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The Invisible Wand: Adaptive Co-management as an Emergent Strategy in Complex Bio-economic Systems

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Table of Contents

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Abstract
This paper provides an economic perspective on concepts related to adaptive co-management (ACM). The discussion is cast within a formal generalised complex systems (CS) framework.

We explicitly explore the hypothesis of whether ACM can be regarded as an emergent strategy under specific conditions. The conditions draw a corollary from the well-known work of Adam Smith that describes 'self-interest' as a forcing factor (the 'invisible hand') that leads to stability and efficiency in economic systems. In our construct of a complex bio-economic system, we postulate that an 'altruistic common interest' can act as a forcing factor (our 'Invisible Wand') that leads to certain dominant emergent strategies that promote long-term sustainability and human well-being. One such strategy, we hypothesise, is ACM. A key question is whether ACM is something that simply evolves naturally from within a system or whether it is in fact a legitimate policy intervention that can be imposed or introduced from the outside.

The specific hypothesis is meant as an exploratory tool that permits us: (i) to develop in greater detail a formal definition of the elements of the system within a CS framework; (ii) to provide economic perspectives on the literature relating to ACM; (iii) to derive some related empirical lessons from that literature; (iv) to demonstrate the limitations of existing economic modelling and analytical constructs for addressing ACM issues; (v) to identify potential policy linkages; and (vi) to elaborate research implications.

We suggest that ACM frequently emerges naturally, and that policy should take a passive role; trying to 'introduce ACM' may in fact inherently undermine the policy's goals. This passive role should be to protect the conditions for emergence, or to remove barriers to emergence; among these conditions is preservation of social capital. Also, policy has a strong education and enabling function that we call dezombification. In this context, it implies that policies should attempt to introduce consciousness into the ACM regime. The consciousness and awareness revolve primarily around the fact that agents are working within a complex system, that they are capable of learning within that complex system, and that they can adapt their strategies as a result of such learning. Finally, these agents should be fully aware that they are capable of changing the rules of the system if necessary.

Authors’ Preface: On Being Economists in the Age of the Panarchy

‘Never before in the history of the world had such a mass of human beings moved and suffered together. It was the beginning of the rout of civilization.’

– H.G. Wells. On the Martian invasion of Earth.
The war of the worlds. 1898.

‘In the year 999 … buildings of every sort were suffered to fall into ruins. It was thought useless to repair them, when the end of the world was so near. Knights, citizens and serfs traveled eastward in company … looking with fearful eyes upon the sky.’

– Charles Mackay. Scottish historian.
Extraordinary popular delusions and the madness of crowds. 1852.

‘This world saw nothing in itself but chaos; it longed for order and hoped to find it in death.’

– Jules Michelet. French historian.
The year 1000 – History of France. 1844.

Welcome to the third millennium. It is 1 January 2001. Our calendar marks this quite simply; it reads: ‘Sundials are 4 minutes slow today.’ Such beautiful mechanical precision. It reminds us of how far our deterministic sciences have come in their powers of prediction, while also taunting us that we are not quite perfectly in step with the cosmos; time, somehow, continues to intrigue us and rule us. ‘Time is the fire in which we all burn.’

But it is a good time to reflect on our history. It is remarkable how frequently writers have predicted the collapse of civilisation. And equally remarkable is how humanity has always found a way to dodge the final death-blows. Doomsday descriptions of the Dark Ages around the year 1000 may paint a frightening scene, but most historians discount their accuracy. Times may have been bad, but the presumed hysteria was a fiction. That age still saw some of the most remarkable advancements of human endeavour. Mayan civilisation was at its peak. The Chinese perfected gunpowder. Dikes were first used to control massive flooding by the sea. Polynesia was being colonised. Literacy and numeracy were on the rise as modern musical notation was perfected and the use of the zero advanced scientific investigation. Not far into the second millennium – in 1090 – Eastern civilisation gave us the first reliable mechanical device for telling time: a water driven clock. Yes, times were bad for many. But somehow we muddled through them. Somehow, we adapted.

And how will history judge us today? As we turn the page in history, media reports besiege us with perplexing or confusing news. Climate change talks have collapsed. Eighty-six per cent of the world’s wealth is concentrated in the hands of 20% of its population. Coral reef die-off is becoming part of what we now call the sixth extinction. There are more wars raging on the planet today than at any other time in history. A leading contributor to death in one part of the world is over-eating while in another it is starvation; we can travel between these locations non-stop within a single day. The coelecanth – a 350 million-year-old fish species thought to be extinct – has been rediscovered. As of 24 December 2000, 283 potentially hazardous asteroids had been catalogued as being in near-earth or earth-crossing orbits. Half of the public medicare budgets in developed countries are spent on extending human life in these countries by about one month. The electronic information revolution is alive and well, but 91% of those connected to the Internet reside in OECD countries. Leading best-sellers in print include self-help books and ‘Dummies guides’. We are six billion souls, still muddling along. Somehow, we adapt.

But our sundial reminds us also that we are just hurtling around the sun, year after year, on what Carl Sagan called a ‘pale blue dot’. This pale blue dot is our home: planet earth. We have finally begun to realise that it, along with all of the animate and inanimate objects on it, are one vastly complex system. And as with any complex system, any part of that system can be just as complex as the whole. Much of this realisation has occurred, in historical terms, very recently. Within a period of a few decades, Apollo 8 has shown us our first earth-rise over the moon, Nicholas Georgescu-Roegen has given us mental images and discourse on Spaceship Earth, the concept of Gaia received some currency, and Benoit Mandelbrot has shown us the intricacies of complexity in what some call the thumb-print of God. We have all but forgotten the dark ages, the middle ages, the age of discovery, the scientific revolution and the industrial revolution. We are waist-deep in the post-modern information age and the age of convergence. Whither next? It might seem that we are at some historical bifurcation point. Pessimists will tell you that the Golden Age we now experience is on the verge of imploding. Optimists will tell you we are on the verge of a new renaissance.

And what might be the basis for this renaissance? It comes, essentially, from our realisation that we are part of a complex system. The methods of reductionist science have run into their inherent limitations and constraints. While such methods may work well for simple systems, they have generally been less successful at providing us with insights into how to design policies within complex interlinked systems. The economic, social and biophysical sciences have all developed substantially over the past centuries, but within each discipline, development has largely been in isolation of other scientific disciplines. Reductionist science has provided answers, but often not to the most pressing questions.

But this is now changing. The science of complexity is starting to make inroads into heretofore intractable problems, and it is breaking down conventional interdisciplinary barriers. We have entered the Age of the Panarchy. Panarchy is the term coined by Lance Gunderson and Buzz Holling (2001) to describe the adaptive, interactive and evolutionary characteristics of human and natural complex systems. A panarchy consists of nested system levels each with its own scale ranges in both time and space, and its own adaptive cycle of growth, accumulation, restructuring and renewal. The natural system levels of forests, rivers, etc., interact with the human system levels of governance, culture, etc., in unending adaptive cycles wherein novelty and change coexist with persistence and stability. The 'fast' cycles provide variability and novelty for experimentation and innovation; slower and larger cycles provide persistence and stability while accumulating and conserving successful experiments. The panarchy thus both creates and conserves because interactions among cycles combine learning (adaptation) with continuity. By understanding the different scales and their cycles, by understanding how knowledge and novelty is created and incorporated, it may be possible to identify points where human intervention can improve system resilience and sustainability.

The term panarchy is derived from the Greek myth of Pan, who was originally seen as the God of the forest but subsequently expanded more generally into the God of nature. Pan has a spirited personality; he is the root of the word 'panic'. He is both creative and destabilising, while also controlling and managerial. Hence, the image of Pan captures the synthesis that has emerged in the union of ecological, economic and social systems. Pan is the force of nature, personified. Panarchy is the complex system in which nature interacts with its human element.

Being economists in this age of the panarchy is both a privilege and a challenge. We must eschew many of the methods that we have used for dealing with small-scale local issues, while developing new theories, methods and prescripts that are relevant to larger-scale problems. For many of the new challenges in this age of the panarchy relate in one way or another to *scale*. System complexities often become most problematic when the scales of observation, analysis or management differ from those to which we are accustomed. Neo-classical economic thought has excelled at dealing with problems at small temporal or spatial scales, so long as the *ceteris paribus* ('all other things equal') assumptions have held true. But over longer time periods, over larger spatial scales, within complex systems, such *ceteris paribus* assumptions are nonsense. The house of cards that consists of the conventional models and prescripts thus falls in light of such challenges.

In writing this paper, we set out initially to provide an 'economist's perspective on the use of adaptive co-management (ACM) in forest ecosystems'. This was driven by the Center for International Forestry's (CIFOR) research programme to assess the utility of ACM as a means to achieving human well-being and ecosystem sustainability. We undertook to do this with a view to examining how the lessons from economics can shed light on the potential role of ACM within forest management. While at the outset it is tempting to stick to fairly reductionist conventions by, for example, looking at lessons from forestry economics, environmental economics, agricultural economics and institutional economics, etc., it became clear that many of these disciplines were already starting to meld. More significantly, many of them were being subsumed by broader areas of scientific investigation that, traditionally, had very few connections to the discipline of economics.

A decade ago, the thought of conducting meaningful, interdisciplinary research was just a twinkle in our eyes. Today, it is becoming a reality. Recent serious texts and efforts are now addressing interdisciplinary social, economic, ecological and institutional issues. Conservation ecology has provided us with the concepts of *panarchy* and related this to the importance of *scale* within various areas of analysis and policy support. Ecological economics has taken prescripts from neo-classical environmental economics and extended these to permit broader investigations of humans as part of the ecosystem: from it we now have the term *Homo sustinens*. Interdisciplinary teams of social, economic and ecological scientists have formed a collaboration calling itself the Resilience Alliance; it focuses on the role of resilience and adaptation as important factors in achieving and defining sustainability. Finally, management science has recently received a significant boost from the insights of the BACH group[1] at the University of Michigan, which has built on the path-breaking work of the Sante Fe Institute in complex systems science. What all of these efforts have in common is that they are all firmly entrenched within a complex systems framework of thinking (see Box 1).

Box 1. A Crash Course on Complex Systems

For those not familiar with complex systems, or wanting an up-to-date primer on such systems, we recommend:

Resilience Alliance (Inaugurated October 1999). An international consortium of 15 research groups. The goal of the RA is to create in practice ecological resilience and social flexibility, thereby building adaptive capacity in ecological-economic-social systems. The RA grew from the 'Resilience Project', launched in 1997 by an international group of ecologists, economists, social scientists, and mathematicians, to develop and test a theoretical foundation for the integration of ecological and economic theory, with institutional and evolutionary theory. Published in October 2001 is the RA's first book; *Panarchy: Understanding transformations in human and natural systems*, edited by L Gunderson and C.S. Holling, Other Project output is at the RA website. http://www.resalliance.org

Conservation Ecology (Vol. 1 1997). The electronic journal of the RA with a goal to develop interactive communities while contributing to the areas of fundamental science and policy. To that end, diversity is sought through research articles that are international, inter-disciplinary, inter-sectoral, or inter-organizational in content. Articles explicitly addressing complexity issues are found in December 1999 Vol. 3 Issue 2 and December 2000 Vol. 4 Issue 2. http://www.consecol.org

Ecological Economics (Vol. 1 1989). Trans-disciplinary journal of the International Society of Ecological Economics to advance the field of ecological economics. Articles address relationships between ecosystems and economic systems. The Society encourages work that integrates and synthesizes different disciplinary perspectives. December 2000 Vol. 35 Issue 3 provides a special issue entitled *The human actor in ecological-economic models* that addresses issues relevant to adaptive management in complex systems. http://www.ecologicaleconomics.org

Axelrod, R. and Cohen, M. *Harnessing complexity* (1999). Inspired by the work of the BACH research group at the University of Michigan; written by a professor of Political Science and Public Policy (Axelrod), and a professor of Information and Public Policy (Cohen). The book provides a descriptive framework to demonstrate how complex adaptive systems research is relevant to social design problems. Practical insights to complex system dynamics are drawn from evolutionary biology, computer science, and social design.

Waldrop, M. *Complexity: The emerging science at the edge of order and chaos* (1992). Waldrop holds a doctorate in elementary particle physics. His book documents the intellectual environment during the mid-1980s at the Santa Fe Institute where complexity emerged as an alternative to linear, reductionist thinking. Students and renowned professors from various disciplines worked through the Institute to develop what they believed would be the sciences of the 21st century.

