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Embracing complexity: the earth system, land and soil

If the old system is in its death-throes, where will we find principles for a new one?

What is positive is that systems have a certain capacity to self-organise. This does not of course mean we should sit back and abandon conscious action to create change. It does, however, mean that there is an objective organising force that we can work *with* while exercising our conscious interventions.

We have spoken of self-organisation, but how is this expressed in real terms? If we can answer this in relation to the land/soil, this would also be relevant in redesigning, through biomimicry, our built/urban systems.

Picturing a world of diversity and interaction

As we have argued, a change of farming model must be part of a broader paradigm-shift, a new way of thinking. In nature, everything is about interactions. The flourishing of a single butterfly species requires an interaction between four different biological realms (plants, animals, fungi and protozoa) (Tao, et al., 2015). The whole evolution of forests is driven by complex feedback relations between trees, fungi and bacteria (van der Heijden, et al., 2008). Huge new realms of bacterial life are now being discovered which cannot be studied in isolation because they do not exist in isolation, only in symbiosis with some other form of life (Hug, et al., 2016). Indeed, research now introduces the notion of a ‘hologenome’, the co-evolution of a host and its symbionts (Shapira, 2016).

Taking this to a conceptual level, ‘The richness of the world around us is due, in large part, to the miracle of self-organisation... We’re accustomed to thinking in terms of centralised control, clear chains of command, the straightforward logic of cause and effect. But in huge, interconnected systems, where every player ultimately affects every other, our standard ways of thinking fall apart’ (Strogatz, 2003, p.43). Complexity is the acting-together of the ‘bits’ of a system to create something which cannot be reduced to its parts, in that ‘... complex systems may produce emergent order... without a prescription for the pattern existing beforehand’ (Thelen, 1989, p.80). In such a system, Lucas observes, ‘We do not understand what will happen in any situation – only that something interesting will’ (Lucas, 2005).

This argument is connected in a deep way to Prigogine’s re-formulation of the entropy idea (c.f. Grant and Woods, 1995), in that we here see entropy not just as a principle of decay but rather as a stimulus to the self-organising loops which act to *overcome* that decay. As an example, at the level of a galaxy, supermassive black holes (though their internal entropy is high) serve as the force which regulates the entire creative process of self-organisation (c.f. Scharf, 2012). At the level of the earth system, the loops and flows which regulate fertility occur at an immense scale. Thus, the entire climate regime depends on the Amazon, but were the Amazon a closed system it would exhaust itself as rainwater washed away nutrients. It seems that these nutrients are replaced by dust blown in from elsewhere (current research is exploring how far this derives from the sediment of a dried-up prehistoric lake in Chad – Armitage, et al., 2015). Similarly, whales have played a crucial role in shifting huge quantities of phosphorus (an element crucial to plant growth) by feeding at the ocean floor and then defecating on the surface (Doughty, et al., 2015).

Let us now apply complexity perspectives more specifically to the soil. Darwin’s thinking was going in the direction of seeing the soil as the foundation for all of evolution, as he homed in on the role of earthworms in circulating nutrients (Darwin, 1881). It is interesting that after travelling the world he ended up in his garden watching worms and, in a sense, he was discovering something important about the systems perspective. Furthermore, worms are only a part of it. Today we also know more about the role of smaller organisms, fungi and bacteria, and more importantly the symbiotic networks – such as mycorrhizal filaments – linking them. Far removed from the paradigm of chemical reductionism, it is the interaction between the soil’s chemical, biological and mineral components which is key (Bourguignon and Bourguignon,

2008) and, arguably, the amazing complexity of the biological realm is the most remarkable feature. Fungi were probably the first life on land, and the whole of their existence is wrapped up in symbiosis: even a fungus itself is curiously an assemblage of cells containing many different kinds of DNA (University of Wisconsin-Madison, 2015). The first plants were algae that probably found themselves blown onto land and could only survive by co-operating with a strain of fungi to access minerals (Delaux, et al., 2015). Through these interactions, soil was created, which today includes 100,000 *named* species of fungi and at least ten times (maybe a hundred times) as many unnamed and largely unknown ones (University of Wisconsin-Madison, 2015). There is similar diversity among bacteria: a single gram of soil may include 20,000–40,000 *species* of bacteria, most of which have never been studied (Brussaard, et al., 1997, p.566). Not surprisingly, then, it has been said that ‘Soil ecosystems are probably the least understood of nature’s panoply of ecosystems . . .’ (McNeill and Winiwarter, 2004, p.1629).

