FINAL DRAFT

A Journey of Discovery

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It is now mid September 2006. I am writing in a sun-drenched room at our cottage in Ontario, thinking of the unrolling events of the last few months. It is a surprising time with some light events and some very dark ones.

For me, the light, bright events, come from the birth of twin grandsons, living on Vancouver Island. They turn my mind from the present dark colors of international and US politics and governance, and add balance in the promise youth opens for the future. And, on the same positive note, I have also met a large group of new and old friends, on two recent trips- one trip to South Africa and one to Montreal, where we met bubbling communities of people, young and old, experimenting in new options for interracial design and novel social and scientific experimentation. The collapse of apartheid in South Africa has slowly opened huge potential and hope. This is just the opposite of the public mood I see in the United States.

It stunned me to discover that major new centers, truly international in character, have emerged for resilience studies and policies- for the world's coral reefs in Australia, for climate change in the UK and for regional and global social and ecological systems in Sweden. And all this is apparently influenced deeply by the discoveries and experiments presented by my own work over the last decades. All that says the world is exuberantly healthy and productive. But there are other, very dark events.

In the United States, the mood and currents of thought and politics perceived among good friends at our main home in the small fishing village of Cedar Key, on the Gulf of Mexico is depressing. They are good friends, but now deeply pessimistic ones. The political situation in the United States is quite simply ugly. It is a time when the power of the state has achieved a rigidity unseen since the triumphs of the falling of the Berlin Wall. Politicians have reacted to extreme disturbances, like the appalling terrorist attacks of 9/11, with a powerful military response, a blind view of history and cultures, and a greedy desire for narrow benefit. Global economic expansion and dependence on peaking oil supplies, particularly in the Middle East, lock geopolitics into a self-destructive state, from which transformation is extraordinarily difficult.

It is the classically destructive phase of the mature part of an adaptive cycle. It is also potentially creative, because opportunities for innovative experiments and novel enterprises start to open at such times. It is a time of potentially creative destruction. And a recent mid term election in the United States in November 2006 at least hints at a shift into a renewal that requires deep changes nationally and internationally. Democracy is indeed a huge invention that stimulates assessment of a society and institutions whose leaders have become rigid and myopic. Democracy, at times, can trigger its renewal.

That is what I want to end up discussing here. But I want to get to that point by musing about the personal contributions I've made, my colleagues have made and our colleagues in science have at times questioned, at times supported. That is the true skepticism of science unfolding. At times it is turned over by truly novel discoveries- a kind of Kuhnian revolution of thought and approach. I think that transformation has happened, and I will describe my personal journey in science that, with other such journeys, contributed to the transformation.

Introduction

In May 2003, three graduate students from a mid-west university in the US, discovered that three of my papers were among the 13 most cited papers/books by authors in the journal Ecosystems 1998-2000. They asked me to comment on the papers- their origin, relevance and directions the field of ecosystem ecology might be headed.

Holling, C.S. 1973. Resilience and stability of ecological systems. Ann. Rev. of Ecol. and Syst. 4: 1-23.
Holling, C.S. 1986. The resilience of terrestrial ecosystems; local surprise and global change. In: W.C. Clark and R.E. Munn (eds.). Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, U.K. Chap. 10: 292-317.
Holling, C.S. 1992. Cross-scale morphology, geometry and dynamics of ecosystems. Ecological Monographs. 62(4):447-502.

Each of those papers was a synthesis paper about ecosystems and their components that was the culmination of several years of earlier work. And, in fact, there were two additional synthesis papers, one of which preceded these three, but with a focus on behavioral ecology, not ecosystems. And one of which followed them, and was the first step in integrating ecological and social systems, again not just ecosystems. Overall, the five papers represent a progression from experimental work seeking for high certainty about simple systems, to systems work of high uncertainty about complex systems. In the latter situation, the unknown is inevitable, methods need to accept that reality and the rules for simplifying are not traditional ones. In a way, the work progressed from a focus on understanding more and more about less and less, to learning less and less about more and more!

The earliest paper was:

Holling, C.S. 1965. The functional response of predators to prey density and its role in mimicry and population regulation. Mem. Ent. Soc. Can. 45: 1-60

It has been heavily referenced over the 41 years since it was published.

The other is much more recent:

Holling, C.S. , Lance H. Gunderson and Garry D. Peterson. 2002. Sustainability and Panarchies. In: Gunderson, Lance H. and C.S. Holling (eds), 2002. Panarchy: Understanding Transformations in Human and Ecological Systems. Island Press. Chapter 3, 63-102.

This last paper presents all I think I have learned over the years about the structure, function and history of ecosystems, social systems and the way they survive, evolve and succeed or fail. I have no idea how well that paper will affect the community of science or practice, but I am very happy with its content, although not with its style of writing.

I am writing now to give a personal view of what I believe I have discovered – my personal, explorers' guide of intellectual journeys that truly excited me when, as it seemed to me, wondrous new lands periodically suddenly emerged that no one had seen or remarked on before. For scientists, those are the times when a tsunami wave of excitement triggers a passion for discovery.

How it began

Let me start with the origins of the first paper the students discovered, that on Resilience. Since that paper really opened my eyes to the ecosystem scale, I'll then spend a bit more time referring to it, and how it originated.

That paper came from a series of earlier experimental studies and papers analyzing a particular process, predation. The goal was to see how far one could go by being precise, realistic, general and integrative. These are goals that normally are dealt with independently in at least partial isolation from each other in order to achieve useful and useable simplification. (The key, classic references are Holling, C.S. 1965. The functional response of predators to prey density and its role in mimicry and population regulation. Mem. Ent. Soc. Can. 45: 1-60 and Holling, C.S. 1966. The functional response of invertebrate predators to prey density. Mem. Ent. Soc. Can. 48: 1-86).

Those studies did well, and eventually led to a way to classify categories of predation into four types of functional response (how much they eat) and three types of numerical responses (how many there are). The categories and resulting simplified models seemed to apply to everything from bacteria foraging for food to submarines hunting ships! But none of that was ecosystem research. It was all traditionally experimental and analytical; but at least it was synthetic, non-linear and had great generality.

The key conclusion relevant for ecosystem science, was that it was possible to develop small suites of well tested realistic models and define a small number of general classes of responses for key population processes. The marvelous dean of ecology at that time, Bob Macarthur, wrote me at the time of the publication of the first Functional Response paper, arguing the work was too detailed and complex to be very useful for theory in ecology. That is true in a narrow sense, but he did not know that the paper was a planned step in a process that finally did yield less complex equations, but ones more complex than was traditional for the theory of the time. The "somewhat more complex", however, led to a world of differences in the behavior of systems, because of the non-linearities in the processes. And, most important, the equations representing the various classes of processes, were sufficiently realistic, something I thought then, and now know, was a central need for further development of theory for ecosystems. That was the first hint of the "Rule of Hand" – not too simple, not too complex- that was highlighted in the conclusions to the book Panarchy (Gunderson and Holling, 2002). That is, all that is needed is a handful of key variables. The classic "disc equation experiments" and paper launched the whole sequence that led, finally, to simpler mathematical representations that captured the essential reality that I thought was needed (Holling, 1959).

The same simple equation and experiments also became the foundation for the development of optimal foraging theory, when Eric Charnov joined my laboratory as a visiting student at the University of British Columbia. He accepted the basic construct of the disc equation, that the time available for a predator was divided into time spent in various categories of search, prey handling and digestive pauses. And I gave him the wonderful data I had collected from experiments with praying mantids, that he then used to show that optimality emerged in prey choices by predators. I never went in that direction myself, but many others have, and so a well tested theory of optimal foraging developed, launched from the infamous disc experiments and equation.

My interests were more focused on describing and integrating the components of behavior to add generality. That is what ended up in the Functional Response papers, where the effects of hunger, learning and avoidance were shown experimentally in a way that permitted expansion of the disc equation. Truly the work began to be applicable to predation by insects, birds, mammals and fish. As an example, one of my students even enjoyed himself in eastern Africa observing the distances of stalk and attack of lions attacking gazelles and wildebeests, He was in one vehicle filming the action as his wife did the same in a protective cage, some distance away. Binocular perception allows calculation of distances between predator and prey! It was a fine piece of work with as much a consequence for understanding the co-evolution of attack and escape strategies as for behavior. And there were a number of other such generalizing examples and tests.