Although we continue to take our role as economists seriously, we also take pleasure in being able to dabble now in other disciplines. The disciplinary boundaries are becoming blurred. Our role has shifted somewhat. In addition to contributing to the interdisciplinary science, we must also interpret the results of this science and find ways to apply it within our current world. Many parts of this current world remain very much a product of policies and interventions that are based on 'non-systems thinking'. Reforming these policies may yet prove to be our greatest challenge.

We thus approach this paper with a very practical viewpoint in mind. We essentially ask the question: are economic policy reforms that promote ACM feasible or desirable? If so, how should they be implemented?

We take a systems approach to the problem, defining the various aspects of the problem within a complex systems context. The nomenclature we adopt follows closely that employed by the BACH group, as we also will draw important parallels between general complex systems thinking and ACM. One of these, for example, deals with the redundancy of subsystems. Another deals with the timing of interventions.

We introduce a strong historical flavour to this paper. We do this for two reasons. First, we believe that the concept of temporal scales in evolutionary systems is far too often neglected; basically, policy-makers are impatient and often seek a quick fix when things may be better left to themselves. Second, from purely a historical perspective, we think that the writings of some of the earliest economists bear revisiting. With due respect to the current generation of economists, we may have more to learn from the dead economists than we might think. A key question we ask is whether ACM can be regarded as a naturally emergent, collective strategy within a typical evolutionary context. If it is, then very little explicit policy intervention may be necessary.

We believe this is a non-trivial issue and one that is likely to receive increased attention. It hearkens to the debates that we have seen over the past century that revolve around the more general need for public policy intervention. Economic science has strong foundations in the strength of Adam Smith's 'invisible hand,' from which efficient markets emerge simply by relying on the presumption that each individual acts in their own self-interest. If, however, various factors within a large-scale, evolving complex system will naturally give rise to ACM structures, then it may do more harm than good to try to introduce such structures explicitly. On the surface this may seem like a scary thought, and we may stand accused of being simply a new variety of *laissez-faire* economists, with blind faith in the system to self-correct in the face of some pending calamity. But our faith is not blind: we ask the same questions that economists have asked of regular short-term market forces. Specifically, we ask whether any particular government, decision-maker or policy-maker indeed can have the foresight or wisdom to know how best to introduce such ACM methods. Complex system theorists call such a controlling entity a *designer*. In the end, we have no answers to this problem, yet. But we can draw some insights from when policy interventions seem to have worked, or not.

In many of these perspectives, a few parts of systems thinking become clear. One is that all such policy interventions are experimental learning processes and that mistakes happen. Shortsighted, static optimisation is a concept of yesteryear. Surprises happen. Scale matters.

After considering the possible general ramifications of systems thinking, we therefore do delve into the various 'economic lessons' that might be drawn from the literature. These lessons relate to issues such as social learning, devolution and collaboration. We should underline at this juncture that doing justice to all of the potential lessons could literally fill volumes; we intend only to give a representative sampling of some of the central issues that have a bearing on ACM within the context of local bio-economic systems (and especially forests). We also hasten to add that we believe that the lessons that pertain to local bio-economic systems are conceptually different from a number of those that relate to some larger-scale, global systems. As a simple example, we have thousands of forest stands around the world, yet there is only one ozone layer. The manner in which we experiment with and learn from working within forest stands is thus fundamentally different from the manner in which we might experiment with our ozone layer.

We then look at the field of modelling. The sundial again serves as a useful point of departure. Models are not meant to be perfect. We agree wholeheartedly with Buzz Holling that models should be no simpler than they need to be, nor more complex. We must design the models for our particular needs. Our mechanical clock, for example, is simply a model of the earth's rotation. As it turns out, this model of the clock is much more useful to us than the actual phenomenon of the sun's apparent movement through the sky. Solar noon happens, on average, every 24 hours throughout the year, but because of the tilt of the earth's axis and the non-circular shape of the earth's orbit, the actual solar days are at times longer and at times somewhat shorter. On January 1, local solar noon would be four minutes later than the clock reads. On February 10, it will be 14 minutes later. On April 15, the times correspond exactly. We can, in fact, predict quite precisely the relationship between solar time – which is a complicated combination of factors involving diverse elements such as the earth's rotation, orbital position, as well as local (predictable) physical phenomena involving shifts in the earth's crust from tidal interactions. We could, very precisely, devise a mechanical model of these complicated interactions. The point is, of course, that it would be very inconvenient to try to run a modern society based on the complicated model of real solar time … if we want to catch the 10:32 train to Florence, the mechanical model will serve us much better. Similarly, when creating models of any system, we need to distinguish among different modelling goals, and different system types. In this paper, we generally distinguish between 'simple', 'complicated' and 'complex' systems. In shifting from modelling traditional bio-economic systems in a neo-classical framework to modelling panarchies, we have shifted from modelling complicated systems to complex systems. Different approaches are necessary; and we review the most promising among these.

The final step of our paper looks at the policy and research implications for ACM, given the empirical lessons learned to date and the modelling possibilities for prediction.

In closing, we would like to emphasise that – in our view – much of the scientific effort in this realm is at the bleeding edge. Any policy prescriptions that might come from it will be subject to the same vagaries and uncertainties that torment all complex systems. Policy-makers will either adopt or fail to adopt these prescriptions for the same reasons that peasant farmers might adopt or fail to adopt newly introduced improved strains of crops. If research in complex systems has taught us anything, it is that conservatism that supports the status quo is likely to prevail until such time as some calamitous event occurs that shocks the system into assuming some other strategy.

This situation will likely persist until 'systems thinking' becomes part of the normal mindset that people confront throughout their lives. Currently, society has largely internalised and adopted the teachings of reductionist science. We think in terms of direct cause and effect. We like to give credit. We like to take credit. We appreciate rewards. Incentives are often structured to promote clear linear thinking. Problem-solving – from grade school to the adult workplace – generally focuses on a range of simple or complicated issues with well-defined *deterministic* outcomes. Solving more complex problems – such as the missionary-cannibal-boat puzzle – is an exercise often relegated to the level of parlour tricks. Yet if history is to judge us well, our next 'adaptation' is most certainly going to have to be that we give higher priority to 'systems thinking'. We must promote cultural norms where we learn how to think, take action and learn in the face of uncertainty. We must dismantle inflexible obsolete structures that work against this. In the end, it may just be one of those parlour tricks that keeps the panarchy from developing irreversibly into a chaotic, self-consuming, anarchy.

ONE

Problem: Bio-economic Systems Are in Peril?

'People have implicitly internalised the scientific method and become used to controlling things. In the past, societies believed that their betterment or salvation lay well removed from everyday existence. Betterment was to be found in the supernatural world, or in some inaccessible utopia. Only recently have we created the Future – with a capital F – as a categorical place for betterment; and we have convinced ourselves that we can control that future and thus control our own betterment.'

– Mark Kingwell. Canadian philosopher and social historian. 2001.

'And why that cerulean color? The blue comes partly from the sea, partly from the sky. ..... Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every 'superstar,' every 'supreme leader,' every saint and sinner in the history of our species lived there – on a mote of dust suspended in a sunbeam.'

– Carl Sagan. Astronomer and writer. 1994.

'Crisis? What crisis?'

– Supertramp. Rock group. 1975.

In 1990, while speeding out of the solar system, the Voyager spacecraft snapped photographs of the planets. From a distance of 3.7 billion miles, the earth appears as a 'pale blue dot' on one such photograph. Carl Sagan uses this metaphor in the above excerpt to underscore the insignificance of our home world in relation to the great expanse of space. For the past billion years, our planet has looked like that. For the next billion years, it will quite likely continue to look like that.

But on the ground changes are apparent. The planet is on fire. Climate change is now inevitable. Fisheries are collapsing. Forests are in decline. We are in the midst of the Sixth extinction, an extinction for which humanity is directly responsible. Poverty persists. All of these problems may not be obvious from 3.7 billion miles away, but they are evident if one lives in their midst.

In casual conversation, we might then all readily agree on what the problem is: the world is going to hell in a hand basket. On the other hand, the devil's advocate among us would note that, throughout history, the world has always apparently been going to hell in a handbasket. So what is new about the current problem?

Many would assert that the difference now is that the *scale* of the problem has reached unprecedented proportions. Irreversible changes are occurring at a pace and at a scale that have been heretofore unimagined. 'But, again,' our friend the Devil's Advocate notes, 'only a handful of the current problems are legitimately global; many are simply a whole bunch of local problems that are scattered widely all over the world. Granted, there may be many of them, but they are still local problems. They only appear global because we seem to know about all of them, and this is simply a product of our new information age. The world has always been plagued by widespread local problems … so again, there is very little new.'

It is at this stage that the philosophers and psychologists take to the floor and state, quite simply, 'What is different are our own expectations. We have collectively become a culture of control freaks.'

Please Suspend your Disbelief

Anybody reading this paper is likely to be familiar with the usual raft of local problems on our planet, so we shall not belabour the point or restate the obvious. What we do want to do is sow some doubt in the minds of the reader regarding the nature of these problems. We would like you to consider the possibility that the main problem is simply that society has somehow convinced itself that we can and should control what is going on. We would like you to consider, whatever your current inclination, that some sort of extreme *laissez-faire* 'hands-off' approach may indeed be as sensible a management strategy as any.

We concede that this may appear radically extreme, even inhumane or amoral, but please consider it for now as a straw man that we hold up for consideration, and debate. We ourselves do not believe that this full *laissez-faire* approach is indeed the best available, but our intuition and experience suggests that we should be tending more towards that end of the management continuum rather than the opposite: one where policies and interventions are actively imposed.

Also, as economists, we have been taught to revere the 'invisible hand' and we thus come from a position of treating deliberate policy interventions with some scepticism. Such interventions are normally justified if and only if they correct system imperfections.

Our main reason for proffering this extreme management scenario is that it opens the door wider into the realm of systems thinking. Some of what we will have to say or observe about 'adaptive management' relates to whether it is in fact an *imposed management or policy tool* or simply an *emergent strategy* that evolves naturally. Too much of the literature on adaptive management explicitly treats adaptation as a policy tool. Within a complex systems framework, such a characterisation is (minimally) probably unnecessary and (more bluntly) probably nonsensical. Intuitively, adaptation is an internal concept; treating it as an external tool seems to us problematic.

Another way of looking at it is as follows. Complex systems that have persisted for long periods of time show a remarkable resilience; they tend to self-correct. Many of these systems are not sentient, and have no explicit manager or policy-maker in charge. They do have feedback mechanisms; the feedback systems reveal adaptive behaviour. Human systems are somewhat different, of course, in that they involve sentient beings and the feedbacks often *seem to* involve policy interventions. But a key point is that, in a complex system, regular concepts of causality – what complex systems theory calls 'attribution of credit' – disappear and it is virtually impossible to say that a given policy intervention has indeed kept the system afloat. We therefore prefer to start the discussion with a relatively blank slate. Somewhat perplexingly, this blank slate also means that we must entertain the possibility that all efforts at policy intervention may be futile.

The Specific Problem

Having said all of that, we are now content to rejoin the ranks of the control freaks and look for ways to deal with the local (persistent) problems of ecosystem collapse and itinerant human suffering. Current management efforts often look to ways of involving local people in the stewardship of the resources on which they rely. Through involving local people, managers have underlined: (i) the importance of creating learning opportunities; (ii) the importance of creating partnerships; and (iii) the need to acknowledge scale effects. 'Adaptation' has become a key aspect of dealing with problems of sustainability and human welfare.

This paper intends to provide a number of economic perspectives on concepts related to adaptive co-management. We focus on local systems in which experimentation and learning is possible. The systems we treat in the paper, and the literature and case studies on which we draw, are intended to relate to *economic systems*: systems in which humans have some key role. But as a reminder that these systems are themselves part of a broader ecosystem, we have chosen more generally to call these *bio-economic systems*. And to underline the fact that these bio-economic systems have internal feedbacks and are themselves interacting with other systems, we refer to such systems more generally as *complex bio-economic systems*. Forest ecosystems and the people that rely on them are an example. Wetlands, watersheds, coral reefs and coastal stretches are other examples.

Adaptive Co-Management Defined

In their seminal work on the panarchy, Gunderson and Holling (2001) paraphrase Einstein and stress that we should keep models and discussions as simple as they need to be, and no simpler. They also beseech writers to explain concepts in straightforward terms: '… If you can't explain it to your neighbor, you probably don't understand it'. We shall endeavour to follow this plea. We start by presenting our interpretation of adaptive co-management.