The specificities of the belowground universe are firstly that, although similar to aboveground in the sense that all systems work on similar lines (nutrient loops, feedback etc.), we need a whole new science to understand it. Secondly, it is strongly differentiated from one locality to another. Thus, ‘patterns of aboveground and belowground diversity are governed by different mechanisms, which are also scale dependent: local soil biodiversity is strongly driven by spatial heterogeneity, and the diversity of microhabitats found within a single, three-dimensional soil profile *could be equivalent to that found aboveground within an entire ecosystem.*’ [our italics] (Bardgett and van der Putten, 2014, p.505). In turn, soil systems are deeply embedded in the feedbacks which regulate the earth system: a large study across European countries showed that, on the one hand, the soil-dwelling community itself needs to be studied as a whole system and, on the other, the functioning of this food web system within the soil is consistently related to ecosystem functioning on a large scale (de Vries, et al., 2013). In all this, issues of scale, spatial heterogeneity and ‘nestedness’ are central.

Truly to understand plants and the land, science must therefore develop new conceptual tools. This takes us back to earlier pioneers of holistic thinking, for example the notion of ‘communities’ in the work of Odum (Odum, 1969). Among more recent methodologies are ‘trait-based’ approaches (Martin and Isaac, 2015) where, in place of the old paradigm’s reductionist emphasis on *yield*, we now emphasise the long-term sustainability of crops, *measured by their interaction with the wider ecosystem*. The implications of trait-based approaches might, among

other things, go against monoculture, and more generally against productivism. Another useful concept is ‘ecosystem multifunctionality’ (EMF) which emphasises that even if we switch to organic methods – which is a necessary but not sufficient condition – this could fail if we neglect the wider ecosystem impact (Solon, 2015). What is interesting is the important role, within EMF, of the interaction between aboveground and belowground biodiversity...and the further interrelationship between this and climate (Jing, et al., 2015), the overall biodiversity of a system being strongly correlated to its resistance during, and resilience after, challenging climate events (Isbell, et al., 2015). Or again, we could add the notion of ‘adaptive mosaic’ (Millennium Ecosystem Assessment, 2005). All the above approaches combine to give some idea of a revolution in thinking, the necessary basis for any meaningful ‘new paradigm’.

Most obviously, we cannot ‘control’ a system of such complexity. This does not mean we cannot aspire to *understand* a complex system, or even influence it, but if we truly wish to, we must think in a different way: one where we do not imagine we can capture the truth by reducing systems to simple components, by assuming one-way chains of cause and effect, or by believing that one particular input (a gene, a chemical) determines everything.

A key feature is the range of processes *connecting* the different parts (this notion will be useful later when we refer to urban food systems, which comprise a mixture of social, biological and built-environment components). Such connections can be represented as networks, and they involve the exchange of information.

Thus, plants communicate through mycorrhizal filaments to trigger pre-emptive response to disease (Fleming, 2014). In an experiment, blight spores were sprayed on a tomato plant and then, after a pause, on a neighbouring plant; the second plant could fend off disease because it was forewarned, through a belowground symbiotic network of roots and fungal filaments, to activate defences (Song Yuanyuan, et al., 2010). Conversely, insects use plants and fungi to communicate. Thus, where plants release toxic defence mechanisms in response to belowground insects eating their roots, aboveground insects are forewarned by volatile chemicals signals, and even leave a ‘voicemail’ to the next generation, stored by modifying the chemistry of soil fungi (Netherlands Institute of Ecology, 2012). One key tool of evolution is immune systems, which are not merely defences ‘against’ the environment, but stimulated by it. Thus, as mycorrhizae establish themselves – that is to say, fungi colonise the roots of plants – this triggers a mild defence, like vaccination, to ‘prime’ plants’ immunity and thus improve resistance to subsequent

disease (Jung, et al., 2012). In all these ways there is a huge amount of information continually circulating, with which comes a risk of information overload, and an important area of research is to understand how plants discriminate between conflicting signals (University of Washington, 2015).