It ended up being truly general, leading, ultimately, to the four basic types of functional responses and equations for them. It also became the point in the early 1960's, where I discovered the tremendous value of simulation models. The expression of the experimental results into a generalized model of predation, showed me how significant the new programming languages and computers were in explosively expanding our power of understanding. They made it more natural to represent non-linearities of various kinds. And projections of the results were dramatically easier.

But it became completely clear that some rigor had to be applied – don't try everything; just expand slowly on the basis of what we know. Then slowly add the partially known and unknown guesses, testing against the reality of whole systems behavior along the way. The work therefore avoided the tendencies that exploded in the International Biology Program of the time, where often more and more was expressed about more and more, in a way that smothered the work in over-complexity. A simple thread of modeling and investigation became much more powerful. Again, that was the discovery of the "Rule of Hand"—complex enough, but not too complex.

At this point two paths opened. One was marvelous work with various beasts to expand the behavioral discoveries. That was done with Larry Dill, a well known behavioral ecologist, who, in my view, is simply the best whole animal experimentalist in the world! He has developed elegant and insightful explorations of salmon and killer whales on the west coast, of archer fish and their aerial prey, of dolphins, dugongs and sharks in Shark Bay, Australia. We developed experiments with small fish reacting to barracuda and model predators, and to mock situations with an endless patterned belt that showed that their movement, once they were located on the edge of their "zone of fear", was dictated by the appearance of a corner- no corner on a belt, therefore no movement. Of mahimahi attacking prey, and of schooling and solitary fish in a Hawaiian oceanarium disturbing and reacting to potential predators. And on to ducks off the coast of British Columbia reacting to boats; and of school children in a field reacting to a runner as an aircraft filmed the interactions. And to flocking ibis in Florida sketching V's, W'S and Y's in the air as they flowed, almost with magic, from foraging grounds to nesting islands. Beautiful situations – not work at all, but full of the joys of understanding the patterns of life.

All showed the foundations we earlier had discovered. That is, there were general laws, expressible in general equations of fairly simple form that explained all the variants we observed and filmed, each as a limiting condition of a general equation. Moreover, we discovered that the rules were not precise and accurate, but rather were simple and just sufficient. In short, they were "quick and dirty" and were adaptive. Adaptive options are retained to correct a response if a mistake is made.

So we concluded that nature does not optimize for the "best" based on assumptions of complete knowledge, in the traditions of simple decision theory. Nor are its responses efficient. The actions were based on just sufficient information to assure adequately the object's fundamental nature and provide options for reversal- likely small enough to attack safely vs. likely big enough to avoid. That is all strictly the consequence of evolved responses. It has the same features that later characterized the tactics and goals of Adaptive Ecosystem Management that Carl Walters and I later developed for designing policies and responses for managing resources in ecosystems. The mistakes become possibilities for learning, not routes to failure. Larry and I began to write a book, but that book, partially done, still waits completion.

That was because another path began to swallow my attention. This path moved me into very new territory, that was truly ecological. By that I mean I began to recognize that the way organisms are affected by their environment is only half the story. The way that effect feeds back to affect the environment itself is the other half. That interaction creates new structures, some at one scale, some at others, and those create new options for evolutionary change. At what scales was that significant? Were all species interacting in important ways? Or were there a few that developed relations among themselves and their environment that created new entities upon which evolution and human management acted? All that was launched by my discovery, or invention of resilience.

Resilience

My bridge to studying ecosystems started once I shifted to combine the functional and numerical response equations with others concerning other processes in order to make a population model, of interacting predator and prey. That is when, suddenly and unexpectedly, multi-stable states appeared. Lovely indeed. Great fun and a big surprise to me! A new landscape for exploration opened.

Non-linear forms of the functional responses (e.g. the Type 3 S-shaped response) and of reproduction responses (e.g. the Allee effect) interacted to create two stable equilibria for interacting populations, with an enclosed stability domain around one of them. It was the responses at low densities that were critical- that is where vertebrate predators have yet to learn to locate the prey easily, and where mates are too scarce to find each other easily. Once discovered, it seemed obvious that conditions for multi-stable states were inevitable. And that, being inevitable, there were huge consequences for theory and for practice.

Up to that time, a concentration on a single equilibrium and assumptions of global stability had made ecology, as well as economics, focus on near equilibrium behavior, and on fixed carrying capacity with a goal of minimizing variability. Command and control was the policy for managing fish, fowl, trees, herds, and freedom was unlimited to provide opportunity for people.

The multi-stable state reality, in contrast, opened an entirely different direction that focused on behavior far from equilibrium and on stability boundaries. High variability, not low variability, became an attribute necessary to maintain existence and learning. Surprise and inherent unpredictability was the inevitable consequence for ecological systems. Data and understanding at low densities, rare because they are all the more difficult to obtain, were more important than those at high-density. I used the word resilience to represent this latter kind of stability

Hence the useful measure of resilience was the size of stability domains, or, more meaningfully, the amount of disturbance a system can take before its controls shift to another set of variables and relationships that dominate another stability region. And the relevant focus is not on constancy but on variability. Not on statistically easy collection and analysis of data but statistically difficult and unfamiliar ones. That needs a different eye to see and a different theory to perceive consequences.

About that time, I was invited to write a 1973 review article for the Annual Review of Ecology and Systematics. I therefore decided to turn it into a review of the two different ways of perceiving stability and in so doing highlight the significance for theory and for practice. That required finding additional rare field data in the literature that demonstrated flips of populations from one level or state to another, as well as describing the recently discovered known non-linearities in the processes that caused or inhibited the phenomenon. That was a big job and I recall days when I thought it was all bunk, and days when I believed it was all real. I finished the paper on a “good” day, when all seemed pretty clear. By then I guess I was convinced. The causal, process evidence was excellent, though the field evidence concerning population flips, was only suggestive. Nevertheless the consequences for theory and management were enormous. It implied that uncertainty was inevitable. And that ecosystems, in an evolutionary time span, were momentary entities pausing in a flip to different states. As I'll describe, it took about 30 years to confirm those conclusions for others.

This paper began to influence fields outside population/community ecology a bit - anthropology, political science, systems science first, then, later, ecosystem science. It became the theoretical foundation for active adaptive ecosystem management. But it was largely ignored or opposed by practitioners in the central body of ecology. What followed was the typical and necessary skepticism released by new ideas, that I'll describe briefly here because it is such a common foundation for developing science.

One early ecological response to the paper was by Sousa and Connell (1985). They asked the good question "was there empirical evidence for multi-stable states?". They attempted to answer by analyzing published data on time series of population changes of organisms to see if the variance suggested multi-stable behavior. They found no such evidence. This so reinforced the dominant population ecology single equilibrium paradigm, that the resilience concept was stopped dead, in that area of science.

It seemed to be an example of evidence that refuted this new theory. But their evidence was inappropriate and the theory was not! In fact, their evidence, as is often the case, was really a model, incomplete because the collators unconsciously used an inappropriate model for choosing data that were incomplete.

There are two problems with their analysis:

1) They did not ask any process question (are there common non-linear mechanisms that can produce the behavior?). That is where the good new hard evidence that I had discovered lay.

2) They rightly saw the need for long time series data on populations that had high resolution. As population/community ecologists of tradition, however, their view of time was a human view- decades were seen as being long. That view is reinforced by a "quadrat" mentality. Not only small in time, but small in spatial scale; and a theory limited to linear interactions between individuals in single species populations or between two species populations, all functioning at the same speed (e.g. predator/prey, competitors). It represents the dangers caused by inferring that "microcosm" thought and experiments have anything to contribute to the multiscale functioning of ecosystems. Steve Carpenter has a perceptive critique of that tendency (Carpenter, 1996).

