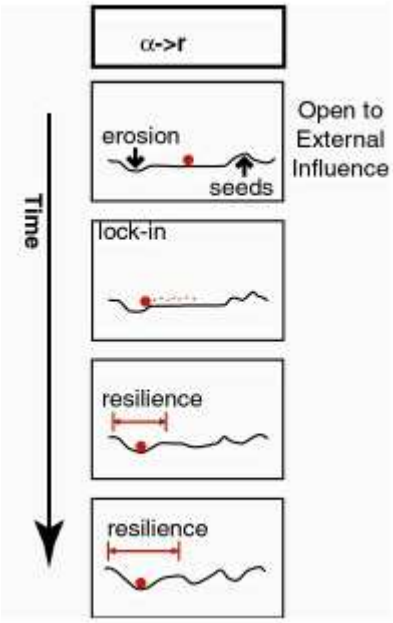
the Adaptive Cycle and Resilience

As the phases of the adaptive cycle proceed, a system's ecological resilience expands and contracts as key properties of the system slowly change.

alpha to r

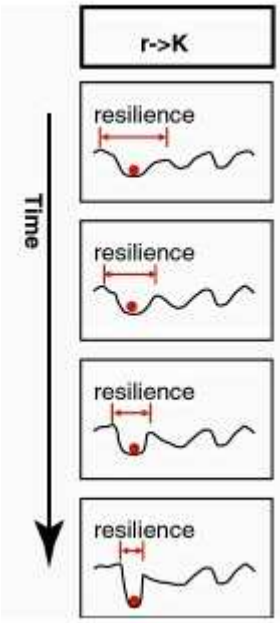


The alpha phase begins a process of reorganization to provide the potential for subsequent growth, resource accumulation and storage. At this stage, the ecological resilience is high as is the potential. There is a wide stability region with weak regulation around equilibria, low connectivity among variables and with a substantial amount of potential available for future development. Because of those features, it is a welcoming environment for experiments, for the appearance and initial establishment of entities that otherwise would be out-competed. As in good experiments, many will fail, but in the process, the survivors will accumulate the fruits of change.

But the same conditions of low connectivity results in the system becoming *open* or *leaky*. This openness is a signal of the Alpha phase. It was first demonstrated empirically by Bormann and Likens (1981) in the famous Hubbard Brook experiment. Various treatments of a small forested watershed in New England (e.g. tree removal, herbicide) mimicked a K to Omega event. The water flow from the watershed was monitored and showed a pulse of nutrient loss, that within weeks was slowed and stabilized as the ecosystem processes became reorganized. The same leaky phase has been described for semi-arid savannas subject to the persistent disturbance of sheep grazing. If that continues, as it can when ranchers have no viable economic alternative, the rangelands progressively and irreversibly erode into a shrub dominated semi- desert that is sustained by low levels grazing (Ludwig et al 1997).

Note that the Alpha phase is the condition for the greatest uncertainty- both the greatest chance of unexpected forms of renewal as well as unexpected crises. As we emphasize later, this is a key element in Nature Evolving- the condition where, momentarily, novel reassortments of species in ecosystems can invent new possibilities that are later tested.

r to K



In both the Alpha and r phases, the seeds from the past or from distant sources germinate, and surviving residual vegetation, previously suppressed, is released. The r phase becomes rapidly dominated by a thriving biota that is adapted to high variability of microclimate and extremes of soil conditions and can further occupy unexploited territory through effective dispersal. Because of these adaptations, resilience remains high. Similarly, it is a condition where, in the economy, the innovator sees unlimited opportunity. Or when producers of new products can aggressively capture shares in newly opened markets. Because connectedness is low, the entities are very much influenced by external variability. As a consequence, they have evolved or are selected from a pool that includes species and individuals adapted to dealing with the stresses and opportunities of a variable environment- the risk-takers, the pioneers, the opportunists.

A period of contest competition among entrepreneurial pioneers ensues. The ones fastest off the mark and most aggressive are the ones likely to persist. Aggressive invasive species start to sequester ecological space. Start-up organizations, whether in businesses, research or policy, initiate intense activity energized by the pioneer spirit and opened opportunity. Markets start

to become controlled by products once they exceed about 5% of the potential.