From this brief survey, we can draw two deductions.

- [1] The old paradigm blinded us to the obvious: farmed nature depends on unfarmed. When the FAO speaks of ‘sustainable intensification’, this means we cannot spread *extensively* by colonising more land, which would not only have an immense impact on climate, but would actually be counter-productive *for agriculture too*, by undermining the wider ecology on which it depends (c.f. Foley, et al., 2011). This is the issue which goes under the economics-speak term ‘ecosystem services’. There is more to this, however, than not extending the cultivated area. China for one has been forced to *retract* it, switching land away from cultivation in its ‘Grain for Green’ programme initiated in 1999, which has already shown remarkable results in increasing soil organic carbon (Song Xinzhang, et al., 2014).
- [2] The larger and more strategic point is that we should not simply see the preservation of ‘ecosystem services’ (i.e. complexity) as a constraint, but rather as an opportunity; not as simply an *external* condition for farming (supplying it with pollinators and natural predators etc.), but as something with profound implications for its *internal* mode of operation: an inspiration for how to learn from, embrace and integrate nature’s self-organising capacities. If we make the farmed environment work in harmony with, *and along the same lines as*, spontaneously evolved environments, a new era of sustainability will open up.

The rich potential of co-operation

A complexity approach in our understanding of physical systems also has implications for social systems: it implies something about rediscovering a principle of co-operativity among the many components of a society, and taking this as the basis for our new paradigm.

To create such a benign linkage between science and society, we must first be conscious of an existing *bad* linkage. The metaphors which have been chosen for science have political subtexts. For this reason, the

struggle to re-activate our holistic understanding of nature is somehow the same as that to reform the principles of social organisation.

When Darwin was grappling for a conceptual model, he read Malthus and something clicked. The factor he identified centres on the notion of 'struggle', of which there are in fact two forms (Bowler, 1976): between individuals of the same species, and between that species and its environment. The result of Darwin's borrowing led to a certain bias in evolutionary theory, overemphasising conflict at the expense of symbiosis. This undeniably chimed with capitalism's desire to destroy those lower-order movements and utopian socialists who advocated co-operation as an alternative to class rule.

Economic liberalism enters this story in a peculiar way. Malthus is close to Hobbes in interpreting the 'war of all against all' in a sense where the free flow of a system cannot possibly self-generate structure – hence Hobbes' obsession with a sovereign. Darwin on the other hand did (correctly) think that order could arise from a system itself, which is indeed the definition of 'emergence' in systems theory. Liberalism joined him in this but the key point is that both Darwinism and liberalism took a reductionist view, whereby the processes *generating* emergent order were essentially competitive: they therefore retained the 'war of all against all' but, unlike Hobbes and Malthus, it becomes a principle to create organisation, not destroy it.

Two further reductionist distortions were implied in liberalism: [a] the whole fabric of social interaction is reduced to one variable, market relations; [b] the specifically human dimension – intentionality, visioning a desired future, with all the socialistic resonances this may have – is outlawed: an important plank of liberal economics is that any conscious intervention to improve society will lead to a result worse than that generated by the free play of (competitive) market forces. In practice, however, the extremist leanings of these arguments were damped down under earlier forms of liberalism – which retained a certain social and managerial concern – and only burst through in their full horror with the triumph of neo-liberalism, circa 1980.

All these borrowings between science and economics resulted in another feedback loop: first evolutionary theory takes its central metaphor from a highly conservative politico-economic doctrine; → then capitalism (which is in reality killing nature) borrows arguments from this distorted view of nature to make *itself* seem natural; → then this ideological climate reinforces the metaphors of science, and so forth. Because science and society have been so closely intertwined in a bad way, this has the progressive potential that it is not really possible to

overturn the old paradigm in one area alone (science or society), without having repercussions for the other. For example, it is hard to think we could restore co-operation in society without also rediscovering a holistic attitude to nature. This is actually quite a strong reason why some hybrid definitions of agroecology-food sovereignty should be seen as an *intrinsically* unified movement for both organic farming and social change: for example, if we understand social co-operation we will have a better mind-set to understand the technicalities of agroforestry, and vice versa. Of course, from the indigenous/First Nations perspective, these categories are not really separate anyway.