The multi-stable behavior can only be interpreted within the context of at least three but, as suggested in the Panarchy paper/chapter, probably not more than five variables. These variables need to differ qualitatively in speed from each other. It is therefore inherently ecosystemic. It is the slow variables that determine how many years of data are needed for their kind of test. None of their examples had anywhere near the duration of temporal data needed.

As an example: The available 45 years of budworm population changes they analyzed seemed long to Sousa and Connell and to all those conditioned by single variable behavior and linear thinking of the times. But the relevant time scale for the multi-equilibrium behavior of budworm is set by their hosts, the trees or the slow variable. What is needed for their tests was yearly budworm data (the fast variable) over several generations of trees (the slow variable), i.e. perhaps one and a half centuries - not 45 years. The normal boom and bust cycle is 40-60 years

It has since taken 25 years of study of different ecosystems to develop data for appropriate tests. Examples include those using paleo-ecological data covering centuries at high resolution, the deep and shallow lake studies and experiments of Carpenter (Carpenter 2000) in the United States and of Scheffer, in Europe (Scheffer et al. 1993), the experimental manipulations of mammalian predator and prey systems in Australia and Africa by Tony Sinclair (Sinclair et al. 1990), and a variety of studies of specific ecosystems- sea urchin, coral reef etc. Terry Hughes and his colleagues' works on coral reefs stand out as examples. Carpenter's important summary paper makes the point (Carpenter, 2000).

Multi-stable states are real and of great importance, although they are difficult to demonstrate. Surprise, uncertainty and unpredictability are the inevitable result. Command and control management temporarily hides the costs, but the ultimate cost of surprises produced by managing systems that ignore multi-stable properties is too great. Active adaptive management as the only alternative management response possible. Steve Carpenter and Buz (W.A.) Brock- a great ecosystems scientist together with a wonderful "non-linear" economist- show why in a classic paper where a minimal model of a watershed, farming styles, of regional monitoring and regional decision regarding phosphate control, encounter the surprises created as a consequence of a multi-stable state (Carpenter, Brock, and Hanson, 1999).

Ecosystem Reality

The second paper the students identified was: Holling, C.S. 1986. The resilience of terrestrial ecosystems; local surprise and global change. In: W.C. Clark and R.E. Munn (eds.). Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, U.K. Chap. 10: 292-317.

For me, the 1973 "Resilience' paper launched the Adaptive Management work, with Carl Walters at the University of British Columbia- a great friend and a truly brilliant, maverick scientist who walks a non-traditional path that creates new traditions. His work on adaptive management methods has been a classic contribution to the field (Walters 1986). More recently he has advanced ecosystem dynamics understanding using his creation of foraging arena theory which had its beginnings in my own predation work (Walters and Martell 2004).

The resilience research led us to mobilize a series of studies of large scale ecosystems subject to management- terrestrial, fresh water and marine. All this was done with the key scientists and, in some cases, policy people who "owned " the systems and the data. So the process encouraged two major advances.

One advance developed a sequence of workshop techniques so that we could work with experts to develop alternative explanatory models and suggestive policies. We learned an immense amount from the first experiment. That focused on the beautiful Gulf Islands, an archipelago off the coast of Vancouver. We chose to develop a recreational land simulation of recreational property. I knew little about speculation, but we made up a marvelous scheme that used the predation equations as the foundation- the land of various classes were the “prey”, speculators were the “predators” and a highest bidder auction cleared the market each year. The equations were modifications of the general predation equations. The predictions were astonishingly effective and persisted so for at least a decade. As much as anything, it reinforced the earlier conclusion that these equations were powerful and general. But the important conclusion concerned the workshop process and the people.

The essence of those workshop methods were fun to present in a critical paper where the workshop processes were described and where key personalities were represented in delightful cartoons drawn by Roy Peterson, a cartoonist in Vancouver, and methods were expressed as a game. (Holling, C.S. and A.D. Chambers. 1973). It was fun to reveal the truth about characters like Snively Whiplash, The Blunt Scot, The Utopians and The Peerless Leaders and such in this way, but a reviewer in Ecology turned it down by saying “no one wants to know about the games people in British Columbia play!” Bioscience reviewers were more enlightened so I happily published there.

Those approaches helped shape the essential design and maintain the flexibility of the big international Resilience Project that I began about two decades later. It produces a turbulent, broad and delightful process of mutual discovery for those who chose to be part of it.

I learned that the key design was to identify large, unattainable goals that can be approached, but not achieved; ones that relate to fundamental values of free speech, freedom, equity, tolerance and education. And then to add a tough design for the first step, in a way that highlights or creates options to design, later, a second step—and then a third and so on. We found that the results were steps that rapidly covered more ground than could ever be designed at the start. At the heart, that is adaptive design, where the unknown is great, learning is continual and actions evolve.

The other advance provided a set of deep studies with modeling efforts, that could be used in a comparative analysis of ecosystems behavior and ecosystems management. Those examples included some 20-30 examples of crisis-ridden histories of forests, fisheries, agriculture, human diseases and water resource development. That is the part that particularly interested me.

One theoretical study suddenly helped significantly, when my eyes were opened to the essential way to understand and display the (relatively simple) causes of complex behavior (Ludwig, Jones and Holling, 1978). It was Don Ludwig and Dixon Jones who taught me the way, using the essence of qualitative differential equation theory.

It all started when Don took a half page I wrote explaining the essence of the causes of forest changes mediated by spruce budworm in eastern Canada. He then turned that into a coupled, three differential equation model that expressed the interacting dynamics of budworm, foliage and trees. Meanwhile Dixon, with help from Bill Clark and I, had been developing the big simulation model of the system that emerged out of a series of workshops with the scientists and policy people in New Brunswick. As part of our philosophy of economy in modeling, I had been careful to leave out the effects of avian predation, relying on an eventual check with measured behavior of the whole system in nature to tell us what essentials we had missed. When we discovered that the behavior of the simulation model simply did not match the field behavior, we used it and our ecological knowledge to discover the "missing process", as a kind of interactive, diagnostic procedure.

The missing piece turned out to be one with certain specific nonlinearities at low densities of budworm and low volume of foliage. The only process we could discover to fill the bill was predation by the 35 different species of insectivorous birds. That linked us back to my earlier set of predation discoveries and we added the effect using the predation equations and parameter data from the field. The effect added progressively stronger predation as budworm densities rose from low levels, and faded thereafter as budworm populations increased- that is, a domed shaped response. Since the densities of birds were essentially constant, that predation effect gradually weakened as the forest aged and the increasing volume of foliage dispersed the searching by birds. The result was periodic outbreak of the insect in older forests.

When these same bird predation effects were then added to Don's differential equations, that too began to reflect what occurred in nature. So it was a beautiful example of the power of linking three key methodological concepts; Don's qualitative differential equation approaches, Dixon's scientifically infused simulation modeling and my general process analysis modeling (Ludwig et al. 1978). The advance led to a clear way to understand and compare the 20-30 examples of complex ecosystem behavior in totally different kinds of situations (Holling, 1986).

The results appeared in the second paper discovered by the students i.e. in Holling 1986. It is a chapter in the first (and maybe only) significant book that deals with sustainability in a fundamental, interdisciplinary way. That book was Bill Clark's inspiration and creation. My chapter for the first time developed the theoretical discoveries emerging from the comparison of those ecosystem studies. Some of the key features of ecosystems popped out: e.g. there had to be at least three sets of variables, each operating at qualitatively different speeds. There was an essential interaction across scales in space and time covering at least three orders of magnitude. Non-linearities were essential. Multi-stable states were inevitable. Surprise was the consequence.

And a puzzle emerged concerning what seemed to be an inevitable pathology of resource management. In case after case, the same pattern appeared. An economic or social problem was identified as being present or looming in the near future. It was then narrowly defined and treated in a least cost manner for fast corrective response. Then, unknown to all, the system evolved.

First, the problem seemed to disappear. Budworm outbreak populations became controlled, forest fires were suppressed before spreading, water was stored and irrigation became possible for agriculture, fisheries were augmented with hatchery stocks, and so on. Second, industry expanded: pulp mills, tree harvesting, agriculture, fisheries and with that, regional economic and social development.