When one reads the literature on adaptive co-management, one is struck by the large number of explicit and implicit definitions of the term. Authors at times refer to adaptive management, adaptive co-management, joint management, community management, and others. The discussions often also imply that there are forms of non-adaptive management, non-adaptive co-management, multi-party management, and so on. Various authors will also provide further details on their own understanding of adaptive management, asserting that they treat some aspect (learning, time scale, spatial scale, partnerships, etc.) differently than some other author. Sometimes 'co-' seems to be shorthand for *collaboration* while in other instances it refers to *community* or *cooperative*. Considerable thought has gone into these definitions, and we applaud all of these contributions. But we are struck by an irony: the various ways in which ACM has been sliced seem to be very reductionist. It seems to us that ACM need not be too rigorously defined, and that we should try to look at the minimum number of attributes that define it adequately.

From that perspective, the common denominators that most definitions seem to include are that ACM involves:

1. the 'co' bit of the definition – a means for the rights and responsibilities of stakeholders to be defined and *shared*; and

2. the 'adaptive' bit of the definition – a means for stakeholders to *learn* through actions in one period, so that they may modify actions in future periods.

In our view, the ACM regime must also implicitly or explicitly cover an adequately long timeframe to deal with the longer time-scale cycles of the bio-economic system in which it occurs.[2] If one chooses cycles that are too short, one might fail to recognise what is in fact an ACM regime. For example, one might imagine a typical co-management regime with central government and local people sharing responsibilities. One might further imagine that there is some 'λ=degree of *co*' that is a parameter in the sharing of this responsibility: $\lambda=0$ when all responsibility is centralised and $\lambda=1$ when it all lies locally; values between zero and unity involve different degrees of sharing. As the system and regime evolve, it is quite imaginable that the ACM regime also changes in its 'degree of co'; indeed, it may even find itself at the extreme end-points for some period, but it would still legitimately be called ACM.[3]

Also, *conscious* participation seems to be an important attribute of ACM; it is closely linked to the learning inherent in adaptation. Most definitions seem to presume that conscious participation is important. CIFOR's definition (2000) explicitly proposes that such *conscious adaptiveness* is critical. We like the inclusion of this attribute, as it reminds us of the *prise de conscience* often referred to by Marxist writers during the various socialist revolutions of the 19th century, as well as the self-awareness Turing tests currently being applied within the field of artificial intelligence. Consciously adapting seems to impart a higher level of purpose and resolve than simply adapting out of habit.[4]

In short, an ACM regime is a long-term management structure that permits stakeholders to share management responsibility within a specific system of natural resources, and to learn from their actions. Participants are conscious of the fact that they are operating within a complex system and that they can learn, can adapt and can modify the rules of their participation.

TWO

Paradigm: Of Panarchies and Complex Systems

'SUCH IS AN ATTEMPT at the classification of the constituents of a chaos, nothing less...'

– Herman Melville, *Moby Dick*, 1851.

'THE REASON THAT THERE ARE no fish in the sea anymore is because of all of the naked sunbathers on the beach.'

– Anonymous Saudi fisherman. 2000.

THE LOCAL RESOURCE USER often has the keenest insights into how things work in their local system. Moreover, the insights are often surprising. When further probed on what fish abundance had to do with naked sunbathers, our fisherman friend responded cheerfully, 'Allah is unhappy that we permit this sunbathing, and he has taken our fish away to punish us.' In the minds of some of the most important stakeholders, seemingly unconnected factors thus become inextricably related. Such is the nature of complex systems.

And historically, the nature of scientific discovery is equally complex. During the 19th century, debates raged on the role that science should take and could take in describing the world. In his *Range of reason*, Jacques Maritain – a French philosopher who subsequently became an influential figure within the United Nations movement – addressed the dilemmas that natural scientists find in reconciling ethical positions, moral positions relating to faith, and how the human condition fits into the broader aspects of nature. Some of these dilemmas are as challenging today. With the mapping of the human genome completed as we turned the corner of the third millennium, it is now all too evident that science again finds itself in a watershed period.

The past 50 years have witnessed major strides in discovery across many disciplines. Within diverse areas of investigation, simple cause-effect models of yesteryear are falling by the wayside. Just as Newton's laws of physics gave way to Einstein's laws, and just as Einstein's Special Theory of Relativity gave way to a General Theory, we are now entering an era where the *science of complexity* has found its toe-hold. Complexity has contributed to our understanding of biology, of large-scale computer networks, of social systems, of ecosystem function and of organisational management. It has taught us to expect surprises, to question the prevalence and even the desirability of stability, to think and look outside of a box, and to be more humble in our attempts to *control* things.

What can complexity tell us about the prospects for ACM? In this chapter, we review some of the recent contributions that have occurred at a more general theoretical level. One such set of contributions – dealing with panarchy – comes from conservation ecology, in an effort that spans social, economic, ecological and political thought. A second set – dealing with complex systems frameworks more generally – arises from the work of the BACH group at the University of Michigan. Arising from this discussion, the chapter subsequently provides some interpretations on sustainability and human well-being, and identifies some potentially testable hypotheses that relate to ACM. We commence, however, with our brief outline of system types.

Simple, Complicated and Complex Systems

To create a common starting point, we feel obliged to point out explicitly some interpretations of different types of systems. For the most part, these interpretations are cast in common-sense colloquial terms, but in delineating them we also draw attention to how other people view or interpret systems.

Simple systems are those with very few elements that behave in a readily understood and predictable manner. Complicated systems are those with many elements that, once understood, still behave in a predictable manner. Complex systems, because of internal interactions and feedback mechanisms, tend to generate surprises.

But the nature of 'surprise' and of 'complexity' itself can be a subjective concept.

A ballpoint pen is inherently a simple system. A typewriter is a complicated system. A computer operating system is complex. Someone might point out that pens sometimes leave blobs of ink on one's shirt, and that typewriters sometimes jam; but the reasons for such surprises are often obvious or readily understood. Some cultures find our usage of the word 'accident' curious –

there is nothing accidental about two cars colliding at an intersection; a simple model could readily predict that such an event would happen. Surprise may therefore itself be a relative concept.

Also, complexity itself is often a matter of experience and scale. People generally readily grasp the need to balance their household expenditures with their household incomes. The necessity of the equality is typically quite clear, whether the means of achieving this balance appear simple or complicated. But people generally do not grasp the need for governments to achieve a similar balance. Surveys consistently show that people feel that it is possible for government to spend more money, without earning or collecting more money. Usually, because of the scale of the expenditures involved (millions or billions instead of hundreds or thousands), there is less common ground and people do not see straightforward constraints or connections. This scale issue is also something that extends to people's ability to understand and assess social factors in large populations. When questioned, 70% of people believe that they have above-average intelligence ... a clear mathematical impossibility.

So complexity is itself a complex topic. Attempts have been made to quantify complexity, to permit us to say that a system has become more/less complex, or System A is more/less complex than System B. But little agreement yet exists on a precise definition of complexity. The approaches (e.g., Cowan *et al.* 1994; Gell-Mann 1995; Bak 1996; Johnson 1997) generally isolate a few factors as contributing to system complexity. These include system randomness, system predictability, and the propensity for properties to *emerge* at a system scale that are not evident at a smaller scale.

Hierarchies and Panarchies

'Panarchy' is the term coined by Gunderson and Holling (2001) to broaden the ecologist's use of 'hierarchy' in the analysis of adaptive structures in complex systems. A hierarchy is a system of ranking conceptually or causally linked phenomena according to an analytical scale. For example, in the forest ecosystem, phenomena occurring at the leaf, tree, patch, stand, forest or biome represent different levels of that system. The phenomena are 'nested': higher (slower and coarser) levels contain all phenomena in lower (faster and finer) levels; what changes across levels is the resolution. Each level can be defined in terms of its scale dimensions in space (centimetres to thousands of kilometres), or in time (minutes to millennia). Each level is also analysed on a conceptual scale based on functional relationships; each level has its own particular adaptive cycles and processes of growth, accumulation, restructuring and renewal. For example, biological processes of plant competition dominate at the patch level; abiotic (fire, weather) and zootic processes (insect outbreaks, disease) dominate at the stand level. The adaptive significance of the ecosystem hierarchy is that all levels interact with each other, passing information and material up or down. In this complex system, emergence and evolution are important properties because higher levels are not just composites of lower levels. The interaction of adaptive cycles and processes at each level/scale and across levels/scales introduces novelty and change into the whole system.

Panarchy expands on the above use of hierarchy in three ways. First, it explicitly acknowledges the interconnectedness of natural and human systems and requires their integration for a complex systems approach to analyses of ecological-economic-social phenomena. Second, it emphasises the dynamic characteristics of adaptive cycles in these integrated systems, in order to resolve the paradox that is the twin pillars of resilience and sustainability: the coexistence of change and stability. Last, and of less significance, it eliminates the confusion of 'hierarchy' the popular use of which connotes a vertical system of command and control. In a complex system, interaction between levels goes both ways, not just 'up'.

In a panarchy the adaptive cycles of human and ecological systems interact. Each has its own variants of adaptive cycles with processes of growth, accumulation, restructuring and renewal. As in ecological systems, human economic and social cycles of adaptation occur within and across different levels (or scales). To illustrate, the nature of economic and social phenomena at the village level is different from that at the regional, national or international levels – but all can be affected by the interactions between their respective adaptive cycles. At the village level (a fine scale) social institutions may grow out of a need to secure and distribute agricultural development capital. Over time, as income levels and distribution change, such institutions may become redundant in their original mandate, leading to their reorganisation to address new problems; or they may disappear completely leaving the social capital and expertise they engendered to move into other or emerging areas of social need. At the national level (a coarser scale), adaptation to international market phenomena might lead to economic policies encouraging investment away from primary resource industries and into technological industries. This will promote the establishment of a new sector, with new income implications and opportunities, initiating still other economic and social adaptive responses in the affected urban centres. Back at the village scale, as farm labour leaves for urban employment, pressure on a village's local natural resources may change. The use of the forest for subsistence may decline because fewer people depend on it; but its use for other products such as furniture may increase as incomes rise. As the product mix demanded from the forest changes, so must the village's forest management regime in order to mitigate any adverse ecological effects of new harvesting pressures.

The panarchy describes the evolving nature of complex adaptive systems and resolves the apparent paradox of the co-existence of stability and change. Ecological research has determined that 'resilience' is at the heart of what we call sustainability. Resilience can be characterised as the amount of disturbance that can be sustained by a system before a change in its control or structure occurs. How many trees can be removed before the forest converts to grassland? How many cod can be harvested before their populations become unrecoverable? How many disaffected people can a society absorb before its government is ousted? Resilience or lack thereof is manifest in the interaction of adaptive cycles. The 'fast' cycles provide variability and novelty for experimentation and innovation; slower and larger cycles provide persistence and stability while accumulating and conserving successful experiments. The slower, larger cycles protect; while the faster, smaller cycles innovate. Diversity at any level, whether of species or cultures and ideas, increases the adaptive capacity (resilience) of that level to absorb disturbance; and through its interactions with other levels, the resilience of the system as a whole. Information and material move across levels; as long as the transfer is maintained, so is system integrity. When diversity loss on any one level compromises this transfer, the system loses resilience.

The panarchy that is the complex adaptive system of ecology, economy and society, thus both creates and conserves because interactions among cycles combine learning (adaptation) with continuity. In a panarchy, new structures and processes emerge from the interaction of adaptive cycles within and across levels/scales. By understanding the different scales and their cycles, by understanding how knowledge and novelty is created and incorporated, it may be possible to identify points where human intervention can improve system resilience and sustainability.

The BACH Framework

We adopt the general framework espoused by Axelrod and Cohen (1999), which provides a structured view of how one might look at complex systems. In their text, they acknowledge the irony of this; to some it may seem incongruous that we still feel that we want to impose some structure on our ideas on complexity. But such structure provides – to a large degree – a useful transitional framework for investigating complex system issues across a multitude of disciplines. In looking at questions of sustainability or adaptive co-management in forests, we find that the structure also permits us to differentiate among conflicting viewpoints of different writers, and to address some specific testable hypotheses.

The nomenclature of the BACH framework (Box 2) can be applied equally well to biotic systems, computer networks or socio-economic systems. We will point to a few aspects of the framework that show how it might link into a typical bio-economic problem.

