ecosystem because the system is constantly changing.

Holling (1973) was the first to recognise the emergence of multi-stable states in ecological systems and their implications for ecosystem dynamics and natural resource management. He viewed ecosystems as complex adaptive systems with dynamics driven by non-linear processes (e.g. spatial heterogeneity) and feedback loops that allow the system to self-organise (Levin, 1998). Holling recognised that high variability was an essential attribute for maintaining system existence and that 'surprise and inherent unpredictability was the inevitable consequence for (the dynamics of) ecological systems' (Holling, 2003, reported in Folke, 2006). He further postulated that for ecosystems, persistence of relationships and entities and a capacity to absorb the effects of disturbance events were the defining features of resilience (Holling, 1973; Holling et al., 1995). This led to 'ecological resilience' being defined as 'the capacity of a system to absorb disturbance and reorganise while undergoing change so as to retain essentially the same function, structure, identity and feedbacks' (Walker et al., 2004). This definition suggests that after a disturbance, resilience should be viewed as a measure of the probability of system failure/extinction rather than as a measure of return time to a particular system state (Folke, 2006; Grimm & Calabrese, 2011). Crucially, in ecological systems, it is the identification of the range of conditions under which system relationships and functions can persist that is important, not the set of conditions needed for a system to remain within a particular or optimal state (see Martin, Chapter 13, for further discussion).

Ecological systems are dynamic evolving systems that have the capacity to adapt and change in response to fluctuations in their external environment. Ecological resilience recognises that a system can exist as a set of states; this set includes all the possible combinations of variables (initial conditions) from which the system can develop its characteristic form, function and relationships. The probability of a system developing its characteristic form is dependent on its initial condition, the stochasticity of the endogenous and exogenous variables driving change, and the frequency, extent and sequence of disturbance events during development (Walker et al., 2004).

Ecological resilience has been defined by some as a system's ability to buffer change; it is the loss of this buffering ability that leads to system change (Grimm & Calabrese, 2011). For example, the introduction of cattle grazing into Argentine semi-arid Chaco has been sufficient to tip significant areas of the system from a characteristic mosaic of grass, scrub and open woodland to a landscape dominated by thorny scrub (Cabido et al., 1994; Zak & Cabido, 2002). This scrubland system is resilient to grazing animals but has a considerably reduced biological diversity of plants, invertebrates and birds

(Gardner et al., 1995), a reminder that resilience is a property of both desirable and less-desirable states. System change is often triggered by what have been called 'slow variables', where change may accumulate gradually over time without any apparent change in system function until a single event abruptly pushes the system into another state (a so-called tipping point). The classic example is the switch from clear to turbid water in lakes (Folke et al., 2004). Focusing on the rate of change (fast and slow) and behaviour (instantaneous and cumulative response) of key system variables is important for understanding how systems self-organise and for identifying the conditions and drivers that may tip a system from one equilibrium state to another (O'Riordan & Lenton, 2013).

In considering the complex adaptive nature of ecological systems as multistate self-organising systems, Holling and Gunderson (2002) proposed the metaphor of the Adaptive Cycle as a generic mechanism for understanding changes in system resilience (Grimm & Calabrese, 2011). The Adaptive Cycle suggests that a system can pass through different phases of development, each of which is characterised by a unique combination of 'potential (capacity) for change and degree of connectedness between internal controlling variables and processes' (Holling & Gunderson, 2002). Four phases are proposed:

(1) a growth and exploitative *r* phase: characterised by rapid growth, expansion and colonisation of new areas; in ecological systems typified by the life-history strategies of small, fast-breeding species that colonise new areas via scramble competition (Begon & Mortimer, 1986);
(2) a conservation/maturation phase: characterised by the accumulation/acquisition of resources, consolidation of position often to achieve dominance or maintain competitiveness; typified in ecological systems by slow-growing species adapted for persistence and contest competition to maintain position, lock-up resources and displace competitors;
(3) a release phase: characterised by a disturbance/disruption and sudden release of resources; this phase may be triggered by natural disasters or disruptive agents such as pests, disease or human intervention; and
(4) a reorganisation: characterised by the emergence of pioneers, innovation, new approaches and restructuring to enable system renewal and adaptation to changed circumstances or the emergence of new directions for system development and transformation.

The metaphor of the Adaptive Cycle is important, as it reminds us that natural systems are dynamic, and that the nature of and capacity for resilience differs between different phases of system development. This variation in adaptive capacity suggests that there are many ways of developing resilience and that stand-alone, prescriptive, quick-fix solutions are unlikely to foster system resilience.