Third, slow, unappreciated changes occurred that meant that resilience was restricting, was declining. In most cases, the resilience declined because spatial heterogeneity shifted to a more homogeneous state. A "spark", once initiated, could therefore spread up scale. That is, conditions for outbreaks in healthy forests spread, forest stands became more homogeneous in age and became fuel rich, salt accumulated in soil as soil water levels rose, natural fish stocks gradually went extinct leaving fisheries precariously dependent on a few enhanced stocks. All became disastrous surprises waiting to happen.

Slowly decreasing resilience faced fast increasing economic and social dependencies that made retreat and redesign extremely difficult. Working with nature was rarely conceived. Instead, the response to correct the surprises, started or continued a sequence that maintained the evolving system with more and more costs. The classic example of that is the Everglades, which, after over 80 years of four crises, now is launched into an eight billion dollar restoration, with little active adaptive design. In contrast, the Columbia River system is deeply involved in a policy that indeed does exploit natural forces in an interesting adaptive scheme.

Other examples of “command and control”, of passive and active adaptation in regional social/ecological systems have been recently described in Olsson et al 2006, leading to a set of considerations and actions we identified for successful transformation toward adaptive governance,

This universal pattern represented one of the social traps later discovered as a potential for panarchies. Subsequent avoidance of the trap can occur through learning and actions to enhance resilience by reintroducing spatial heterogeneity at appropriate scales. But often the remedial responses simply continued and extended the process, protected by gradually increasing investments of money to monitor, subsidize and control.

And I used the paper to present the first big theoretical synthesis. That was the place where the “Adaptive Cycle” was first described and presented. That is, there are four components of change in ecosystems, the traditionally known and slowly evolving exploitation and conservation phases and the newer, fast, unpredictable creative destruction and renewal phases. The first two are when capital and skills are slowly accumulated, but resilience is typically gradually lost. The last two are when unpredictability explodes, capital is freed for other roles and novelty can become implanted. Moreover, those same four components seemed to provide a general metaphor for all systems, and examples were discussed from economics, technology, institutions and psychology. In fact, I discovered that the creative destruction phase had already been posited decades earlier by an economist, Schumpeter, for international businesses. Maybe economists were not all so narrow!

From Ecosystems and Economics to Social Systems

That was the foundation for another series of studies that finally led to an effort to collaborate with economists, ecologists, social scientists and mathematicians to develop an integrative theory and examples of systems change and evolution. The rationale was that the theories developed in each of those disciplines were not wrong, just incomplete in different ways. The results and the integration was presented in the “Panarchy “ book of the Resilience Project (Gunderson and Holling 2002). I tried to summarize my present understanding of complex adaptive systems in the first three chapters, and in the conclusions in Chapter 15. Perhaps those chapters, and the book, will eventually have the citations and influence of the three papers that were highlighted by the student's discovery of key Ecosystem references.

Writing the third, key chapter of theoretical synthesis, (Holling et al. 2002) was like a "mind dump"! I was happy with the content I wrote, but the style is very condensed, very dense. Some sentences could have been expanded to a few pages, some short paragraphs to a full chapter. But space was limiting.

As modest help, I also wrote an essential condensation of the book in Holling, 2001. And a more lightly written summary that expanded the work to its possible relevance to the big social and political changes that were set in motion after the terrorist attacks on September 11, 2001 (Holling 2004). I suggested it was the time for small scale abundant experiments in living, and working. It is a time when individuals have the greatest chances for influence, as resisting institutions weaken and fail. Do not develop an overall plan for those experiments, but set a tactical goal, which, in this case is novelty, safety and low cost. The invention of the internet offers explosive opportunity. Some fail, some succeed and that can provide seeds for subsequent healthy re-creation. That is a way for the trap, now global, to be transformed into something more positive for the future of people. There are ways out!

But maybe that alone is too naïve and hopeful. Consider the present moment.

I wrote the above paper one and a half years after 9/11. Now it has been five years. What has been unrolling is the same pathology as described earlier for the resource management pathologies. So far, the responses to terrorism have been largely quick and expensive military fixes and security checks, followed by quick successes. But the result has led political leaders to ignore the slowly enrolling causes, and long-term failure.

Therefore, in addition to a plethora of experiments, now it is clear we also need to attend the slow variables as well. We need responses to the slow, deep changes that have caused the explosion. It is not just evil loose in the world. There is humiliation, inequality and ignorance, combined with an exaggerated fixation on a particular extreme identity found in the fundamentalism of the religions of Abraham- of Christians, Muslims and Jews. That is a slow process to create; a slow process to redress. And all is made more rigid by the dependence of developed countries and of powerful ones on the oil of the Middle East. People seem locked into their personal, fear-ridden regimes that are self re-enforcing, creating differences between them, not bridging them: a deep, deep trap. Panarchy perhaps helps in providing a theory and contexts.

The essence of our conclusions to the Panarchy book occurred to me on a plane as I flew to a meeting with officers of a foundation that was new to me. I had to summarize, succinctly, the whole resilience project for them, and this became the way to do exactly that. There were, initially 12 conclusions- my 12 Commandments from the Resilience Mountain! But I do like those conclusions. They appear in Chapter 15 of the Panarchy book.

A broad, flexible and openly managed MacArthur Foundation grant made integrative work possible for that project. A marvelous group of people became the heart of the panarchy component - Buz Brock, Steve Carpenter, Carl Folke, Lance Gunderson, Don Ludwig, Lin Ostrom, Garry Peterson, Martin Scheffer, Brian Walker and Frances Westley. This is a mix that is strongly ecosystemic but also has powerful economic, social and mathematical science expertise.

One workshop was held in Zimbabwe at a moment in the nation's history where experiments were being tried and successfully implemented that shifted from disastrous drought-sensitive cattle ranching to larger spatial scale cooperative wildlife management and tourism. Ranchers learned to remove the barriers in their minds and the fences on their land. They learned to abandon the ideas of the past because there was literally no alternative- loans and insurance were impossible to get and savings had disappeared.

During that period, the government watched and security agents stalked. Ultimately the larger scale of federal government action destroyed the imaginative regional experiments on recovery. And now the country erodes and slowly collapses. It is truly destruction, without much sign, yet, of recovering creative destruction.

In that workshop, the economists proposed a specific route to theory expansion that seemed to me to be too limiting, too much a useful stretch for economics, but insufficient for our larger theme. So I encouraged two projects to emerge. One, (the economists') was called the theory project. It faced the difficulties presented by non-linearities in their models- an important step in itself. The second (the ecosystem/social) was therefore named the ante-theory project (or to some, caught by the humor of the situation, the "anti"- theory project). We could have attempted a synthesis at that time. But spawning two separate activities seemed to have a greater potential for discovery. That happened, but it was with something of a sacrifice in quickly joining ecology and economics. That still requires interesting further steps in order to achieve a deep and useful synthesis that might join ecosystem science, non-linear economics and social science.

That is all part of the penalty and opportunity in cross-disciplinary investigation among brilliant, accommodating but stubborn participants. In such cases, the best for the moment often is not to solve the problem, but just separate, encourage two streams, and continue to see what develops. I think we are still in that slow, but healthy process.

I got involved on the Science Boards of the Beijer Institute and Santa Fe Institute and a bit in Beijer's biodiversity project run by the economist Charles Perrings. Later I launched my own "Resilience Project", with Karl-Goran Maler and Carl Folke at Beijer that led in five years to well over 100 papers written by a wide disciplinary range of participants, that were published in specialist and interdisciplinary journals. We guessed that over 300 scholars became part of the sequence of workshops

In addition, a core part of the project was the design and preparation of four books. One was the integrative Panarchy book (Gunderson and Holling, 2001) that was meant to show what we developed to test and integrate the separate theories and knowledge in ecosystem science, economics and aspects of the social sciences.. The other books were designed to address separately the ecosystemic, social and economic dimensions of resilience. The ecosystem book focused on multi-stable states in large scale ecosystems (Gunderson and Pritchard, 2002). The social one was a lovely book on governance of and institutions for social-ecological systems (Berkes, Colding and Folke, 2003). The economic one concerned non-linear economics focused on renewable resource ecosystems (Dasgupta, P. and K.-G. Maler 2003).