Box 2. The 'BACH' Complex Systems Framework (based on Axelrod and Cohen 1999)

Agents, of a **variety** of **types**, use their **strategies** in patterned **interaction**, with each other and with **artefacts**. **Performance measures** of the resulting events drive the **selection** of agents and/or strategies through processes of error-prone **copying** and **recombination**, thus changing the frequencies of the types within the **system**.

Strategy. A conditional action pattern that indicates what to do in which circumstances.

Artefact. A material resource that has definite location and can respond to the actions of agents.

Agent. A collection of properties (especially location), strategies, and capabilities for interacting with artefacts and other agents.

Population. A collection of agents or, in some situations, collections of strategies.

System. A larger collection, including one or more populations of agents and possibly also artefacts.

Type. All the agents (or strategies) in a population that have some characteristic in common.

Variety. The diversity of types within a population or system.

Interaction pattern. The recurring regularities of contact among types within a system.

Space (physical). The location in geographical space and time of agents and artefacts.

Space (conceptual). The 'location' in a set of categories structured so that 'nearby' agents will tend to interact.

Selection. Processes that lead to an increase or decrease in the frequency of various types of agents or strategies.

Success criterion or performance measure. A 'score' used by an agent or designer in attributing credit in the selection of relatively successful (or unsuccessful) strategies or agents.

Emergent properties. Properties of the system that the separate parts do not have.

Designer. An external actor that introduces new artefacts, strategies or agents. This is related to a policy-maker who might deliberately alter the consequences of available strategies.

Attribution of credit. Use of a performance criterion by an agent to increase the frequency of successful strategies or decrease the frequency of unsuccessful strategies.

Adaptation. The outcome of a selection process that leads to improvement according to some measure of success.

Complex Adaptive System. A system that contains agents or populations that *seek to adapt*.

First, it is clear that the overall system consists of a number of interacting agents and artefacts. The agents may be people, organisations or other entities. The artefacts are the tools that they may use, or the elements of the environment on which they may act. Most traditional socio-economic analysts would regard trees in a forest as artefacts; a long-term view might regard a tree (or the forest) as an agent itself, as it can evolve and adapt to different conditions.

Second, a key point within a complex adaptive system is that such agents (or the population as a whole) in fact seek to adapt. Adaptation occurs to achieve some desirable level of success or performance. Strategies that do not work disappear. Learning happens. Variation and experimentation drive the learning. Axelrod and Cohen underline that 'variation provides the raw material for adaptation'.

A final point to which we wish to draw attention is the element of the *designer*. The framework does not explicitly say whether the designer is internal to the system or external to it, but the implication is usually that it is some entity (or person) that can influence the system from the outside. Policy-makers may be designers. It should be recognised, however, that this designer may in fact also be an agent in a larger complex system, and that the designer's strategies may also respond to a variety of feedback.

Some Key Concepts – Sustainability and Human Well-being

The field of forestry management is strewn with different ideas of sustainability and human well-being.[5] It is not our intent to reiterate or mediate among these definitions. What becomes clear within a CS framework, however, is that one might legitimately think in terms of well-being or sustainability from different perspectives.

Sustainability can be thought of as either sustainability of agents, strategies or the system as a whole. Many writers will implicitly touch on elements of all of these. Forest managers tend to speak of sustainability of the forest, which may either be an artefact or an agent within their implicit model. Socio-economists may think of the sustainability of the individual well-being, which relates more strongly to the condition or survival of individual agents. Many system modellers (and those interested in policy) will focus on whether a given interactive strategy seems to be sustainable; successful strategies are copied and unsuccessful ones are eliminated. Finally, the systems ecologists might focus on the sustainability of the system as a whole; this highlights the role of the panarchy within such a structure. Identifying any and all of these perspectives is an important step in attempting to understand or manage a specific bio-economic system. Saying that one of these interpretations of sustainability is correct and one is incorrect is likely to be unhelpful. The CS framework helps us distinguish between these types of sustainability. More significantly, however, it can give us insights into whether some of these types of sustainability may in fact be influenced externally. Many properties of a complex system in fact emerge, and it may be that some forms of sustainability are emergent, while others are goals.

The issue of goals brings us to the next related concept: human well-being, although the discussion may equally well apply to the concept of sustainability. The CS framework underlines the need for some performance measure, or some measure of success. Different measures can co-exist, and each agent will have some set of success criteria. Again, we must distinguish between these criteria at an agent level and at a system level. We must always keep in mind that properties of the system *need not apply* to individual agents. We may therefore choose to define human well-being at the system level quite differently from how we see it at the individual agent level. Similarly, individual agents may well define human well-being differently for humanity as a whole than they would for themselves. We use this insight from the CS framework to address, for example, the concept of rationality.

Economists have long-identified rationality with individual self-interest. This rationality, moreover, has also been the basis for much of modern economic thought. But such assumptions fail to explain much observed human behaviour, from altruistic self-sacrifice, to simple economic experimentation about which restaurants people might prefer. Self-interest may be a motivating force, but it is not the only motivating force. Other factors may be equally or more important and, most significantly, no less rational (Sen 1987; Ostrom 1990; van den Bergh *et al.* 2000). In a CS framework, *self-interest* and the *common good* are not necessarily seen either as mutually exclusive or as complementary. Individual agents may, however, place different levels of importance on them depending on other conditions within the system. Through interaction, experimentation, success and failure, the system and its agents evolve.[6]

Lessons

Lessons from a large number of different types of complex systems may be directly transferable between systems. Axelrod and Cohen (1999) highlight a number of such general lessons, and we here illustrate their potential application with bio-economic systems and some general policy prescriptions that may be relevant to ACM.

First, they argue that systems should be organised to balance *exploitation* of existing ideas and strategies and *exploration* for new ideas. Systems seem to shift between these extremes, and they are two different means of introducing variation within a system. In forestry systems, one must be careful not to become locked into one or the other mode for too long. Many management systems seem preferentially to exploit existing strategies without permitting experimentation with new strategies. Much of this has to do with relative incentives to experiment; such incentives may be a potential subject for policy intervention.

Second, in any system involving humans, it is critical to build networks of reciprocal interaction that *foster trust and cooperation*; such networks harness the complexity in a positive manner, as they build social capital. The role of social capital has been well recognised in forestry literature as well (Uphoff 1992; Waddock 1993; Tendler and Friedheim 1994; Brown and Ashman 1996; Ostrom 1994, 1999a; Kant 2000; Lise 2000). The existence of such capital facilitates adaptation. From a policy perspective, we need to keep in mind that it is easier to destroy this capital than it is to create it. A structure that has 'partially evolved' may be better left alone to continue at its own pace, rather than trying to accelerate its evolution.

Third, Axelrod and Cohen find that within a complex system, one must *assess the strategies in light of how consequences spread*. This is a difficult lesson to absorb, because it is in fact a CS way of saying: look for linkages in unusual places. Their use of the word consequence implies that there is still causality in some sense in complex systems. We don't always expect to find it where we are used to looking for it. Allah's displeasure with naked sunbathers, or fishermen wasting their time looking at naked sunbathers, may be one such connection.

Fourth, systems theory has shown us that we should *promote effective neighbourhoods*. Some of the more interesting early economic modelling that was done on this topic was that posited in Thomas Schelling's (1978) seminal text, *Micromotives and macrobehavior*. He found, not surprisingly, that people often congregated with like-minded people; but people also liked a bit of variety or diversity. In modelling what seemed to be simple and consistent behaviour, he showed that the resultant outcomes were often lousy both from an individual agent's perspective, as well as from the perspective of the population as a whole. An entire field of systems dynamics evolved from this that concentrated on individual strategies, rules of interaction and what might work best as a strategy. Learning strategies in repeated simulations – those reminiscent of adaptive cooperation – usually produced the most effective outcomes over the longer term. The concept of an *effective neighbourhood* speaks to this. Promoting effective neighbourhoods means that, if one can be identified, it should be used as a learning structure within a broader system design framework (i.e., the neighbourhood and its parts become an agent, that may be replicated elsewhere). In policy language, the promotion of such neighbourhoods may be achieved simply through site visits, cultural exchanges or publication of case-study type of research.

Fifth, one should *use social criteria* to support the growth and spread of valued criteria. Much of the CS literature focuses on how people behave in response to prizes, but a more relevant line of investigation within bio-economic systems is simply to pay attention to what criteria are valued locally. Money, for example, is not always that highly valued. Policies and incentives that look just at monetary rewards, or disincentives that focus entirely on financial punishment, may miss the mark entirely. Even as economists, we are surprised that the profession has been so uncreative in its treatment of incentives and disincentives. Children are often happy with parental love and recognition; they don't always need an increase in their allowance when they do something right. Performing dolphins will jump just as high when rewarded with a tummy rub; they don't always need a fish meal. How much fish can any one dolphin, or any one human, eat anyway?

Sixth, one should *look for short-term finer grained criteria* of success that can *usefully stand in* for longer-run broader goals. This is what most agents in fact do naturally within a complex adaptive system. Management science also spends a great deal of effort on this issue. In bio-economic systems, much attention has focussed on looking into various criteria and indicators, and how they might link to long-term goals. From a policy perspective, however, one must question whether these proxies are being used in a management framework, whether the ones that are being used do in fact 'stand in' for the long-term goals, and whether procedures are in place that permit monitoring success against these criteria.

Seventh, *leadership* plays a critical practical role. Axelrod and Cohen observe, from their experience, that a single agent in a system, employing or advocating a particular strategy, will be copied. This provides a powerful policy or design opportunity within *any* system.

Last, and most important in our view, Axelrod and Cohen counsel to *not sow failures when reaping small efficiencies*. Complex systems suffer from four types of failure that can be characterised as: (i) independent failure of system parts; (ii) correlated failure of system parts; (iii) stress propagation failures; and (iv) external attacks. Systems that can avert failure are those with in-built redundancy, in-built fail-safes (precautionary failure modes) and counter-cyclical feedbacks to relieve or dissipate stress. Oddly, many such positive design features fly directly in the face of traditional (partial) methods of economic policy optimisation and design. Redundancy implies duplication and costs money. Failsafe methods appear as being risk-averse whereas we often are taught to act as if society as a whole is risk-neutral. And counter-cyclic interventions may dampen economic growth as much as they protect us from downturn. Also, however, the idea of achieving 'small efficiencies' is well known to economists; most policy interventions are assumed to occur in a state of partial equilibrium (*ceteris paribus*) and we should be reminded that within a complex system even an apparently small intervention may have significant impacts. In chaos theory we call this the butterfly effect … a butterfly flapping its wings in Asia may affect weather patterns around the globe days later.

And, finally, we would like to add our own lesson to the above. The *attribution of credit* is, in our view, the most problematic aspect of getting people to buy into a CS framework or mindset. Even though individual agents try to judge successful strategies, the nature of complex systems is such that inferring cause is next to impossible. A corollary to this is that assigning credit (or blame) is equally problematic. A common mistake in complex systems analysis is to give credit or assign blame to a small part of the system (an agent or a strategy) when in fact the entire system structure is responsible. A second mistake is to attribute credit to a set of factors when, in fact, a different set is responsible. Strategies are often misconstrued and mis-credited. Interestingly, such mistakes are often one-time misinterpretations; recurrent observation and multiple experimentation reduce the likelihood of such mistakes occurring. What remains problematic, however, is the ability to identify a single agent, type or strategy as contributory to success. In the real world, people like rewards and do respond to incentives of all sorts. People also seem to have a natural desire to take credit and assign blame. Within a complex system, such desires are not easily realised. But this also opens the door to what we feel – as economists – is one of the strongest potential elements of any policy discussion: that involving the specific incentives facing individual agents.

Some Testable Hypotheses

In closing this discussion, we will put forward a few hypotheses regarding ACM that we believe are testable. It is not our intent to explore, test or answer all of these hypotheses within the confines of this paper. They will require significant ongoing research, synthesis and discussion by the broader community. We pose these hypotheses to illustrate that, by formalising a CS framework, we have a means of addressing some general problems that are of policy interest:

1. ACM is more likely to succeed if the local structures involve individuals with strong leadership qualities.
2. The 'best' division of sharing of responsibility within ACM is a function of system complexity.
3. Adaptive co-management is an emergent property of a complex bio-economic system.

The first hypothesis dealing with leadership has already been addressed by many studies that show the importance of leadership. Within a CS framework, however, we are also forced to consider explicitly how the strategies of that particular leader are copied, how variations might occur through copying errors, and how policies might inadvertently prevent copying or variation.