The concept of disturbance as a trigger for reorganisation highlights a further interpretation of resilience as a measure of a system's capacity to learn, innovate, adapt and transform (Folke, 2006). Faced with global challenges of climate change, human population growth, migration and economic globalisation, the ease with which ecological and human systems can adapt and transform themselves to different circumstances will be critical for their survival. In considering the nature of system change we need to remember that change can cascade across different scales and rapidly undermine the resilience of systems operating at levels below and above the origin of the disturbance factor. The interaction of conservation and pastoralism in the chapter by Homewood et al. (Chapter 9) is a good example of this.

Resilience is thus the capacity of a system, be it an individual, a farm, a forest, a city or an economy, to deal with change, to continue to develop and retain function. It is also about the capacity to use shocks and disturbances – such as a financial crisis or climate change-induced weather extremes – to encourage system renewal and innovation. Resilience thinking embraces learning, diversity and above all the belief that humans and nature are strongly coupled to the point that they should be conceived as one social–ecological system (Folke, 2006).

Why is resilience important now?

> In our fast-moving global economy . . . what matters most is not how successful a [system] is at present, but how resilient it will be facing future challenges.
>
> (Swanstrom, 2008)

It is pertinent to ask why this book is focusing on resilience rather than on the more widely discussed topics of sustainable agriculture and, more recently, sustainable intensification. Resilience recognises that change is inevitable and that systems such as human society and ecological systems are designed for change. They have change mechanisms built into them in the form of genetics, behaviour, social organisation, networks and learning. These systems are dynamic and are driven by feedback mechanisms that enable them to self-organise and adapt.

Resilience thinking has at its heart the requirement to maintain system function (Holling, 1973; Walker et al., 2004). In this respect, the outcome of resilience can be aligned with sustainability or sustainable development. In its most frequent formulation, the latter has been defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Bruntland Commission, 1987). In economic terms, Neumayer (2010) has argued that sustainable development is that which 'does not decrease the capacity to provide non-declining per capita utility for infinity'. Resilience, by focusing on the adaptive process, recognises that there are many potential approaches to maintaining system function. Not all of these approaches will be desirable or sustainable, and it is the role of the resource manager and policymaker to determine those that are. By providing an environment that facilitates the emergence of a variety of system approaches, however, resilience thinking can enable system function delivery to be maintained in the face of change through continuous system development, innovation or transformation (Folke, 2006, see also Harris et al., Chapter 14). Thus, the resilience concept offers important insights and tools in the quest for sustainability.

Sustainability is interpreted differently by economists and ecologists, a difference that has been explored fully by Neumayer (2010) using the concepts of 'Weak' and 'Strong' Sustainability. Neumayer characterises Weak Sustainability as the substitutability paradigm. Advocates of this paradigm assume that natural capital (natural resources) is either abundant or substitutable, and that a reduction in the stock of natural capital can be compensated for by increased availability of manufactured and/or human capital (knowledge, creativity and skills). The implication is that 'a rise in consumption can compensate future generations for a decline in the stock of renewable resources or a rise in pollution stock' (Neumayer, 2010). Strong Sustainability, on the other hand, considers natural capital to be non-substitutable by other forms of capital and requires losses in the stock of natural capital stock to be compensated for by adequate 'shadow projects' (Barbier et al., 1990); for example, a reduction in natural energy resources due to coal-mining could be compensated by investment in renewable energy projects. Building on this definition of Strong Sustainability, certain forms of natural capital can be considered critical such that their use should be constrained within the regenerative capacity of the existing stock (Daly, 1992); for example, balancing the rate of topsoil erosion against the rate of soil formation. In this way, the stock (and therefore its function) is maintained. One of the challenges for this 'balancing' approach is exactly the one raised in our discussion of resilience above: the occurrence of external 'shocks', e.g. flood, financial collapse, war, etc., which can unexpectedly 'tip' a system from one state to another.

Using the concept of the Adaptive Cycle, resilience thinking offers a number of insights and approaches that may help in the quest for sustainability. First, it reminds us that systems change, that change is rarely linear and that systems can occupy several different states. It also suggests that system collapse is to be expected and that change offers opportunities for system renewal, the recombination of structures and processes and the discovery of new development pathways delivering the same service but in different operating environments. During the process of change, systems may embrace new approaches and technologies (e.g. the use of batteries, computers and electricity to drive machines replacing petrol engines and mechanical control systems) or old 'technologies' can re-emerge as the true cost of their replacement is revealed (e.g. use of wild pollinators to pollinate crops: see Williams et al., Chapter 6). The Cycle highlights the fragility of large, highly connected systems, suggesting that there is a limit on the size and level of complexity that a system may sustain. An expectation of system collapse highlights a need to nurture learning, to encourage a diversity of approaches and to maintain capital reserves to draw on in the event of unexpected 'shocks'.