Younger colleagues are now becoming the "engines" and spirit that are now taking over and driving the intellectual advances. I think in particular of Marty Andries, Graham Cumming, Line Gordon, Marco Janssen, Ann Kinzig, Jon Norberg, Per Olsson, and Garry Peterson. I have learned from each of them directly, and perhaps helped them, as well as from a bunch of others who are working closely with other folks who helped lead the Panarchy project.

Resilience and multi-stable states now seem to be pervading notable parts of ecosystem science and related social sciences, and even emerging in policy. Both features are affecting international policy of some nations. And I note in a bibliographic survey by Marco Janssen, that the original 1973 resilience paper has been a central reference that links vulnerability and resilience research. That is indeed pleasing since it took such a long time to happen. And it was delightful to have a major review paper on resilience appear in the same Annual Review series that my original paper did 31 years earlier (Folke et al 2004). Carl Folke made that happen!

Finally, among the emerging influential pieces, Martin Scheffer has a major book on the same subject in press with Princeton University. It was inspired by his own remarkable experimental demonstrations of ecosystem flips in shallow lake systems in Europe- the first experimental demonstrations of the reality of multi-stable states in ecosystems.

And Thomas Homer-Dixon's recent book (2006) on political change in a turbulent world, culminates with the significance of resilience and panarchy. He names it "The Upside of Down: Catastrophe, Creativity and the Renewal of Civilization". Now that is Panarchy! It is where crisis and opportunity merge in the affairs of man. It is a book that expands the theoretical and applied relevance to the profoundly important issues underlying international, religious and economic extremism of our times.

And recently I read the new book by Frances Westley and colleagues (2006), "Getting to Maybe"! The title is a take-off on the well known book on negotiation techniques, "Getting To Yes". But the work avoids the certainty of "Yes", replacing it with the realistic, evolving reality of useful "Maybe's". She describes the paths achieved by ordinary people designing mutual relationships and creating imaginative organizations at local, and regional scales. She describes the way to move to engage real politics. It is a deeply revealing book based in large measure on the complexity theories of Panarchy, and the practical experience of Frances, a very wise person!

Testing the Theory (or Testing Panarchy)

The third paper was Holling, C.S. 1992. Cross-scale morphology, geometry and dynamics of ecosystems. Ecological Monographs. 62(4):447-502. That paper was inspired by the paper just reviewed above. I designed it to be a test of the basic structure proposed. That is, that there are fast/slow dynamics and cross scale interactions occurring in a dynamic hierarchy. If so, then all ecosystems should be dominated by variables that cluster or lump around a small number of scales and frequencies. The original argument was that measurements of sets of any kind of data from an ecosystem would cluster into a small number of "lumps". The lumps would be shaped by breaks in the speeds and spatial scales of organizing variables across the Panarchy, and by the discontinuities inherent in the non-linear adaptive cycle.

The paper examines the most easily collected data I could think of - that is of the body mass weights of mammals and birds in different boreal latitude biomes- forest, prairie and marine. The test exceeded the capacity of any traditional statistical technique but the data did show clear indications of lumpiness. Moreover the lumpiness, at some scales, was unique to the ecosystem being sampled. Although the initial hypothesis was essentially that a landscape structure created the lumps, other hypotheses (e.g. founder effect, phylogeny, trophic size concentration) were proposed and tested. Only the landscape argument, or more accurately, the hierarchical/panarchical hypothesis, held up. The rest failed.

Fascinating relationships occurred when mammal body mass lumps were compared to those of birds, suggesting very different numbers of dimensions to their search- mammals as one dimensional searchers (they search a path!), birds as three (they search a volume!). A lot more testing is needed but the speculation is fascinating and fun. The causes of size dependent home range data of herbivores and carnivores suddenly became clear and coherent. The lump categories or lump patterns emerged as a signature of the structure of each ecosystem. I tend to see these as an analogue to spectral images characterizing chemical systems.

Later work by colleagues studying other ecosystems confirmed and extended the basic idea. Craig Allen has a big set of data from ecosystems around the world, all of which show the lumpy structure (Allen and Holling 2002). And his demonstration of body mass lumps in mammals, birds and reptiles of the Everglades also shows that the structure is very robust. That is, extinct species of one size are replaced by new species of similar sizes. Complex systems (as in the tropics) result in complex lump patterns (Carla Restrepo, in press), lumps suddenly add a cross scale dimension to the role of biodiversity (Peterson et al. 1998), the extinction of large mammals 11,000 years ago in the new world, was actually an extinction of lumps associated with transformation of coarse scale landscape (Lambert and Holling 1998). Havlicek and Carpenter (2001) examined their marvelous data from years of data collection in their experimental lakes areas in Wisconsin, and see the same lumpy structure and demonstrate that the structure is strongly conserved. Raffaelli (Raffaelli et al. 2000) shows littoral organisms are organized in body mass lumps in an experimental set up whose manipulations show strong persistence of the lump structure.

Craig Allen has become a leader in the field, and shows that there is an amazing correlation of separately measured attributes of species in ecosystems with the lump structure. Basically he demonstrates that invasive species, endangered species, migratory and nomadic ones strongly correlate with the edge of body mass clumps as separately measured. More broadly, he also demonstrates that population variability in both space and time is highest at these gaps (Allen et al. 1999 and Allen 2006). This high correlation consistently emerges from data obtained in different ecosystems from around the world.

Finally, the same lumpy structures are seen in social and economic data concerning city size and firm size (Bessey 2006, Garmestani et al 2005, 2006) and international gross domestic product (Rusty Pritchard, unpublished). Buz (W.A.) Brock, a well known economist who identifies non-linear attributes as central to economic behavior, hypothesizes that some aspects of economic growth theory suggest causes similar to those I have suggested for ecosystems. I suspect the same is true of the size of organizations. It will be interesting to test whether cities, organizations and economies on the edge of lumps, have the same features of living on the edge of crisis and opportunity as do organisms. If so, that would be extraordinarily significant for policies of development, whether for expansion of local business, regional settlement, or poverty alleviation.

It now seems that these intriguing discoveries have potentially big consequence for questions of change and transformation in any social or biological system. The breaks across scales create the conditions for endangerment, invasiveness and the other attributes mentioned above. In effect, such places are where novelty emerges in an interaction between crisis and opportunity. It is where novel changes can occur as an adaptive cycle starts to renew after a “creative destruction”.

I argue that those body mass breaks are caused by the scale breaks in a Panarchy, as adaptive cycles move from operating at one scale range to another. That is where resource variability and unpredictability is greatest. In a boreal forest, for example, the scales dominated by distinct processes range at least from centimeters and days at the scale of needles and their defoliators, through meters and decades at the scale of whole trees and patches, to 100's of meters and several decades for stands of even age trees, to, eventually, hundreds of kilometers and millennia for forest biomes. At each of those scale ranges, different processes dominate.

This generation of and entrainment of novelty creates options for systems, maintains the adaptive capacity of a system, and serves as a reservoir of potential functions that may be required following transformations or as normal system dynamics evolve. Such novelty is at the heart of resilience.

But there is skepticism, about lumps, at least. Manly (1996) showed that traditional conservative statistical techniques only identify at most two “lumps” in Holling’s data, where I identified 8 or more. Siemann and Brown say there are no lumps at all, although like Sousa and Connell earlier, they asked and tested entirely the wrong question. And so it goes-----

The fine physicist from the Santa Fe Institute, Murray Gell-Mann, suggested to me that I organize a meeting with supporters, skeptics and other experts, in order to review the whole argument and data. It is an example of the role such an integrative center like SFI can provide, and Craig Allen and I organized the session. The basic conclusion of most participants at the end of the meeting, was that the lumps were real, their number was certainly similar to the numbers I identified, their cause could be the one that I could not disprove, but that other causes might be involved as well. The participants, skeptics and supporters, agreed to test the idea further with entirely new data from new systems. Those new studies each confirmed and extended the discoveries and we have organized all of them in a new book manuscript. It is now in press (Allen and Holling 2007).