The second hypothesis deals with the division of sharing of responsibility addresses the 'λ=degree of *co*' factor we described in the Preface (page 8). For relatively simple systems (or for complicated systems), co-management may not be of much use. For a simple system, it is possible that very little adaptation is required, and that a single responsible authority (centralised or decentralised) may be adequate. For complex systems, however, it may be that the degree of decentralisation is itself an emergent property that depends on the nature and extent of the system's complexity.[7]

Finally, the third hypothesis – that of emergence of ACM – is what we will look into in more detail in the next chapter. At this stage, however, we note that most empirical work – especially in forest systems – has focused on studies of conflict and conflict resolution.[8] It is, academically, perhaps less interesting to study collaboration and the timely emergence of adaptive, cooperative structures that permit a society to continue existing. Bad news is more interesting than good news. Nonetheless, to test this aspect of the hypothesis the research community will need to look at whether such systems do in fact seem to emerge naturally in some evolutionary sense.

THREE

Proposition: ACM is an Emergent Strategy

'EVERYTHING THAT CAN BE INVENTED, has been invented.'

– Charles Duell. US Patent Office. 1899.

'WHO THE HELL wants to hear actors talk?'

– H.M. Warner, Warner Brothers. 1927.

THE INTERESTING THING ABOUT COMPLEX systems is that they produce surprises. Surprises can come in many forms. Post-it notes were invented by surprise. People were surprised when the Berlin Wall fell and German reunification commenced. The emergence of the Internet was, to many, a surprise. In this chapter, we look more closely at the phenomenon of emergence within a complex system. Specifically, we consider whether ACM can be regarded as an emergent strategy. By spending some time on this discussion, we hope to familiarise the reader more with the ways of CS thinking, while also exploring a key aspect of ACM that is of direct policy relevance: can policies promote ACM?

In putting forward this proposition, we confess that we deliberately start by being sloppy in calling ACM an emergent *strategy*. We do this to draw some attention to the attributes of what a strategy is in CS, and to how we should correctly regard ACM. More accurately, in the vernacular of CS, we should ask whether ACM is an emergent *property* of the system. Strategies apply to individual agents. An individual agent can be a single person, a group of like-minded people, an organisation or a subset of the population of agents that regularly interacts. Strategies are themselves often thought of as a set of rules; different strategies have different sets of rules of behaviour. Just as one can speak of populations of agents, one can speak of populations of strategies. Strategies exist at a fairly basic level of a system.

By contrast, emergence is something that happens at a system level, but not at an individual level. Neurons in a brain do not exhibit consciousness, but all of them working together within a network exhibit the emergent property of consciousness. Through simple repeated trading and bartering, prices emerge. Strategies do not, by definition, *emerge*.

But we shall continue to call ACM a strategy for the time being because many people regard it as such through normal connotation. Policy-makers often think of ACM as a regime or strategy that one can introduce into a system, or into a part of a system. In fact, however, ACM is not a strategy.

Let us start with a typical example of a single forest area. A local forest cooperative co-manages a forest area with central government. Central government demarcates boundaries and prosecutes illegal poachers. The local cooperative plants, harvests, and sells forest products; it also monitors and reports any illegal activities. Monthly meetings are held for regular reporting and an annual meeting is held to review long-term goals and targets and adjust future actions. Central government monitors the condition of the forest during an annual audit, with the help of local people. This ACM scheme consists of different agents (people, bureaucrats) having different strategies (some legal, some illegal) within a defined pattern of interaction. Parts of the forest itself are an artefact in this system. Extant mechanisms permit learning and adaptation. All of these features – agents, artefacts, strategies, patterns of interaction – are normally characterised as part of the ACM structure. The system will have many other features that could be identified upon closer inspection, such as different methods of copying strategies. These other features are part of the system, but need not be part of the properties of ACM. ACM is thus more than simply one agent's strategy.

Let us now expand the scale. We oversee multiple forest areas, each with different local conditions. Each area has a different type of management scheme in place. Each employs some form of ACM, but they exhibit different λ (sharing) parameters. In this case, each area may appear to have two agents – a central government and a local cooperative – along with its local forest as an artefact. Each *area* might be said to exhibit a given 'strategy', and it is in this sense that we often think of ACM itself as a strategy. Upon close inspection, however, each area will have further agents and features as described earlier for any single forest. But the broader description may also permit something that is not evident within a single forest: it permits information sharing among physically separated areas. It is in this sense that virtual space also becomes important; virtual proximity may permit copying of strategies among physically separated areas. In practice, for example, a cooperative in the Philippines might try to do what a successful cooperative in India tried. From this perspective, ACM might itself be regarded as a strategy that can be copied.

In effect, therefore, ACM might be regarded in two different senses. In one sense, it is a set of features that describe part of the state of a subsystem. In this sense, it is a property … a property that may well emerge from the system itself. In a second sense, it may in fact have attributes of being a true strategy that may be subject to significant design influences.

This type of duality is common throughout the literature on complex systems. It recurs as various investigators note that it may not be possible to control complex systems, but it is possible to influence them in some manner. The title of Axelrod and Cohen's book – *Harnessing Complexity* – underlines this notion.

A relevant question then becomes, 'to what extent is ACM an emergent property?' If it is frequently emergent as part of a natural evolutionary process, then it may not be subject to a great deal of policy intervention.

Emergence

In treating this problem of emergence, we can look at a number of possibilities.

First, we can look to see if there are any cases where an ACM regime did seem to evolve without any apparent external intervention. There is some limited evidence that this does occur. One such case in forestry is in India. Lise (2000) documents a forest site in Uttar Pradesh where forest councils have long existed. People demanded the right to self-organise, with formal rights for the communal management of forest resources. Forest councils consist of villagers and the role of the state in management is minimal. Another forest site in Bihar, India, is managed with negligible state involvement. A local NGO manages what began as a 'sharing model' to resolve a situation of economic stagnation involving a village and a group of private land owners. The sharing model allows for the pooling of land and labour resources; output is shared equally among the landowners and workers. Also, part of the output is set aside for community projects such as schools, wells and roads. Such natural evolution of land co-management is also documented in India by Parikh and Reddy (1997), who find that the growth of almost 1000 village-level cooperatives over a period of decades came largely from self-organising momentum coupled with a supportive national-level NGO – the National Tree Growers Cooperative Federation. Of course, the long history of the cooperatives in India (Ray 2000) implies that substantial social capital was in place in many of these instances.

Coastal systems have also been found at times to self-organise in this fashion. Sathirathai (1998) documents the self-organisation of coastal communities in Thailand when their mangrove resources fell into steep decline. The self-organisation managed to halt the decline, and central government subsequently stepped in to give further assistance. Also, marine areas of Palau have, apparently, fallen under an adaptive co-management regime over a period of many decades (Idechong 2000); this was in response to local initiatives undertaken by fishermen concerned with declining fish catches.

Some of the factors that contribute to emergence seem quite straightforward. The study in India (Lise 2000) specifically analysed survey information to determine the reasons for participation. Factor analyses showed both social and economic considerations were important in the decision to participate; social considerations were relatively more important. Econometric analyses found that participation is positively related to (i) the level of forest dependency; and (ii) forest quality. In short, threats to the forest tended to bring people into a participatory process.

Second, we can ask if the regimes that emerged appear to be stable and promote system resilience. Specifically, we would expect that emergent regimes are a result of ongoing interactions that prevent failures. Through time, structures, modes of interaction and strategies have evolved that have prevented the system from failing. In the case of Palau, for example, it was characterised by strong leadership, in-built system redundancy and strong shared goals among the local people; the central government was involved to bring law-breakers to trial when illegal poaching occurred. This balance of power evolved slowly over a period of some 20 years, permitting the accumulation of social capital. A detailed World Bank survey by Bettencourt *et al.* (2000) looked at 31 coastal communities in the Pacific islands of Fiji, Palau, Samoa, Solomon Islands and Tonga. In areas of stress, a co-management practice seemed to emerge without being explicitly imposed: 'national management rules that were perceived as relevant and that were subsequently adopted as local rules were perceived to have significantly better compliance than either purely national or purely community rules'.

In the forestry sector, four recent studies conducted for the Economy and Environment Program for Southeast Asia (EEPSEA) provide some insights. Nguyen Bien (2000) analysed the evolution of three different forestry regimes in Vietnam's North Uplands and compared them to some resettlement sites in the Mekong Delta (Mai Van Nam and Nguyen Tri Khiem 2000). Zhang *et al.* (2000) investigated the evolution of co-managed forestry regimes in Hainan, China. Bogahawatte (1999) studied a site in Sri Lanka, where a 1995 national law in effect requires aggressive pursuit of community forestry at all sites in the country. The general finding from these studies is that the more stable (and sustainable) conditions were to be found in those areas that had undergone some natural evolution to a co-management regime (China, North Vietnam). In South Vietnam, where regimes had been imposed by central government, none of the models of resource management (co-management, private ownership, state control) seemed to generate acceptable levels of local well-being or resource protection. In Sri Lanka, the local participants were willing to participate in the programmes as long as they received substantial government investments in the way of roads and other development; there appeared to be little concern for forest quality. Again, the naturally and more slowly emergent regimes seem to be most resilient.

Third, to test the hypothesis of emergence, we must ask whether the resultant regimes demonstrate properties at a system scale that are not evident within individual subsystems. To our knowledge, this feature has not been explicitly investigated.

Finally, we can ask whether *imposed* systems of ACM in fact work. As the management approach is still in its infancy in this mode, it is likely too early to judge with any degree of fairness. Many writers have documented the apparent problems with ACM (Walters 1997; Rogers 1998; Lee 1999), with the usual observations that it works well in theory but not so well in practice. It may well be that the practical efforts have not paid attention to some of the system attributes. We discuss below some potential testable hypotheses that may inform this.

Description, Prescription, Evolution and Design

The question of emergence is critical for a very simple reason. If ACM is naturally emergent, then all we can do as scientists is describe the evolutionary process; policy interventions are likely to do more harm than good. If ACM is not naturally emergent, then we are free to prescribe it as a policy tool, and design ways to make it work.

ACM may or may not be an emergent property. We suspect that, over long time periods it is in many cases emergent, and the next chapter explores this aspect in more detail based on the history of economic thought and experience with other emergent phenomena surrounding the 'invisible hand'.

Within the general area of emergence, however, we find that this discussion and framework does provide us with some potentially empirically testable hypotheses within forestry systems. Again, we do not claim to have the breadth of experience to validate or falsify any of these hypotheses here. We offer the following conjectures:

1. As simple systems evolve through time into complicated systems and eventually into greater levels of complexity, they will naturally adopt progressively more adaptive management schemes, culminating in some form of ACM. This can occur with little, if any, external intervention or design.

2. Systems that mismatch the level of complexity to management regime, because of flaws in copying, interaction or selection, will fail. This failure will occur whether the management regime was one that was evolving within the system (i.e., the system experimented with a regime and collapsed because of it) or whether the regime was introduced externally as a policy intervention.

3. Premature introduction of ACM as a policy intervention could lead to system failure. This may occur because the introduction of such a process disrupts existing evolutionary processes within the system.

All of these conjectures are readily cast within different parts of CS thinking. The first, relating to emergence, looks explicitly at the way strategies are destroyed and created. The second conjecture can address aspects of copying, redundancy and reasons for system failure. The third conjecture is in fact an extension of the exploitation versus exploration balance required in complex systems; exploitation of an existing evolutionary process may be disrupted by the introduction of exploratory prerogatives associated with a 'new and improved' ACM.

FOUR

History: From Invisible Hand to Invisible Wand

'I HAVE HITHERTO SOMETIMES spoken as if the variations ... were due to chance. This, of course, is a wholly incorrect expression, but it serves to acknowledge plainly our ignorance of the cause of each particular variation. ... [The facts] lead to the conclusion that variability is generally related to the conditions of life to which each species has been exposed during several successive generations.'

– Charles Darwin. *Origin of Species (Chap V)*. 1859.

'JUPITER'S MOONS ARE INVISIBLE TO THE naked eye and therefore can have no influence on the earth, and therefore would be useless, and therefore do not exist.'

– Francisco Sizzi. Professor of Astronomy. 1610.

ECONOMICS IS INDEED THE DISMAL SCIENCE. Thomas Carlyle, historian and social critic of the 19th century, first made this observation about economics. This statement was made at a time when the great economists Thomas Malthus and David Ricardo were writing about the world's economic future. Neither painted a bright future for the common worker, observing that world population would grow faster than food production would allow. They both called for restraint in food consumption, but both submitted that it is not in human nature to use self-control in population growth. Destiny controls this growth. Adam Smith, on the other hand, had a different viewpoint. Carlyle painted Adam Smith as an optimist.