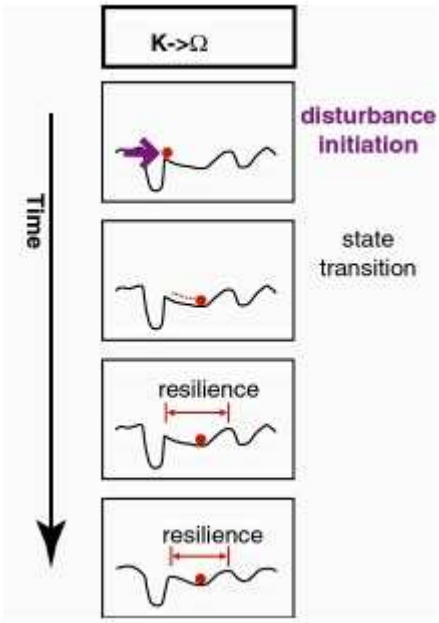
This starts a progression from r to K as the winners expand, grow and accumulate potential from capital. We use the term capital in the broadest sense, including, for example, carbon and nutrients for the biota, production and managerial skills for the entrepreneur and marketing skills and financial capital for the producer, and physical structure for all systems. Connectivity between related entities begins to increase because facilitation and contest competition inexorably increase as expansion continues. The future starts to be more predictable and less driven by uncertain forces outside the control of the system. Microclimatic variability becomes moderated by vegetation, soils improve, quality and quantity of supplies become more certain, the trust needed for effective cooperation increases and becomes more dependable. In short, the actors, whether species or people, develop systems of relationships that control external variability and by so doing reinforce their own expansion. That is, connectivity increases

Diversity of species, companies and products peaks just as intense competition and control begins to squeeze out those less able to adapt to the changing circumstances. It is during the intermediate stages of ecosystem succession, for example, that the greatest variety of species is found (Borman and Likens 1981). As the system evolves towards the conservation phase, K, connectivity among the flourishing survivors intensifies, and new entrants have increasing difficulty to enter existing markets. The future seems ever more certain and determined.

Since the competitive edge shifts from those that adapt to external variability and uncertainty (r-selected entities), to those that control variability (K-selected), more return is achieved by increasing efficiency for utilizing energy- from sun or fuels- of minimizing costs, of streamlining operations. At the extreme, this can result in increasing returns to scale, just as Arthur describes for some corporations and products (Arthur 1990), so much so that new entrants, new innovations, have reduced opportunity to enter irrespective of their potential superiority. In the forests of the south-eastern United States, for example, long-leafed pine have little chance of becoming dominant once the forest shifts to hardwoods, anymore than hardwoods have a chance once pine dominates. Both states are self-maintained. Hardwood, once abundant, shades out pine regeneration. Pine, once abundant, maintains a fire cycle that prevents hardwood regeneration. They represent different stable states for the same system.

Not only capital and connectivity changes in the progression to the conservation, K, phase. Ecological resilience also changes, but by decreasing, not increasing. The stability domains contract. That is, control of variability might be strong, but it operates over narrower, and more demanding, conditions. In the forest, fuel for fires and food for insect defoliators reach critical levels as processes that inhibit fire propagation (e.g. fire breaks) and insect population growth (e.g. avian predation) are homogenized and diluted. Markets for products can become saturated and profit margins can narrow, with little flexibility for further efficiency increases. Reduction in wages becomes a target for cost cutting, and the trust accumulated during growth is thereby weakened. Organizations can become bureaucratized and internally focused, losing sight of the world outside the organization. Those, of course are tendencies, whose inevitably depends on management and design. It is those exceptions that identify the limits to the heuristic presented to this point, and the possible features of human systems that can distinguish them from others

K to Omega

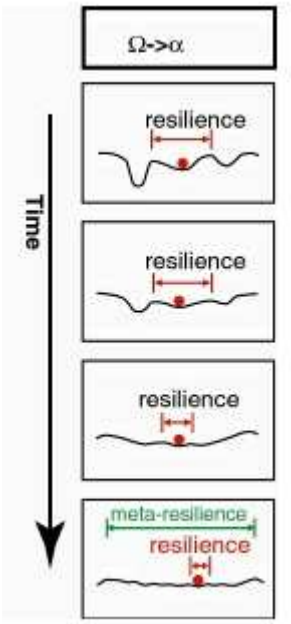


In the cases of extreme and growing rigidity, all become accidents waiting to happen. The triggering event may be entirely random and external - a transient drying spell for the forest, a new critic appointed to the Board of Directors of the company, an election of new Minister of Government responsible for the agency. We have seen examples of all in earlier case examples (Gunderson et al. 1995). Such events previously would cause scarcely a ripple, but now the structural vulnerability provokes a crisis and transformation, because ecological resilience is so low.

As a consequence the resulting Omega phase can release, in the words of the great economist Schumpater, a gale of creative destruction. Accumulated capital is released from its bound, sequestered and controlled state, connections are broken, and feedback regulatory controls weaken.

In the shift from K to Omega, strong destabilizing positive feedbacks develop between the revolting elements (the insect defoliator, the aroused stockholder) and the established aggregates (the trees in the mature forest, the bureaucracy of the firm). But that process is transient and only persists until the resources to do so are exhausted. Insect pests run out of food, and fire exhausts its fuel. Workers are fired in efforts to reduce costs and CEO's are fired to set the stage for restructuring. Potential plummets.