I liked the whole process and argument because it is the first time I could predict anything very rigorously- that is, “what are the likely endangered, invasive, nomadic species?”! According to Craig’s analysis, the only variables that correlate with endangerment and invasiveness are time of introduction and closeness of size to the body mass lump edge (Allen et al. 1999). All the other suggestions in the literature- such as size and trophic status, do not hold up as consistent predictors. I hope that work will continue and become generalized to other systems and to inexpensive ways to monitor existing systems.

But, if so, it will take years! The results of the work seem too different from our traditions in science and statistics, where uni-modal distributions, continuity and Type I error statistics have been the standards for simplification. None of those are appropriate for tests of lumpy, discontinuous or multi-modal distributions. The necessary art of simplification has a different foundation for this work than traditional ones. But it does open a terrific new landscape of thought for further discovery.

The start of that process began 18 years ago, and led to the paper that presents the test of the reality of the Panarchy/hierarchy conclusions (Holling 1992). Now it is clear that discontinuities in patterns and processes exist and they disrupt our ability to apply popular scaling models and approaches. Such scaling methods are powerful, and have shown that there is a template that organizes eco-physiological variables of organisms. But they are a first order result. The famous graph showing metabolism vs. size of mammals from bacteria to whales is a classic example. More recent work by West et al. (1999) has discovered the physical, fractal mechanisms that define the parameters of the relationship. Tasty, indeed!

But that is an explanation that focuses on the universal property of physical conditions that set the template. Biological and societal processes create the concentrations of opportunity along that template. That leads to the “lumpy” world representation that now has led to the new book demonstrating the existence of lumpy organization in a variety of ecosystems, in animal geographic ranges, in city sizes, migrating species, economic activities and firm sizes (Allen and Holling 2007). Note that although the evidence continues to grow, only a subset of ecosystem scale ecologists, social scientists and economists have accepted the theory and examples in a way to further test and expand theories of change. Lots of traditional ecologists are critical and do not understand the essential foundations in theory, empirical examples and societal examples.

That is because, historically, most natural scientists study systems that are manipulateable- that is, below the size of a quadrat in nature or a bench in the lab. That is how my own research started 50 years ago. That has exercised the traditional experimental scientific method with its testing of alternative hypotheses. But it does not sit comfortably with the uncertain reality of large-scale (regional to global) social/environmental systems where experiment comes only through adaptive experiments in combination with appropriately scaled policies and with alternate models of the system. That requires different, broader approaches and methods.

Diversity and Resilience

The three synthesis papers all converged on some observations and conclusions concerning how resilience, really robust resilience, arises from diversity. I had long shared most biologists' faith that the two were linked. But then, in contrast, I had also become convinced that the structure of ecosystems emerges from the effect of a handful of key processes and their few associated species. They create a self-organized entity. Were these few species not the central species whose function had to be preserved? Were not the rest simply those that existed in response to the basic structure provided by the key processes and species? Was the faith in the value of many species exclusively an, essential, but still purely aesthetic value? Another nice puzzle!

But the two values- one of aesthetics and one of structure and function- came together for me from discoveries presented in three additional papers. One was Holling, 1988. That work examined the impacts of the 35 species of insectivorous birds that set the essential 40-50 year boom and bust cycle of the spruce budworm and forest in New Brunswick. I used our budworm/forest simulation model to explore the significance over the full range of potential predation from nothing to maximal. Three distinct cycles appear – one around 15 years in length, one around 50 and one around 100 plus years. The first is set by foliage dynamics, the second by avian predation and the third by tree generation time. But I was surprised to discover that the 40-50 year cycle was maintained over a very large range of predator densities. The 35 species add robustness to that effect, operating consistently until the densities are lowered by more than 70%. Then the system flips into one or other of the other cycles. That is a demonstration of response diversity, something that Brian Walker also showed for plant functional types (Walker et al 1999). In both cases there is a lumpy structure – of mass for the birds and of biophysical measures of function for the plants. That is, plants and animals echo the same structure.

That is all brought together in a synthesis by Peterson et al. (1998) of alternative models for diversity and ecosystem behavior. It exposes, for the first time, the existence of two scales for diversity processes: diversity that affects resilience within a scale and diversity that affects resilience across scales. It is based on the recognition of lumpy attributes of ecosystem properties. In that paper, we show show the mechanism by which astonishing robustness occurs across scales because multiple species in a functional group (e.g. avian predators of spruce budworm) can substitute for one another in different climatic conditions and can spread their influence across scales in space because their differences in size are associated with different scales of movement. Hence there are two aspects of response diversity responses- within a scale and between scales.

What I learned of Organizations

I have been lucky enough, or inspired enough, or periodically unsettled enough to have worked in five organizations during their times of innovative inspiration, and two organizations as they wound down or consolidated. As much as any research, those experiences shaped my thoughts and sometimes actions about the inevitability of growth, collapse, novelty and renewal.

I learned an important organizational need during this time. Specifically, the more integrative demand required by studies of ecosystems, economies and societies needs integrative support that sees fundamentals in both theory and application. Early on that came from grants and enthusiasm provided by Evan Armstrong, an insightful leader in Canada's Dept of the Environment- a guy who was not a scientist at all, but was a manager and was, of all things, Assistant Deputy Minister of Finance. Integrative organizations then became the supporters of such work, as they began to emerge as a consequence of integrative methods begun during WW II. For me, the International Institute of Applied Systems Analysis provided an astonishing place, in its early years around 1972, to work with some of the best in different fields- George Dantzig in optimization, Howard Raiffa in decision theory, Tchalling Koopmans in economics, Mike Fiering in water/stochastic modeling, and Alex Basykin in mathematics. We all learned from each other as we tested the usefulness of novel methods for novel systems. Bill Clark and Dixon Jones were my partners in this and each has made huge contributions to related fields.

That experience became the opportunity for us to identify and then test the value of methods developed in other fields- particularly economics, operation research and decision theory. Our conclusions were presented in Clark et al. (1979). It was a huge step in understanding the strengths and limitations of familiar methods and of new methods from other fields. That effort and the experience at IIASA shaped our research and education activities for the next decade at least.

Later, the Beijer International Institute of Ecological Economics became the center of integrative work that much influenced me. Carl Folke and Karl-Goran Maler were the brilliant minds and designers of this remarkable institute. It became a truly integrative center for studies of excellence. And the Santa Fe Institute has had the same innovative, integrative role in the development of Complexity Theory.

That leads me to jump a bit to the future. The large influences of wonderful, integrative organizations like IIASA, Beijer and SFI, can come and go. They often become burdened by their success and rarely are able to maintain the same liveliness and novelty needed over time. Instead, the novelty develops in one place and then typically shifts elsewhere, expanding, extending, testing and deepening the work as it moves. The intellectual area or topic becomes the evolving entity, but often not the founding organization itself.

Still, IIASA, Beijer and SFI live on, and with the natural process of acquiring new leadership, they each can move to new phases of innovation. That is more likely if the design of the organization has a modest capital of structures bound up in it. If that is true, then the Beijer Institute, the least encumbered of these centers, promises a new phase of novel work. All the more so since I have just learned that the new Director chosen by a committee of the Royal Swedish Academy of Sciences is Carl Folke, a singular and wise man of great accomplishments!

For the same reason, the Internet perhaps also provides an alternative means to develop integrative and adaptive organizations at low cost. They could, perhaps, offer a more sustainable organizational partner to encourage novel, integrative research among groups. That is what led us to form the Resilience Alliance www.resalliance.org and the Internet journal Ecology and Society. The Alliance is formed by about 15 groups from around the world, people who all share the same enthusiasms and flexible desires for novel and relevant work. They each provide a modest annual membership fee to publish the journal and maintain the organization. Committed people, and grants do the rest. Integrative workshops interspersed with integrative research, integrative educational material and programs and novel modes of communication provide a foundation for both fundamental integrative science and policy research.