Adaptation and the Invisible Hand

Adam Smith finished his *Wealth of nations* in 1776. He wrote it in the wake of Newton's philosophy of nature, a time when the thinkers of the day viewed the world as a harmoniously ordered mechanism. 'A general harmony of Nature' was believed to exist for the natural world, as well as for human society. Everything in Nature had a purpose, including human behaviour. When Smith wrote the *Wealth of nations* and his earlier work on moral philosophy, he was looking for the harmony of Nature manifest in social systems. He found the 'invisible hand': the myopic individual pursuit of economic self-interest that turns out to be of economic benefit to society as a whole. Smith believed this invisible hand phenomenon to be part of nature's grand design for humankind. Naturally desirous of bettering their condition, self-interested individuals unwittingly and collectively cause the emergence of the common good (and thereby the wealth of nations). Society's resources are allocated efficiently and fairly. However, this end result could only be realised if individuals were free to pursue their self-interest, unfettered by government; and if they behaved with propriety and fairness.

We can cast this description of *Homo economicus* in terms of complex adaptive systems. Individuals undertake economic strategies based on available information and resources. They adjust or even abandon strategies throughout their economic lives, as they adapt to the myriad of interactions in the panarchical complex system. They grow in abilities and capacity, accumulating information and resources along the way. Adaptation and innovative strategies emerge in response to changes at the individual or family level; or to changes incoming from other levels (industry, government). Competition would be one such emergent strategy. Throughout these cycles of adaptation, individuals pursue strategies formulated on the bases of their new and accumulated information and resources while interacting with the economy, buying and selling goods and services. Market prices emerge. Should they be efficient and fair prices, this emergent property of the market can be said to be one that benefits the whole of society. It is Smith's invisible hand, efficiently allocating society's scarce resources.

The Moral Factor

Smith's major work preceding the *Wealth of nations* was *The theory of moral sentiments* – his effort to develop an ethics based on the unifying principle of 'sympathy'. Again appealing to Nature's grand design, he believed that ethical behaviour was innate to humans; it sprang from our natural endowment of sympathy. We give sympathy and in turn endeavour to be worthy of the same. This innate predisposition impels us to act decently. But by the time he wrote the *Wealth of nations*, much later in his life, he was less convinced that mankind would unfailingly act decently. Although he expounds on the common-good benefits of the *laissez-faire* economic strategy in his later book, he is also scathingly critical of the commercial classes and of government. He describes the dehumanising effects of the division of labour: the lazy, vulgar, rapacious, avaricious, monopolising, and intimidating behaviour of landowners and merchants. He also describes the inept, corrupt and wasteful inclination of government. But he does not waiver in promoting *laissez-faire* … for the common good.

The Common Good and Individual Self Interest

Smith's endorsement of the unfettered pursuit of self-interest – *laissez-faire* – in spite of his empirical observations of its excesses and negative externalities, followed from his belief that it was better than the alternative. He believed that it would more likely bring about the common good than would feudal servitude. By Smith's time, Enlightenment was firmly entrenched, and historical power arrangements and societal structures were on their way out. Smith saw commerce and manufacturing as 'liberating instruments', which would result in the demise of a system of dependencies. By allowing individuals to pursue their own self-interest, they would become less dependent on feudal lords; who in turn, having more shopping opportunities would have less money to maintain tenants and private militia. Smith's time was one of both economic and political evolution. He believed that from unfettered commerce and manufacturing – despite its shortcomings – there would emerge a higher level of civilisation with good government, individual liberty and security.

A New Role for *Laissez-faire*

In the language of complex systems, the common good is an emergent property, a characteristic of a nested hierarchy of functional relationships. More precisely it is the emergent property of the panarchy because at work here are interactions within and among various levels in the ecological-economic-social complex system nexus. The agents (*H. economicus*) formulate and pursue adaptive strategies of self-interest. Their collective behaviour reverberates throughout the panarchy giving rise to novel system properties: the 'common good', which includes wealth, political freedom, better government, etc.; and some 'common bad', such as environmental degradation, social alienation and income inequality. But, to varying degrees across economies, individuals are not unfettered in their pursuits. A good deal of government exists to manage the negative effects of collective self-interest. Its success – measured by social upheaval and environmental decay – varies across nations.

At the village-level scale of common-pool resources, the best strategies for more than 20 years – since the articulation of the 'tragedy of the commons' (Hardin 1968) – called for complete state, or private, management. The complex system that is resource management was not fully understood, and successful adaptation to system-wide changes could not be achieved. After innumerable cases of government failure to implement appropriate management or privatisation plans, policy analysts are back at the village level. The current emerging strategy is one of collective management by users. This in a sense is a movement towards a *laissez-faire* approach to management. Users are fettered less by government in the management of their resources. It is believed that they are best equipped to adapt to system changes.

From the perspective of the panarchy, what is interesting here is the emergence of a new strategy: adaptive management – with varying degrees of collaboration or fettering. The system has learned from repeated unsuccessful experiments so it is innovating; it is doing just as its moniker implies – adapting.

Will this be a successful adaptation? Will the emergent property of this type of management be for the common good? Smith believed that we naturally wanted to better our condition and our innate endowment of self-interest allowed us to achieve that end, individually and collectively. One might argue that it is in the economic self-interest of the villagers to manage their common resources wisely. However, this presupposes *H. economicus* – rational economic man. There is plenty of everyday and scholarly evidence that economic man is not so rational. The assumption of economic rationality ignores the social dimension of human existence. Repeatedly, research has found that social factors are essential in the individual's decision to participate in collective management or action (Brown and Ashman 1996; Ostrom 1999a, b; Lise 2000). Effective cooperative problem solving is most often found where individuals can share comfortably their knowledge and goals, where they trust one another to keep promises, and where there is an acceptable balance of power. These are elements of social capital.[9] Hence the decision to collaborate is a social one dependent upon the individual's relationship to the others in the particular group. To what extent will they follow or imitate the group? To what extent do they see themselves as part of the group? In traditional societies, people often see themselves first and foremost as members of the group. These sorts of people are definitely not *H. economicus*; their actions are not based solely on economic opportunity. In modern industrial societies, people are closer to being *H. economicus* because people generally consider themselves as independent individuals first. Even so, people continually demonstrate moral responsibility superseding economic considerations. Some have argued that humans cannot escape this moral characteristic because our history is one of living in community (Daly and Cobb 1994; Sen 1987; Siebenhüner 2000). If that is the case, *H. economicus* is a narrow description of what humans are and how they might be expected to behave. This latest management adaptation may well create some emergent common good.

Where does this leave Smith and his theory of the self-interested individual? Smith is not responsible for the construct of *H. economicus*. His individual was driven by the grand design of Nature, not economic reason. His individual was endowed with natural sympathy that would give rise to ethical behaviour; he would pursue his self-interest but would endeavour to do so decently and fairly. Smith's individual was community oriented for he sought the approbation of others; he was not firstly an independent individual void of a social dimension. He is closer to *H. sustinens*, an image of the type of human being required for achieving sustainability (Siebenhüner 2000). This individual is endowed with social, emotional and nature related skills. This individual is not ruled solely by economic reason, this individual is known to act altruistically, pursuing the common interest.

Altruistic Common Interest as an Invisible Wand

If we combine this movement towards a *laissez-faire* management style, and the recognition that *H. economicus* narrowly describes human behaviour, we can image an 'invisible wand', analogous to the invisible hand. Unfettered by government in matters of management, individuals' altruistic pursuit of the common interest leads to emergence of the common good, which in this case is appropriate sustainable management, as opposed to efficient prices.

As was discussed above, unmitigated *laissez-faire* has shortcomings – market failures wherein prices are not efficient – and the common good is compromised. In these cases, government intervenes to try and correct the distortion; or in other words, to remove the barriers to the full emergence of the common good. Such barriers might include monopolistic behaviour, uncompensated environment damage (pollution), or unfair labour practices.

If *laissez-faire* is applied to adaptive management, there will likewise be scenarios wherein the emergence of common good is thwarted because of management and institutional barriers. As in the economy, it will be the role of government to intervene and remove these barriers. Such barriers will and do include: improper design of institutions; policies that ignore the moral and communicative (social) dimensions of humans; plans and programmes insensitive to the social capital of the people involved; over-ambitious timeframes for programme objectives; and a general reluctance to resist manipulating.

The Role of Policy

In Chapter 3 we complained that if ACM was emergent, then there would be no role for policy. In this chapter we have tried, however, to draw some parallels between the invisible hand and the invisible wand. Economic history has taught us that, even if some (presumably) desirable properties such as free trading markets are emergent, there can be a role for public policy interventions to ensure that the conditions for emergence are maintained intact. Public policies thus regulate against monopolies, nationalise public goods and act as rule enforcers in the realm of property rights. Similarly, even if ACM were an emergent property within a complex system, one would anticipate that policies could be designed that *protect the conditions for emergence*.

FIVE

Perspectives: A Fresh Look at Some ACM Concepts

'FLATWORMS LACK BRAINS, YET show the faculty of true learning. They can learn to choose the correct path in a simple T-maze. They try turning left and turning right, and gradually select the behavior – or form the habit – which produces the better result. This is selection of behavior by its consequences, which behaviorist psychologists call 'the Law of Effect.' The evolving genes of worm species have produced worm individuals with evolving behavior.'

– Erik Drexler. *Engines of Creation: The Coming Era of Nanotechnology*. 1986.

'IT TURNS OUT THAT QUITE a lot of human activity can be accomplished unconsciously – e.g. unconscious perception, memory, and learning. And some have argued that there are major neural pathways devoted to unconscious processing of visual inputs that leads directly to motor action. This has led some to suggest that each of us contains a 'zombie within' that unconsciously produces many of our motor responses, without our realizing it.'

– David Chalmers. Philosopher and Associate Director of the Center for Consciousness Studies. 2000.

WHY DID EVOLUTION BOTHER TO produce us if zombies would have survived and reproduced just as well? Zombies are physically identical to normal human beings, but completely lack conscious experience. Zombies appear in Hollywood movies and philosophy articles. We all probably think that we know a few, too. The question regarding evolutionary development is one posed by Owen Flanagan and Thomas Polger (1995) in their work on consciousness.[10] They argue that one of the most difficult questions facing the definition of consciousness is what function it in fact serves.

Many authors feel that conscious participation within an ACM process is an important element of ACM. CIFOR's definition explicitly refers to *conscious adaptiveness*. Others have argued that it is necessary for learning to occur or for collaboration to be effective. Empathy for another person's viewpoint is thought by some to be a part of conscious thought. But we know that even worms can learn and adapt, and that zombies can participate in meetings and look after themselves and their environs.

At this stage, we cannot even begin to guess what the role might be of consciousness within ACM. What we can do is make a conscious effort to look at some of the concepts inherent in ACM in a critical fashion. To this point, our paper has dealt primarily with ACM in quite general terms. We have not yet looked at the guts of ACM. In this chapter we shall pay more attention to these guts and attempt to provide some perspectives on individual concepts that one runs into in ACM. Many of these concepts have also been addressed within the economics literature, and we shall here weave together some lessons from economic thought, incorporating also the language and lessons of complex systems. The topics we shall touch on here include (i) social learning; (ii) collaboration; (iii) responsibility; (iv) risk and surprise; (v) devolution; and (vi) project integration. We conclude with some remarks relating to the arrival of our millennial Renaissance man – *Homo sustinens*.

Social Learning

The process of adaptation through learning and experimentation is a fundamental component of ACM. In the language of complex systems, learning falls into the realm of 'variation'. The variation can occur in many ways, but we would like to draw attention most specifically to some of the economic lessons associated with copying and adaptation in response to external stimuli.

From an economic perspective, we often presume that individuals respond to some form of incentive or disincentive. This includes learning. We know, for example, that individuals are willing to invest time and money in education for the sake of getting a job that pays well and can support them. But this incentive effect seems limited to simple systems of one-person or one-household models.

In the realm of more complex systems and social structures, other relationships can take precedence over the simple incentive effects. Most notably, individuals seem prone to copy successful strategies of successful agents. Although we see it in business organisations (Cialdini 1984), it is also evident in many developing-country settings. While Gandhi's leadership qualities were frequently emulated (Gardner 1995), we also see such emulation at the everyday farming level. Agricultural extension practices for introducing new crops are most successful when tied to a few successful demonstration projects that have been implemented by farmers who were previously regarded as successful (Smale 1998).