The nature of agriculture and resilience in agriculture

This book focuses on agriculture, a livelihood that has endured for millennia and one that is critical for human health, well-being and survival. While agriculture is most readily identified with food production, the practice of agriculture has consequences well beyond those of the supply of food. The establishment of farmed land was the catalyst for human settlement, the organisation of human societies and trade (Mazoyer & Roudart, 2006). Today, agriculture continues to supply resources to industries such as energy, textiles and clothing, medicine and health, leisure and tourism, as well as managing resources for industries such as water, waste management, heritage and nature conservation. In many cultures, the ownership of land and livestock are assets symbolic of status, influence and wealth (see Ewbank, Chapter 7, and Homewood, Chapter 9). Agriculture is also responsible for many of the negative externalities experienced by human society today: water pollution, land degradation, loss of biodiversity and enhanced greenhouse gas emissions, particularly from ruminant livestock and irrigated rice production systems. Such externalities are also the product of increasing societal demand for year-round supplies of high-quality, low-cost, global food products and of the search for more efficient ways of producing these goods (see Gardner, Chapter 2).

The success of agriculture is in large part still dependent on the natural resources available to it. These dictate the type of livelihood (e.g. pastoralist, cropping, mixed farming, intensive or extensive agriculture) and assets that can be established. Uncertainty surrounding the supply of natural resources such as pollinators, water and nutrients to agriculture coupled with volatility in food markets, environmental change and changing policy frameworks have increased the vulnerability of many producers to unexpected events. In this book, we consider the ability of agriculture to respond to unexpected change, focusing particularly on the role of ecosystem services and biodiversity in enabling agriculture to maintain, adapt and transform its outputs and production approaches in the face of environmental and economic uncertainty.

We first review the context within which agriculture operates, as part of the global food system, before exploring how this context influences the capacity of agricultural producers to adapt to change (Gardner, Chapter 2, and Hodge, Chapter 10). We then consider ways in which ecosystem services and biodiversity can enhance the resilience of agriculture, exploring their role in:

- buffering farms against environmental uncertainty (e.g. through soil conservation, limiting nutrient and water loss – Tilman, Chapter 3, Hails et al., Chapter 4, and Abson et al., Chapter 11);
- enhancing crop productivity and reducing production costs (e.g. through enhancing nutrient supply, soil quality, pollination and pest control – Tilman, Chapter 3 and Williams et al., Chapter 6),
- managing agricultural externalities (e.g. water pollution, greenhouse gas emissions, salinity – Hails et al., Chapter 4, and Harris et al., Chapter 14);
- enhancing the 'value' of agriculture through, for example, diversifying farm income streams and the provision of Public Goods (e.g. carbon management, wildlife conservation, aesthetic and cultural landscapes – Hails et al., Chapter 4, Drechsler & Wätzold, Chapter 12 and Buckwell, Chapter 15).

These roles are explored in the context of agricultural systems in both the developed (Gardner, Chapter 2; Ramsden & Gibbons, Chapter 5; Abson et al., Chapter 11; Harris et al., Chapter 14) and developing world (Ewbank, Chapter 7; Homewood et al., Chapter 9), in relation to biotechnology as a potential contributor to agricultural sustainability (Meyer, Chapter 8) and with respect to the management of agriculture and natural resources, particularly the relationship between efficiency, resilience and sustainability (Gardner, Chapter 2; Ramsden & Gibbons, Chapter 5; Hodge, Chapter 10; Harris et al., Chapter 14).

Finally, we consider how the contributions of biodiversity and ecosystem services to agriculture might be evaluated (Hails et al., Chapter 4; Hodge, Chapter 10; Harris et al., Chapter 14) and integrated into policies that encourage producers to build and retain resilience in their agricultural systems for future generations (Drechsler & Wätzold, Chapter 12; Martin, Chapter 13; Buckwell, Chapter 15; Fisher & Kareiva, Chapter 16).

The book is divided into two parts:

Part I considers the resilience of agriculture and agroecosystems and how biodiversity and ecosystem services might contribute to this resilience;

Part II examines approaches for integrating biodiversity and ecosystem services into agricultural systems and sets out some of the challenges facing producers and policymakers in fostering resilience in agricultural systems.