The Resilience Alliance has a very simple structure. It is our entry to the set of experiments needed to sustain innovation and excellence in a troubled world. There has been one very successful change in leadership when Brian Walker of Australia took over from me. He designed an essential and very significant phase of grounded testing of theory, and added new organizations and people. In the next couple of years he hopes for another shift in leadership and direction. Will the very busy folks involved find one person, or two, who can commit to that? We will see; I sure hope so.

What is this Panarchy Thing?

"Panarchy". That is an odd name, but one that is meant to capture the way living systems both persist and yet innovate. It shows how fast and slow, small and big events and processes can transform ecosystems and organisms through evolution, or can transform humans and their societies through learning, or the chance for learning. The central question is what allows rare transformation, not simply change.

I have discovered people have two distinct ways of perceiving change. Some see the world evolving in a regular, continuous way. Others, like me, see the world evolving in a spasmodic way- sudden change and slow, sometimes erratic responses after such changes. Both viewpoints are, in some sense true. They each give a different perception of changes and its causes. But their differences generate arguments. The same arguments are seen in other issues. For example, some argue that biological evolutionary change is not gradual but is "punctuated”. There is lots of evidence supporting that view, but because the fossil record is incomplete, the evidence is incomplete. As a consequence, one's philosophy dictates belief, so there is not a lot of consensus. There is a similar argument about the evolution of scientific knowledge between the gradualists like Popper, and the revolutionists like Thomas Kuhn. We saw the same difference in view among our good archaeologist friends.

Terrific to have these different views appearing in a way that permits some considered conversation. Now is the time!!!

The aspect of Panarchy that is most novel and significant concerns the phase when resisting institutions start to break down or transform, releasing the chance for a renewed system to emerge. At that moment, novelty that had been simmering in the background can emerge and be debated. And new associations begin to develop among previously separate innovations. The big influence comes from discoveries that, at that time, emerge from people's local experiments at small scales, discoveries that can emerge at times of big change, to trigger bigger changes at large scales. That process highlights the keys for the future.

One key is maybe best captured by the word "hope". I see hope might be emerging in the US from the results of the recent mid-term election in 2006. Certainly the results of that election have triggered a sudden storm of new and intelligent, but confused discussion. That is just what Panarchy predicts, and it certainly makes me suddenly a little more hopeful about our mid-term future.

The second key has to recognize that the small, that is the individual human, can at times transform the big, that is the politics and institutions of governance. But there are traps, and their potential needs some discussion.

The multi-authored book describing the integrative nature of Panarchy (Gunderson and Holling 2001) is partly a culmination of 50 years of my own research work, together with that of a fine group of friends and colleagues in the Resilience Project. During that project, my ideas expanded and grew as they interacted with the ideas of others- other ecologists, economists, social scientists and mathematicians- all co-authors of Panarchy. Some of those were senior and well established colleagues. Others were younger colleagues who became both the nurturers and nurtured in the work. It was a process of mutual, creative discovery that then turned personal for each of us.

For me, over those 50 years the old notion of stable ecological systems embedded in the equilibrium images of Lotka-Volterra equations, moved to that of resilience and multi-stable states (Holling 1973, Carpenter 2000), then to cycles of adaptive change where persistence and novelty entwined (Holling 1986), then to nested sets of such cycles in hierarchies of diversity covering centimeters to hundreds of kilometers, days to millennia (Holling 1992) and then to the transformations that can cascade up the scales with small fast events affecting big slow ones (Holling et al 2002) as acts of "revolution".

Jargon, yeah. So, Lance Gunderson, Garry Peterson and I said, why not go "whole hog" and invent the term "Panarchy" for the ideas, by drawing on the mischievous Greek God Pan, the paradoxical Spirit of Nature. Join Pan, then, to the dynamic reality of hierarchies across scales, where nature self-organizes lumps of living stuff on a more continuous physical template described by power laws. Physics defines the attributes of the power law. Biology self-organizes concentrations of opportunity and of species along the power law relation. Social dynamics does the same for social structures and organizations.

Part of that organization is maintained by diversity within a scale and across scales (Peterson et al 1998 and Walker et al 1999), a uniquely panarchical representation of the role of diversity in maintaining a sustainable system. For ecosystems and landscapes, all this is arranged over an interactive scale from centimeters and days to hundreds of kilometers and millennia. Nothing static- all components flipping from quiet to noise, from collapse to renewal. Transformation is not easy and gradual. It is tough and abrupt.

It seemed to become clear why and how persistence and extinction, growth and constancy, evolution and collapse entwined to form a panarchy of adaptive cycles across scales. Hierarchy and adaptive cycles can combine to make healthy systems over scales from the individual to the planet. Over days to centuries. The panarchy shows that we benefit from local inventions that create larger opportunity while being kept safe from those that destabilize because of their nature or excessive exuberance. When innovation occurs we can sense its fate. When collapse looms we can judge its likelihood. And the timing and kind of responses to this swinging, turbulent process can be designed as an act of strategic decision. Sustainability both conserves and creates. So does biological evolution.

But it can also build dependencies, some of which become pathological blocks to constructive change. They create traps, and those require the most searching investigation now.

Where Ideas Originate; What makes some useful?

I have been asked why I have so many novel, yet useful ideas, ones that eventually move to some kind of fruition, testing and, usually, after a very long time, acceptance. I do not really know, so what I write here is a guess.

I am prodigiously curious about nature, and that triggers initial ideas. I am also terribly persistent and stubborn about developing and testing an idea that grabs me; at those times I am totally and narrowly focused, driven by the potential. That is what eventually makes an idea useful. So I conclude that nature creates the idea; stubbornness makes it useful! But I have had to learn how to see nature. It is curiosity, anecdote, funny correlations, jokes and metaphors that have done that.

I enjoy communicating the excitement and the evolving stages of these ideas to others. And I like to discuss all this in classes with students, involving them directly in whatever research is most topical. That leads me to careful mentoring of some younger colleagues whose talents stand out. Earlier I mentioned a number of them.

I am delighted if others become interested and propose extensions or alternative explanations. I get profoundly upset if, at such times, someone says these suites of nascent ideas, or any one idea is wrong and that projects based on them should stop. I have got into big arguments with distinguished scholars over that one! In contrast, I see them as rich ways to explore the unknown; I see them as rich ways to develop friendships that endure.

Frances Westley once pointed out to me the three principal types of scientist she sees. Those are consolidators, technical talents, and artists. Consolidators accumulate and solidify advances and are deeply skeptical of ill formed and initial, hesitant steps. That can have great value at stages in a scientific cycle when rigorous efforts to establish the strength and value of an idea is central.

In contrast, I love those initial hesitant steps and like to see clusters of them. That is the kind of thing needed at the beginning of a cycle of scientific enquiry or even just before that. Such nascent, partially stumbling ideas, are the largely hidden source for the engine that eventually generates change in science. So I am not a particularly good consolidator.

I also am not a preeminently good technical person, though I do have sufficient technical experience to have developed considerable, well-grounded skepticism of the biases existing in traditional methods. I know some statistics, something about modeling, something about mathematics and a lot about biology. I enjoy integrating across all those talents.

But I love the nascent ideas, the sudden explosion of a new idea, the connections of the new idea with others. And I love the development and testing of the idea till it gets to the point it is convincing. That needs persistence to the level of stubbornness and I happily invest in that persistence. I guess I fit somewhat into the artist type, less the technical type and still less into an efficient consolidator.

As part of that kind of scientist, I have tried to develop senses that help me listen to intriguing voices that are hidden amongst the noise. Owlish ways to hear the rustle of the mouse. The simplest example of what I mean is in sculpting, another pleasure I have. I start with a number of hazy ideas, and then I discover the image caught and hidden in the swirls of the wood's grain. I listen to the voice of the wood.

My research has always been like that. In the early days of investigating predator/prey functional responses, the device that helped retain generalization was components analysis. It was a way to engage levels of complexity and maintain generality. It required a beast-for-the-moment design- the beast most appropriate for the step in hand. The result was many voices, each playing facets of one song. Praying mantis, insect parasitoids, deer mice and shrews, barracuda and iao, salmon, the suite of insectivorous birds in the boreal forest. Lions and gazelles. It was a way to listen to the hidden voice of nature. Those voices led to the discovery of resilience. Not a song but a symphony!