Omega to Alpha



If the progress from r to K represents a prolonged period during which short term predictability increases, the shift from Omega to Alpha represents a sudden explosive increase in uncertainty. It is the phase where conditions arise for formal chaotic behavior. The consequence of this alternation between long periods of somewhat predictable behavior and short ones of chaotic behavior results in systems periodically probing and testing limits. The process generates and maintains diversity, of, for example, species in ecosystems or functions in an organization. And that diversity "lies in waiting" to allow the system to respond adaptively to unexpected future external changes.

The capital remaining is that left over from what was accumulated in the mature forest or mature firm. It exists in a variety of forms: in the dead branches and tree trunks not consumed by fire or insects, in the nutrients released by decomposing organic material, in the seed banks established in soil, and in the animals and propagules that move over small and large distances. The capital has shifted from one of high potential in K, momentarily, to one of low potential where the residual capital is unavailable to or not actively involved in ecosystem growth or maintenance processes. The dead wood needs to decompose to become available. Nutrients released in the soil begin to leak away until soil processes of immobilization slow the loss and processes of soil mobilization begin to make it available for reestablishment. The forest is going through a reorganization, with weak interactions between elements.

The result is that the variables and actors have few resources and there is, momentarily, lower potential until the reorganization is consolidated and exploited. Species and individuals have loose connections to others and function in a wide, loosely regulated domain of stability as they progress to the phase of reorganization, Alpha. Resilience is high. The released capital begins to leak away, but the wide latitude and flexibility allowed variables and actors means that unpredictable associations can form, some of which have the possibility of nucleating a novel reorganization and renewal. This is the time when exotic species of plants and animals can invade and dominate future states, or when two or three entrepreneurs can meet and have the time and opportunity to turn a novel idea into action. It is the time when accidental

events can freeze the direction for the future.

Moreover, the totally unexpected associations and recombinations that are possible in the Alpha phase, make it impossible to predict which events in this phase will survive to control subsequent renewal. The phase becomes inherently unpredictable.

Similarly, some of the skills, experience and expertise lost by the individual firm remain in the region. They are not lost, but they exist only as a potential for future utilization in new or old enterprise. It takes time for the reorganizations to expose the potential in surviving capital.

The Alpha phase turns what might otherwise be a fixed, predictable progression or cycle into wonderfully unpredictable, uncertain options for the future. Controls over external variability are weak. Because of the weakness of connections, the potential capital now becomes more freely available, and the high resilience and low connectedness makes for random assortments among elements, some of which can nucleate unexpected processes of growth.

As an ecological example, when there was a massive planetary transformation during the retreat of the ice sheets 15,000 years ago, a protracted phase of Alpha conditions gradually shifted northward. Paleoecological reconstructions demonstrate that whole ecosystems did not move as integrated entities (Davis 1986). Rather, individuals species moved at their own rates to establish themselves where climatic and edaphic conditions made survival possible. Once established, novel associations became possible among previously separated species. Where chance compatibility existed, sustaining relationships then could develop among key species to form and re-enforce relationships that were mutually a re-enforcing. A self-organized system became possible. In summary, the major ecosystems we know now were nucleated as a mixture of independent species established in an Alpha phase of the adaptive cycle and consolidated during the r and following phases. Subsequent sequences of adaptive cycles then could establish stronger interactions among mutually supporting species in a process of competitive and synergistic sorting. That led to the development of self-organizing processes - of a mix of biotic interactions, like competition, facilitation, predation and herbivory and abiotic ones like fire and storm. The result is the ecosystems we now know of as boreal coniferous forests, temperate deciduous forests, grasslands and the like.

The adaptive cycle exhibits two different stages. The first, from r to K, is the slow, incremental phase of growth and accumulation. The other, from Omega to Alpha, is the rapid phase of reorganization leading to renewal. The first is predictable with higher degrees of certainty. The consequences of the second phase is unpredictable and highly uncertain. It is as if two separate objectives are functioning, but in sequence. The first maximizes production and accumulation; the second maximizes invention and re-assortment. We have no theorem to prove it, but our intuition suggests that any complex system, if it is adaptive, must generate these two phases in sequence, at some scale. The two objectives cannot be maximized simultaneously, only occur sequentially. And the success in achieving one, inexorably sets the stage for its opposite. The adaptive cycle therefore embraces the opposites of growth and stability on the one hand, change and variety on the other. Attempting to optimize around a single objective seems fundamentally impossible for adaptive cycles, although optimizing the context that allows such a dynamic might be possible. In that case, the nested cycles themselves become part of the machinery to probe and explore an adaptive landscape.

Very similar patterns of interactions, at landscape scales, have been discovered in a number of terrestrial and near terrestrial ecosystems-but not all ecosystems, as we will shortly note for pelagic and semi arid grasslands. Where the full cycle does operate, periodic flips from one state to another are mediated by changes in slow variables that suddenly trigger a fast variable response, or escape.

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Models

We do have a growing number of specific mathematical models that expose the specific non-linear processes that produce this behavior.Links to models page A simple Excel model of budworm and forest dynamics.

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