Social learning is also strongly correlated to risks and threats, as evidenced by responses in Indian agricultural and small forestry settings (Bliss and Stern 1982; Stern 1989). We have previously noted that Lise (2000) also found that ACM structures and adaptation were strengthened if there were higher degrees of resource dependence. Conflict or crisis seems to engender a greater sense of urgency, which creates an indirect incentive to vary one's strategy. This is an interesting result, in that it also implies that the threat of loss is a greater motivator to change and variation than is the promise of gain. This finding is consistent with much of the experimental economic work on compensation. This body of work (e.g., Knetsch and Sinden 1984; Knetsch 1994) compares willingness-to-pay (WTP) for something new with the willingness-to-accept (WTA) compensation for the loss of something existing. WTA measures are typically an order of magnitude higher (in monetary terms) than are WTP measures.

Collaboration

'All for one, one for all, and everyone for himself.' This variant on the rallying cry of the Three Musketeers seems to be as close a description as any for how people really behave. Or at least such are the findings of a decade's worth of theoretical and empirical research on economic collaboration. We all have it within ourselves to look after the underdog, to sacrifice oneself for some greater good, or to be totally self-centred and self-indulgent. Which of the three characteristics is dominant at any given time seems to depend on a host of variables.

In complex systems models, collaboration is a potential strategy for an agent. Most of the economic analyses relating to collaboration do not investigate such collaboration as a complex systems problem, but they do look at the motivations behind such collaboration, in terms of incentive effects to partner with others. The models tend to fall into various types of behavioural areas, often in a game theory framework (Ostrom 1990; Ostrom *et al.* 1994; Blount 1995; Gintis 2000a, b). The usual assumption had always been that people would only collaborate if it were in their personal self-interest. But experimental evidence demonstrates this is not the case. Modelling shows that cooperation is often a natural outcome in repeated games, and that systems may even self-organise around a collaborative effort if there is a common good at stake. This suggests that in some circumstances, for example, the open-access problem may not, in fact, be a long-term problem in a complex system. Feedback effects eventually create incentives and cause people to adjust their harvesting strategies that treat the resource as if it were communally owned. At present, the best fits to reality (Ostrom 1998; van den Bergh *et al.* 2000) would characterise people as norm-constrained, error-prone, locally maximising agents. In practice, this means we generally prefer to follow a set of decision rules or practices, and may make explicit judgements only on selected issues. Those judgements we make and strategies we select are subject to errors, from which we may or may not eventually learn and adjust future strategies.

Another issue that has received increasing attention in the economics of collaboration deals with *transaction costs*. North (1990) formally distinguished transformation costs from transaction costs, where transaction costs were defined as 'the cost in defining, protecting, and enforcing the property rights to goods'. Transformation costs are 'the costs of inputs of land, labor, and capital involved in the transforming the physical attributes of goods'. Transaction costs are hypothesised to form a barrier to collaboration or to the establishment of appropriate tenure arrangements (Bromley 1991).[11] Much theory and empirical evidence supports the idea that transaction costs can at times be substantial, and may therefore influence the optimal institutional arrangements. But closer investigation of the nature of the barriers has provided other insights into the role of transaction costs in cooperative structures.

Empirical work around the issue (Sumalde 1999) in the Philippines provides some important insights that are probably of no surprise to other social scientists, although they do not fit well with the conventional economic model. First, she finds that the transaction costs are typically relatively small in relation to the values of the benefits of the resource-management issues. In this respect, they do not form a cost barrier to management. Second, the presumption that voluntary management time is a cost needs to be re-evaluated. Many participants in fact enjoyed their participation experiences and tended to regard it as a positive social occasion. Third, issues around cost sharing were typically easier to resolve than were issues around benefit sharing. Resolution of these simpler issues improved the collaborative process and in effect added to the 'social capital'. Contrary to common economic assumption, therefore, transaction costs in such settings may not be a significant barrier to collaboration. The social benefits to interaction may in fact outweigh the presumed transaction costs.

In a forest setting in China, Zhang (2001) found that collaborative, community-based structures had lower transaction costs than did private structures or government-mandated structures. Transaction costs with conventional forest management are significant, when compared to production costs. But transaction costs are substantially lower in a 'share-holding system' that relies on semi-privatisation with shared participation of community-based forest managers and central authorities.

Responsibility

The definitions for responsibility have not yet been formalised in a context that is amenable both to analysis within a CS framework and to usage in ACM and economic theory. We shall, therefore, present our proposed interpretation here. ACM always involves some form of sharing of responsibility. The sharing aspect is inherent in collaboration, but the idea of responsibility is something that generally sits with a single agent.

Within the language of complex systems, responsibility can be regarded either as a *type*, as a *strategy* or as a *selection criterion* to which other agents attribute credit. It is a *type* if a particular agent has a responsibility (i.e., a job) to do something. As part of a *strategy*, we consider that an agent might choose to behave responsibly or irresponsibly. As part of a means of *credit attribution*, we can attempt to measure whether an agent has been successful in accomplishing some outcome that is the target of their responsibility. For example, if it is a person's job to catch poachers, then they can either do their best to catch poachers, or shirk. As a measure of success, we might judge that an agent has been responsible if they catch a lot of poachers, or if there is no poaching going on. Within a CS framework, we must recognise that these three interpretations of responsibility are quite different, and could co-exist. For example, the agent whose job it is to catch poachers may be shirking, but no poaching may be happening because of other factors.

As a topic within the economics literature of relevance to ACM, most of the more interesting conclusions relate to what is called principal-agent (P-A) theory. In this context, the idea of 'responsibility' captures both the idea of responsibility as a strategy and responsibility as a success criterion.

The basic problem in P-A theory is that a principal is initially responsible for something, and the responsibility is delegated to an agent. The defining characteristic of the situation is one of *asymmetric information*. The agent typically has access to different (usually more) information than does the principal, yet the principal has some need to make decisions that are based on this incomplete information. P-A problems are thus within the realm of information theory (Feltham *et al.* 1988), and the problems apply to a wide range of issues. Insurance companies wanting to sell insurance need to consider that they are not insuring an 'average population', but rather a 'population that is applying for insurance'. This population that applies for insurance tends to self-select, and the theory tells us that those applying will generally have a higher risk than the true average of the population. This gives rise to what is called a moral hazard problem: as an insurer, you may not want to sell your product to the only people who want to buy it.

Although insurance has very little to do with ACM, the more general lessons from P-A theory and asymmetric information theory are of relevance. A key lesson is that the actual behaviour (strategy) of the agent is most likely to align with the behaviour desired by the principal if the goals of the principal and the agent are commensurate. This implies that they must have the same measures of success. If the goal of the agent is to have a job with income, and the goal of the principal is to make a profit, then there may be a high probability of shirking if there is asymmetric information (i.e., if the principal can't see what is going on). In such circumstances, it may make more sense to strike a revenue-sharing agreement that distributes risk; in that manner there is no longer an incentive to shirk. In forestry management, net royalties collected on behalf of the state are a form of revenue sharing that achieves this.

In simplest terms, if it is difficult to observe strategy and easy to monitor success, then responsibility, rewards and incentives should be defined based on results. If it is difficult to define or monitor results, but simple to monitor strategies, responsibility should be defined and monitored in terms of the tasks and behaviours that the agents use. If it is difficult to monitor both strategy and results, then it is likely that responsibility should be defined simply as a job (a *type*), but that a large degree of entitlements are conferred with this job.

Devolution

The delegation of rights and responsibilities to local institutions, individuals or other agents is commonly called devolution. Many countries are following explicit paths of devolution that see greater decision-making authority being moved away from central governments.

Within a CS framework, devolution can be regarded in a number of ways. It can be regarded as a strategy in itself, or it can be regarded as a property that encompasses a series of strategies, artefacts, and patterns of interaction. There are no doubt those in the audience who would argue that devolution is a policy tool, and others that might argue that it is itself an emergent property from a democratising society. [We shall sit out that particular discussion; it is enough of a job to argue that ACM is naturally emergent, although we confess to being predisposed also to the treatment of devolution as emergent.]

Whether one treats devolution as a policy tool or as an emergent property, the lessons from the economic literature seem to be unanimous: revenue sharing is a significant issue. This applies to almost any sector, but studies in the forestry sector confirm this.[12] It is significant for a number of reasons: the revenues involved are often substantial; local capacity to manage high levels of income are usually weak; strengthening local capacity often requires those increased revenues; and discussions around revenue-sharing are more likely to generate conflicts than are discussions regarding sharing of responsibility or costs. Moreover, issues around corruption at times also arise within this context. In managing such programmes, the revenue-related items of design and implementation have often been delayed or deferred to give local agents some time to get their institutional house in order. Within a systems context, this simply acknowledges the dynamic context of the beast.

Risk Tolerance and Surprises

Much has been written about the treatment of risk and uncertainty in conventional economic analyses. Some substantial recent progress has been made, however, in experimental methods that have a direct bearing to complex adaptive systems and ACM. We therefore focus on these developments.

- *Heuristic learning*. Conventional economic models of risk and uncertainty treated individuals' attitudes towards risk and uncertainty within a context of utility theory in which risk preferences were well-behaved. Current lessons from economic experimentation show that individuals' attitudes are not invariant, and that a continuous process of learning and expectation modification, *with frequent error-handling*, in fact occurs (Shafir and Tversky 1992, 1995).

- *Assymetric risk aversion*. Well-being has traditionally been treated as a risk-neutral assessment of the expected levels of pay-off. Experimental evidence suggests, however, that well-being is more greatly influenced by relative than by absolute changes in income (Lane 1991, 1993; Oswald 1997), and that individuals are habitually loss averse (Kahnemann *et al*. 1990, 1991). People tend to prefer the status quo, and often use that as a simple 'behavioural rule' in the absence of what they regard as relevant information pertaining to the alternatives. In economic terms, they tend to assign twice as great a negative change in well-being to a loss of X dollars, as they would a positive change in well-being to a gain of X dollars.

- *Hyperbolic discounting*. While the economic literature is replete with accounts of what an appropriate discount rate should be for comparing future to current preferences, this literature has consistently assumed that individuals and societies should have an exponentially declining preference function. In fact, experimental evidence (Loewenstein 1987) suggests that the function is hyperbolic; this implies that individuals have high short-term discount rates but that they have lower long-term discount rates.

The implications that these findings have for ACM are that decision-making frameworks should reflect the potential for changing preferences. Also, disruptions to the status quo may pose greater risks to established norms than was previously thought.

A Comment on Integrated Projects

So-called 'integrated' projects have received a great deal of attention in the delivery of foreign aid. These projects involve the integration of multiple sectors with the basic idea that, if we look at a larger system, we are more likely to do something right. We thus have a veritable alphabet soup of integrated development and conservation initiatives (IDCI), integrated coastal zone management (ICZM) projects and integrated development projects (IDP).

Common to most of these projects are the following economic motives: (i) the elimination of duplication to improve cost-effectiveness; (ii) the creation of collaborative partnerships to improve the efficiency of information flows; and (iii) the reform of incentive structures and salaries to motivate individuals and promote institutional strengthening. How well have these worked?

While there are no extensive accounts or evaluations of such programmes, the record is somewhat troubling. Westmacott (2000) conducted a survey of over 50 such projects and suggests that only about 20% are achieving their objectives. Interviews with project managers suggest that failure is a norm. She remarks that the failures seem to occur because of improper timing of interventions and disruption of local social conditions within existing institutions.

To her conclusions we would add that, from a systems perspective, many integrated projects are executed in a way that removes system resilience; they remove redundancy, they introduce new interaction patterns in an ad hoc fashion, and they focus entirely on material reward systems that often ignore extant social criteria for success. In summary, they seem to ignore the fact that people are human.

The Arrival of *Homo sustinens*

Social learning, collaboration and responsibility are essential to ACM, but to what extent are humans capable of these behaviours? The dominating conception of humans as *Homo economicus* (rational, self-interested and utility maximising) casts doubt on an innate ability to act with a social and environmental conscience. But as noted earlier, the credibility and usefulness of *H. economicus* is under attack. In the search to identify all that is needed to improve environmental sustainability, a new conception of humans has been proposed: *Homo sustinens* – the human that lives in accordance with sustainability (Siebenhüner 2000). To that end, *H. sustinens* must be capable of (i) cooperation and communication; (ii) emotion as well as rationality with respect to nature; (iii) learning and creativity; and (iv) moral responsibility. Is this human out there?!