More recently, at last I heard the "world is lumpy" music that emerges from patterns in ecosystems at scales from centimeters to hundreds of kilometers, from days to millennia. And the approach used to examine the subtleties is a bit of strong inference, but more of adaptive inference and multiple lines of evidence- from every major biome in the world, from endangered and invasive species, from nomadic and sedentary organisms (Holling and Allen 2002). And beyond that, similar rhythms, once heard, seem to be in economic systems, social and behavioral.

Adaptive ecosystem management has been the same process. The workshops evolved to let human voices speak- scientist, scholar, and practitioner. I learned who they were, in heart and spirit, and each had a different contribution. The Peerless Leader learned the guiding melody. The Blunt Scot was on percussion. The Snively Whiplash provided the creative dissonance. The Utopian dreamed the impossible dreams. And the Compleat Amanuensis recorded it all. The Benevolent Despot hummed a lot. All these folks and the revealing workshop process and models are described in Holling and Chambers, 1973.

At this point, I am delighted with the results of some of my more recent inventions, which have been made with great help from colleagues of the international Resilience Alliance and the Internet journal Ecology and Society. I really do not know what the Alliance and its journal will become as they evolve. But basically right now they provide a foundation to develop devices to listen to the quiet voices of people- scientists and scholars of many stripes, practitioners, and for them to listen to each other. In universities, government, the public and the private sector. I wish in business as well. For the moment, it is people in the Netherlands, Sweden and the UK, in Spain and Malaysia, South America and Madagascar, Canada and Australia. In Africa. And not just in the US. We identify voices that have been masked by the noise, ones where novelty and experience combine. We are finding ways to have deliberative conversations among listeners.

Where to go Now?

I was surprised and delighted to learn during this year, 2006, that several organizations have recently been established with resilience as one of their primary themes. The most recent is a new Center on Resilience and Sustainability for Social/Ecological Systems in Sweden. It has just been formed by Stockholm University, the Beijer Institute and the Stockholm Environment Institute. It joins three other centers that have been recently established with resilience as their focus– for International Coral Reefs in Australia, for Climate Change at the University of Norwich, UK and, more loosely, for Parks, ecosystems and people in South Africa.

All have indicated programs for collaboration among the groups, and other members of the Resilience Alliance itself. That is all a very new acceleration of work on both the theories and practices of resilience. They are extraordinarily appropriate places for launching novel experiments, novel knowledge and novel actions at this time of international turmoil. They provide places that beautifully stimulate novelty and excellence across disciplines in a flexible atmosphere where discussion and debate periodically pace deep deliberative enquiry. The Internet can play a big role that creates an international place for such enquiries and debates. They are outstanding examples of the creation of integrative support for fundamental interdisciplinary study.

I started this paper with a good news report and a bad news one about events I now see locally, nationally and internationally.

Essentially I have learned that at such times I certainly do not try to solve the problems of the rigid or the collapsing system. Instead, I initiate a variety of experiments, mobilize my understanding, develop experiments, models and tests, and wait for an opportunity to emerge that might use the results. In our variety of regional studies that always happened. At that time a menu of possibilities then exist for renewing the system. And we hope that happens globally as well.

No one at this time of deep change should define the profile for the research that will grab the emerging systems in the world. Instead, it is precisely the time to ask what interests you? It is the time where individuals can have the greatest effect.

So, in closing, here is what interests me, one individual, now.

Social Traps: I'd sure like to learn more about different societal traps and why some are irreversible. We guessed at two in the Panarchy book's third chapter. One was a "poverty trap" where a society flips out of an adaptive cycle at a large political scale in a way that progressively triggers similar collapses at ever-smaller scales. Structure (organizations and institutions) is destroyed in the process, leaving the society finally as independent families separately struggling for survival, having lost their portion of the society's capital. Learning and self-help is minimal. We also posited a "rigidity trap", where wealth was great, resilience high and internal connectedness strong. That is the kind of hierarchist trap that freezes the adaptive cycle by ejecting dissidents and minimizing learning. I think of the fundamentalist religions as examples- dangerous examples. I know the healthy state for a society is one where there is a nested set of adaptive cycles; continually testing changed circumstances and adapting to them. But they can slip out of that sustaining state, into traps. Some of those traps are essentially irreversible. We need to learn more about them. We need more examples that demonstrate them. And we need to learn ways that can lead to ways out of them.

Social Adaptive Cycles: I'd also like to discover where and why some social systems- public organizations, private firms, regions, nations, international consortia- are much slower than ecosystems to break creatively and seem so much slower to transform into new structures with new opportunities. That often seemed to be the case for our case studies of regional public and political organizations, at least, where a market does not force change. And for national and international assemblages, think of the anthropological and modern examples- anarchy and the first World War, the Marshall Plan and its incredible success in facilitating recovery in Europe, and the fall of the Berlin Wall, which had mixed results we are still living with. Panarchy, resilience and the connections of memory and revolt between scales provide a new focus for this old question.

Living on the Edge: I am very interested to see tests that show whether cities, organizations and economies on the edge of social/economic/ecological lumps, have the same features of living on the edge of crisis and opportunity as do animals living on the edge of their body mass lumps. That is where the dynamic nature of panarchies starts to provide insights into constraints and opportunities for changes and transformations that can ride the natural forces.

A Panarchy Game: I would love to see collaboration between those who have developed panarchy thinking and those who are developing certain kinds of games. Will Wright, the 46-year-old creator of SimCity and the Sims, was an early one, and now has efforts that capture abilities to zoom in to the small and out to the large or into the fast and out to the slow. These are the games of the "Long Zoom and the Long Now" (Brand 1999) that are emerging independent of the kind or research that led to Panarchy. But it is driven by the same goals, the same fun, and the same intensity. The two need to be joined for a bump in innovation.

Globalizing Experiments: I'd also like to see more experiments on the Web and the internet, some in conjunction with occasional face to face meetings, some designing new ways to present educational programs, some using novel ways to display complex data or policies simply, some providing new ways to present and explore information, like Goggle's zooming earth data, some developing interactive games for regional and global social and ecosystemic designs, some presenting more Blogs, debates and discussions, some that use movies that express dynamic changes in an intelligible manner. We have done some of that- most notably by Garry Peterson for his Young Scholars Dialogues in Ecology and Society and his more recent Blogs in Ecology and Society and on the RA web page. We need more.

Self-organization Combining with Evolution: I'd like to support studies that explore how the link between self-organization of entities at different scales in the Panarchy link with natural selection to affect the speed and scale of evolutionary change. I believe that self-organization and natural selection jointly flourish and interact as a new way to view evolution, opening up another fruitful landscape for enquiry and theoretical development. In the sciences of biological evolution, that combination can often be viewed as either an obscure or an excessive representation! But it is suggestive and provocative, and that has particular value at times of deep change. It again opens a new landscape of thought for investigation and action from local, to regional to global scales. That is a big journey from its start, over 40 years ago, when I was immersed in lovely experiments of deep enquiry about praying mantids!

To conclude, I argue that we preeminently need novel integrative work. Specifically, novel work that integrates the economic and social with ecosystemically driven understanding. Multi-scale, searching for the relatively simple features of complex systems. Fundamentally non-linear. A testing of a range of methods and a disbelief in any of them. A wedding of theory, empirical examples and application. An emphasis on a search for generality, which needs cooperative works with others expert in other fields, but ones who share the curiosity and fun of mutual discovery. That is much more valuable, now, in this time of political turbulence and transformation in the world, than new policies and new planning exercises. They are too early, and too dangerous in their reliance on successes that worked for past problems. We now live in too new a world.

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This is but a sketch of a life. A sketch of a professional life. Behind its journey has been a family who have embraced, opposed and shared the unrolling events. Without them, I would not have dared and would not have imagined the wonders I found. Quite simply, my wife Ilse, my two sons Chris and Jamie and my daughter Nancy are a treasured part of this journey. They deserve a companion essay to show how much they have made the professional journey one of great joy and a sharing of different oceans, different ponds and lakes, different forests and mountains and different skies.

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