Since the Malthusian strand is not just politically reactionary *but also bad science*, it is logical that a counterattack should come partly from within the scientific community itself and, for the same reasons, it is equally logical that this should carry progressive socio-political resonances too. In recent biological theory, the over-simplified and over-conflictual reading of Darwin has been typified by the work of Richard Dawkins who, while correctly arguing for a self-organising universe (Dawkins, 1988), propagated a reductionist emphasis on simple causation and competition, encapsulated in his notion of the 'selfish gene'. A critique of Dawkins therefore helped focus a push from the scientific community to rediscover complexity and holism, and has generated an important literature, including the work of Dennis Noble (Noble, 2006). A particularly useful statement is Brian Goodwin's advocacy of a perspective which 'shift[s] the metaphors that are used to understand evolutionary processes. In Darwinism... the metaphors are of competition and conflict and survival, and in Dawkins' writing it becomes embodied in the notion of selfish genes. Well, from the perspective of organisms as complex dynamic systems... what you find is that organisms are interacting with each other in all kinds of different ways. They are as co-operative as they are competitive... The whole metaphor of evolution, instead of being one of competition, conflict and survival, becomes one of creativity and transformation... ' (King, 1996). The *transformative* flavour of this is very much in the spirit developed by Prigogine and Stengers (1984), and the notion that the future is not 'given' (Prigogine, 2003).

Inevitably too, the self-correction of science spills over into a critique of Hobbesian-Malthusian-liberal distortions about social organisation. To reinforce this, let us take an example from an apparently social line of argument, namely Hardin's 'tragedy of the commons' thesis (Hardin, 1968), which could in a way be considered a social equivalent of Dawkins' selfish gene.

Although Hardin's paper is mostly a Malthusian diatribe on population, it makes use of the so-called prisoners' dilemma (PD) model to argue that collaborative efforts will be defeated because it is never possible to trust the other guy, and that actors who work in the common interest are penalised when free-riders grab the benefit of their actions without having to invest the effort. While nominally a social theory (with very strong pro-ruling-class implications of slandering common property regimes), this has implications for science and notably evolution...and has been refuted from within these fields. Thus, Martin Nowak theoretically demonstrates the possibility in biological systems of emergent co-operative behaviours, despite the PD argument (Nowak, 2006). This is confirmed experimentally in quite an interesting context: the *earliest* forms from which it is thought all life evolved already reveal a self-organisation or 'molecular ecology' (Attwater and Holliger, 2012). The research notably shows that 'mixtures of RNA fragments that self-assemble into self-replicating ribozymes spontaneously form cooperative catalytic cycles and networks' (Vaidya, et al., 2012) (RNA [Ribonucleic acid] is an important constituent – and arguably precursor – of life).

The point, I would argue, is not to attack Darwinism per se but to purge it of the 'junk DNA' which drifted into it from the socio-political context of his time. If 'complexity involves an interplay between cooperation and competition' (Baranger, n.d.), the point is not to exclude competition, but rather to recognise that *evolution tends to select for those organisms which are better co-operators*... for the simple reason that cooperativeness gives them an advantage to out-compete their narrowly competitive fellows! Thus, experimentally, 'When such cooperative networks are competed directly against selfish autocatalytic cycles, the former grow faster, indicating an intrinsic ability of RNA populations to evolve greater complexity through cooperation.' (Vaidya, et al., 2012). Similarly, in Noble's research, genes are selected for their ability to cooperate in the larger phenotype, within which each gene may in fact express many different functions according to context (Noble, 2006). Bacteria send out signals enabling the culture as a whole to adapt to its environment, and while (on the PD model) we could expect free-riders to use this information without wasting energy sending out signals themselves, it transpires that, although 'cheaters' are indeed thrown up by mutation, they are continually purged by natural selection. Groups of bacteria (themselves identical, but where the fringe layer is both more exposed to attack and has greater access to nutrients) develop a co-operative way of defending themselves against antibiotics, dubbed