The concluding chapter draws together the lessons learned from the different economic and ecological approaches set out in the volume, highlights areas where the two disciplines can work together and indicates areas where research and policy development are needed to build agricultural resilience for the twenty-first century.

References

Barbier, E.B., Pearce, D.W. & Markandya, A. (1990). Environmental sustainability and cost–benefit analysis. *Environment and Planning A*, **22**(9), 1259–1266.

Begon, M. & Mortimer, M. (1986). *Population Ecology: a unified study of animals and plants*. 2nd edition. Oxford: Blackwell Scientific Publications.

Bruntland Commission (1987). *Our Common Future*. Oxford: Oxford University Press.

Bucher, E.H. (1987). Herbivory in arid and semi-arid regions of Argentina. *Revista Chilena de Historia Natural*, **60**, 265–273.

Cabido, M., Manzur, A., Carranza, L. & González Albarracín, C. (1994). La vegetación y el medio físico del Chaco Arido en la provincia de Córdoba, Argentina Central. *Phytocoenologia*, **24**, 423–460.

Daly, H.E. (1992). *Steady-state Economics*. 2nd edition with new essays. London: Earthscan.

Folke, C. (2006). Resilience: the emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, **16**, 253–267.

Folke, C., Carpenter, S., Walker, B. *et al.* (2004). Regime shifts, resilience and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution and Systematics*, **35**, 557–581.

Gardner, S.M., Cabido, M.R., Valladares, G.R. & Diaz, S. (1995). The influence of habitat structure on arthropod diversity in Argentine semi-arid Chaco forest. *Journal of Vegetation Science*, **6**(3), 349–356.

Grimm, V. & Calabrese, J.M. (2011). What is resilience? A short introduction. In: *Viability and Resilience of Complex Systems: concepts, methods and case studies from ecology and society*, edited by G. Deffuant & N. Gilbert. Berlin: Springer-Verlag, pp. 3–13.

Grimm, V. & Wissel, C. (1997). Babel, or the ecological stability discussions: an inventory and analysis of terminology and a guide for avoiding confusion. *Oecologia*, **109**, 323–334

Hastings, A. (2013). Multiple stable states and regime shifts in ecological systems. Mathematics TODAY, February 2013, 37–39.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, **4**, 1–23.

Holling, C.S. & Gunderson, L.H. (2002). Resilience and adaptive cycles. In: *Panarchy: understanding transformations in human and natural systems*, edited by L.H. Gunderson & C.S. Holling. Washington, DC: Island Press, pp. 25–62.

Holling, C.S., Schindler, D.W., Walker, B.H. & Roughgarden, J. (1995). Biodiversity in the functioning of ecosystems: an ecological primer and synthesis. In: *Biodiversity Loss: ecological and economic issues*, edited by C. Perrings, K.-G. Mäler, C. Folke, C.S. Holling & B.-O. Jansson. Cambridge: Cambridge University Press, pp. 44–83.

Levin, S.A. (1998). Ecosystems and the biosphere as complex adaptive systems. *Ecosystems*, **1**, 431–436.

Martin-Breen, P. & Anderies, J.M. (2011). *Resilience: a literature review*. Brighton: Institute of Development Studies, Bellagio Initiative, University of Sussex. http://opendocs.ids.ac.uk/opendocs/handle/123456789/3692

May, R.M. (1974). *Stability and complexity in model ecosystems*. Princeton, NJ: Princeton University Press.

Mazoyer, M. & Roudart, L. (2006). *A History of World Agriculture: from the Neolithic age to the current crisis*. London: Earthscan.

Neumayer, E. (2010). *Weak versus Strong Sustainability: exploring the limits of two opposing paradigms*. 3rd edition. Cheltenham: Edward Elgar Publishing Limited.

O'Riordan, T. & Lenton, T. (2013). *Addressing Tipping Points for a Precarious Future*. Oxford: Oxford University Press for the British Academy.

Swanstrom, T. (2008). *Regional Resilience: a critical examination of the ecological framework.* Working Paper No. 2008, 07. Berkeley, CA: Institute of Urban and Regional Development, University of California.

Walker, B., Holling, C.S., Carpenter, S.R. & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society*, **9**(2), 5.

Zak, M.R. & Cabido, M., (2002). Spatial patterns of the Chaco vegetation of central Argentina: integration of remote sensing and phytosociology. *Applied Vegetation Science*, **5**, 213–226.

Zolli, A. & Healy, A.M. (2012). *Resilience: why things bounce back*. London: Headline Publishing Group.