'metabolic co-dependence', which includes an emergent oscillating behaviour which is in some sense a form of 'conflict resolution'. Such behaviour is both *logical*, in the sense that it can be modelled mathematically, and actually observable (Liu, et al., 2015). Bacteria employ the process of 'outer membrane exchange' in order to repair any of their associates who get damaged in some way: 'Social organisms benefit from group behaviours that endow favourable fitness consequences among kin.' (Vassallo, et al., 2015). This research is similarly crucial in understanding the transition to multi-cellular life, where 'Researchers are interested in how the evolutionary transition occurred toward multi-cellularity; that is, how cooperation develops and single cells are not just interested in themselves.' (Wall, 2015). This contrasts with '[T]he Darwinian view [where] each individual is out for themselves' (ibid.). Recent research explores the hypothesis that what drives diversification is *avoidance* of competition: different species evolve through remaining in proximity, occupying microhabitats within a similar niche (Gatti, 2016), a development which cannot be explained by competition. It is therefore not hard to see why, among animals, selection frequently operates in favour of conflict-managing behaviour and, interestingly, game-theoretical frameworks can again be applied in describing this (for examples, see Davis, 1983, pp.108–123, 135–145).

In all this, the point seems to be that somehow *conflict itself acts as a stimulus for co-operation* – in a similar way, we might say, to the sense in which entropy stimulates its opposite, complexity. The above argument will be important for our understanding of symbiosis in nature, from which we can learn as we develop the technical basis of a sustainable farming paradigm. However, we also need to look at the specifically human aspect.

The physical aspect of human evolution has been closely linked with social interaction. Thus, it is at least a plausible hypothesis that the size of the brain developed in association with the process of forming social networks (Dunbar, 1998) but it is not merely a question of the brain's size, because certain types of cell may play a role in social network formation (Coghlan, 2006). It is true that a specificity of human evolution has been that adaptation becomes more a matter of culture than of biology. But here too, we can see processes of conflict-management at work which are, in a way, an extension of conflict-control in the natural world, only now expressed in a cultural form. Conflict is wasteful, and human social systems have developed ways to resolve it (Suliman, 1999); this would apply equally to conflict within societies and between them. This whole argument is interesting in

critiquing the ‘war of all against all’ notion, in the sense that conflict is important precisely as a stimulus to overcoming it. Here, Barkun’s analogy between acephalic traditional societies (which lack a sovereign or head) and the international system (which similarly has no sovereign) is interesting (Barkun 1968).

In today’s dominant ideology, the linear/simplifying paradigm tries to dominate every sphere, whether we speak of farming or media. Hobbesian-Malthusian ideas are easy to project, and continue to serve, as they always have, to squeeze out any notion of a radical alternative future premised on association. When Wendy Barnaby began researching a book on ‘water wars’ and was surprised to discover that co-operative responses to water scarcity overwhelmingly outweigh conflictual responses, her publishers immediately withdrew their interest (Barnaby, 2009). Nevertheless, research increasingly reveals how crowds, far from ‘stampeding’ irrationally, tend to increase their co-operative and rational behaviour in situations of stress or danger (Bond, 2009). Many disasters are known to stimulate heroism and altruism, an argument developed in an interesting way by Rebecca Solnit (Winn, 2009). The 9/11 studies programme of the University of Delaware (Tierney, 2002) shows how not only did ordinary people respond in a constructive and rational spirit to catastrophe, but also that a significant aspect of the relief effort was spontaneously self-organised by them, in contrast to the failed, militaristic and top-down Federal Emergency Management Agency disaster response to Hurricane Katrina in New Orleans.

The ‘default mode’ – one might almost say ‘reflex’ – of humanity may therefore be much more collaborative than ruling discourses want us to think, and this could have important implications for future threats to food security. Of course, it is not just about reflexes, but about purposive visioning. And there is in fact an argument that this visioning faculty is similarly collaborative in essence: ‘the crucial difference between human cognition and that of other species is the ability to participate with others in collaborative activities with shared goals and intentions: shared intentionality’ (Tomasello, et al., 2005, p.1). The above connects us directly to socialism, as well to the co-operative principle with which it has intrinsically been linked, from the utopian socialists onwards.

This has something to do with the relationship between, on the one hand, people as *part* of nature and, on the other, people *reflecting and acting upon* nature. Consideration of this will be the topic of the next chapter.