Research in the fields of evolutionary biology, neurobiology and psychology, leaves one fairly certain that *H. sustinens* does indeed exist, but is perhaps muted because of existing social structures (such as those predicated on human nature as *H. economicus*). Evolutionary biologists point out that humans could not have survived this long without communication and cooperation, which were essential to catch dinner and raise the children. Likewise in the category of survival traits is our apparent emotional response to nature: it is often a source of joy and peace. Regarding our capacity to learn, cognitive psychologists believe that the brain's process of learning is one of constant innovation. Knowledge is not copied, it emerges as new information is mixed with the learner's existing stock. That being the case, humans are preconditioned to create new ideas and strategies. Further, current psychological thinking is that both cognitive and emotional processes are involved in learning, and that cognitive success depends on positive emotional involvement. And, neurobiologists have found evidence that rationality is an interplay of emotional and cognitive processes.

Last is the issue of *H. sustinens* and moral responsibility. Psychologists believe that environmental responsibility can only be engendered intrinsically. Extrinsic motivation such as monetary incentives cannot bring about long-term lifestyle changes of the sort required for conscious environmental stewardship. They believe that self-determination based on *conscious volitional decisions* is what gives rise to individual learning, and to intrinsically motivated behaviour. This is the sort of behaviour wherein an individual finds joy and other non-monetary rewards in the activity itself. It is believed that self-determination creates a feeling of autonomy and by doing so promotes personal growth – which includes learning about social and environmental interdependencies.

What does all this analysis of *H. sustinens* mean for ACM? Our evolution has given us plenty of practice at being communicative and cooperative. We are capable of emotional attachment to nature. We are extremely capable of learning and innovating – as long as it is an emotionally positive experience. And we learn best and most comprehensively when we are unfettered in the choice and conduct of our activities. For ACM this means that successful cooperation is entirely possible, if the associated learning process is an emotionally positive one. This is more likely to be the case when the amount of 'co' in ACM is closer to the *laissez-faire* end of the collaboration continuum, thereby facilitating individual self-determination and the emergence of *H. sustinens*.

SIX

Prediction: Modelling and Analysis – Finding our Inner Magicians

'PREDICTION IS VERY DIFFICULT, especially if it's about the future.'
– Niels Bohr. Physicist and Nobel Laureate. ca 1920.

'NO MODEL EXISTS FOR him who seeks what he has never seen.'
– Paul Eluard. French poet and artist. Co-founder of surrealist movement. ca 1930.

'BUT HOW CAN ANYONE PREDICT where science and technology will take us? Although many scientists and technologists have tried to do this, isn't it curious that the most successful attempts were those of science fiction writers?
– Marvin Minsky. Professor, Massachusetts Institute of Technology and Director of MIT Media Lab and AI Lab. 1994.

ECOLOGISTS HAVE TAUGHT US THE difficulty in moving from a laboratory- or plot-scale experiment to a landscape or ecosystem scale. Complex systems behave in a scale-dependent manner. Their self-organising capacity, the manner in which they generate surprises and respond to shocks, are all attributes we attempt to observe, understand and explain. Models play a critical role in this.

Social scientists – and economists in particular – have a great fondness for models. With equal ease we happily model entire continental economies or individual households. We model the price of petroleum in 2050, we model the likelihood of someone taking a bus or car to work, and we model the response of corn production to rainfall. We are particularly fond of modelling prices and values – of commodities, of individuals' enjoyment of rainforests, of biodiversity, and even of chewing sticks used to clean teeth. All of these models give us insights into how systems work and how people behave and interact. From these insights we gain knowledge, some of which may be useful in designing policies or in adapting our own actions.

The desire to understand systems and to design policies persists, even now that we recognise that the systems we need to understand and manage are complex systems within the panarchy. In this chapter we ask, 'Are the models of yesteryear up to the task?'

Conventional Economic Modelling Revisited

A treatise on conventional economic modelling techniques would fill volumes. Our intent here is simply to make some general observations of how conventional economic modelling can or cannot fit into a complex systems framework.[13]

Most conventional economic modelling is deterministic. Economic models generally provide crisp predictions once they are provided with input data or observations. These crisp predictions will have confidence intervals attached to them, using accepted statistical procedures. The greatest strength of using such models to describe complicated systems is that: (i) the model builders gain insights into how the systems function; and (ii) through simulation it is possible to conduct experiments to determine which factors have the greatest impact on the deterministic outcomes. Such conventional modelling cannot address many of the attributes of complex systems, which are typically not deterministic.

Many models operate within a neo-classical partial equilibrium framework. Assumptions of partial equilibrium prevail in most economic modelling efforts. This is associated with the well-known *ceteris paribus* assumptions. Under this construct, an intervention or change is small enough that it affects local conditions, but does not cause a major shift or realignment of the system. This assumption is often violated in complex systems. The violation occurs because of feedback effects or because the interventions are of a large enough scale that they influence factors outside of the local neighbourhood.

Few dynamic economic models incorporate learning and time scales are inadequate. Dynamic modelling and time-series analyses seldom include a learning function in any explicit form. This is not because analysts are unaware of learning behaviour; it usually arises simply because of the nature of time-series analysis. It is statistically difficult to isolate different trends, and learning may look little different from or may be correlated to other trends. In using such models for prediction, it becomes even more difficult to model a learning variable over the longer time scales that are typically of interest to us in managing complex bio-economic systems. As complex adaptive systems explicitly need to incorporate learning, conventional economic modelling often falls short of meeting this requirement.

Most conventional models implicitly treat environment as an external factor. The usual treatment of the environment in conventional models is to regard it as an input. This means that water, forest products or other natural goods are simply treated as factors of production that may be substituted with other factors of production (labour, technology, etc.) The limits of such substitution are frequently questioned and, in complex systems, substitution is a much more sophisticated strategy than what is usually modelled in economic studies. Again, this treatment of the environment as an external factor is a special case of partial equilibrium analysis.

Human behavioural models reveal individual strategies. One useful attribute of many economic modelling efforts is that they provide insights into human behaviour at a microeconomic level. Individual choice and preference models are capable of revealing how individuals will respond or adapt when faced with various choices or stimuli. This type of parametric information has been successfully used in more complex models. It provides an example that *economic models can often describe well the simple and complicated components of some subsystems*.

Economic gaming models describe strategic behaviour and learning. Economic models have at times been cast in 'gaming' terms to describe the strategic behaviour of interacting agents. The well known textbook example of this is that of oligopolies or duopolies, but gaming and simulation have a long history in economic thought dating back to the work of von Neumann and Morgenstern (1944) that now finds its place in many other areas (Schelling 1978; Hofstadter 1979; Gintis 2000b) Lessons from such modelling of gaming contributed to our understanding that rational utility-maximising agents may voluntarily select common-property management as a preferred alternative over open-access and private property (Runge 1986). Such models have also provided us with greater insights into how reciprocal (tit-for-tat) strategies might influence economic outcomes (Gintis 2000a) or contribute to a preference for collectivisation (Ostrom *et al*. 1994).

Hybrid Economic Models

We classify hybrid models loosely as a first-generation type of model that attempts to link economic attributes to other (primarily environmental) factors. In practice, these models attempt to address some of the concerns related to partial equilibrium or try to bring environmental factors into the realm of economic analysis.

Much of the recent modelling effort here has been in the realm of relatively simple extensions to conventional economic valuation. Most of these involve some style of linkage model that draws connections between one or more larger systems, such as the 'economy' and the 'environment'. The models are then used as an educational tool to show the relative values of environmental resources, or as a policy tool to inform how resource allocation might be accomplished more effectively (in economic terms). Many of these models also take steps to connect other systems that may share a common geographic area (e.g., coastal-zone models that look at agriculture, fishery and mangrove forest trade-offs).

These hybrid models do contribute to our understanding of systems, to the extent that they start to show how parts of the systems may behave. They do not, however, directly describe a complete complex system. We feel compelled to comment briefly at this stage on the increasingly common practice of 'benefit transfer'. This highly reductionistic procedure involves taking valuation results from one study area, and transferring the values to some other study area. The transfer is usually accomplished on the basis of a few normalising transfer coefficients (e.g., population, incomes, ecosystem area). Experimentation and testing of this technique has generally shown that complicated and theoretically sound benefit-transfer models are very poor predictors, and that 'naïve' models with no theoretical basis do a reasonably good job (Navrud 1996). While researchers are still puzzled by this result, we suspect that the answers lay somewhere in complex systems theory.

Another form of hybrid model is the systematic aggregation and connection of observations resulting from separate forms of models. Bouman *et al*. (2000) take this approach to compare models of substance flow analysis, life-cycle assessment and partial equilibrium analysis. Rather than attempting to link these models explicitly into a single model – with its itinerant complexities and difficulties of understanding – they elect to keep the models separate and conduct the integration at the interpretative stage. This type of modelling moves away from the black box approach that policy-makers often have difficulty with, and relies also to a greater extent on the judgement and experience of the investigators.

Modelling Frontiers

The primary means found to date to investigate larger complex systems phenomena is through the use of simulation. Describing such systems has led to the development of complex system simulator models that augment simple deterministic cause-effect models.

One risk in using complex system models is that they have a tendency to become overly complex. There is often a temptation to try to model the entire system, which can add complexity without necessarily adding to understanding. The more successful techniques are those using intuitive interfaces between the analyst and the model, in effect permitting the model to grow as the analyst becomes familiar with how well the model represents actual situations. Much of the work done to date in ecological economics has focussed on the use of a dynamic modelling environment, which permits linking of ecological, social and economic parameters (many of these are based on models such as the STELLA II framework developed by Hannon and Ruth, 1994). More complex causal sequences have been developed using fuzzy logic models or neural network models that permit the use of qualitative information in an organised cause-effect type of structure (Munda 1995; Ruitenbeek *et al.* 1999; Tinch 2000). While all of these methods are still in their infancy, it is expected that their application to all resource management problems – including sustainable forestry – will expand as analysts gain familiarity with the relative simplicity of the techniques.

In most senses, however, these models remain deterministic to the extent that they still typically represent a large number of individual local relationships. The types of surprises they generate are generally less surprising than the ones we encounter in real life.

A Note on Rule-based Models

A relatively new type of modelling available is what we characterise as 'rule-based models'. Most of these include some form of the human behavioural model that differs from the neo-classical assumptions of strict rationality.[14] Such models have the ultimate in bottom-up structure as they intend explicitly to define the rules by which individual parts of a system interact or behave. Fuzzy logic rule bases (Kosko 1992, 1993; Bardossy and Duckstein 1995), strategic rules within repeated games (Gintis 2000a, b; Jager *et al.* 2000) and rule-based constraints on behaviour within experimental economics (Ostrom *et al.* 1994; Ostrom 1999a, b) are examples of such modelling techniques.

What these modelling techniques do, in essence, is attempt to describe the core components of a complex system model. They build on gaming structures and introduce explicit institutional and other variables. Through simulation, it becomes possible to see what sort of properties emerge from the rules. To date, very little empirical work has been conducted within this realm. One interesting recent result is that certain types of institutions tend to emerge from such models, rather than being imposed externally (Weisbuch 2000).

Another intent of many of these models follows implicitly from the observation by Norton *et al.* (1998) that preferences are not invariant; they are themselves endogenous and can evolve as a system evolves or changes. Within the forestry sector, Hyde and Köhlin (2000) also note that forest inhabitants have a remarkable capacity to adapt and change their preferences in the face of environmental shocks and disruptions. While this observation does not seem very profound to anybody that is familiar with their own preferences (and how often we tend to change our minds about things), it draws attention to the fact that most conventional modelling techniques in fact assume that preference structures and individual behaviours remain invariant. Similarly, most policies are designed based on this assumption. In the longer term the assumption of varying preferences thus also opens a new and obvious avenue for policy: the manipulation of such preferences through education, advertising or shifting of cultural norms.

A Note on Bayesian Analysis

The Reverend Thomas Bayes is a much-maligned mathematician born in London in 1702. In addition to being a Presbyterian minister, he invented Bayesian statistics and established a basis for much of modern statistical inference. But the methods in common use today differ from those he contemplated. In Bayesian statistics, we adjust our expectations as we make more observations through time. In an oft-used example, a new child in the world may start by assigning a 50/50 chance that the sun will rise the next day. Upon observing that it does rise, the child might then adjust its expectations for the next day; it expects a 67% probability that the sun will rise. This progression then continues – 75%, 80%, 83%, 85%, and so on – until quite quickly it has a high expectation that the sun will rise every day (but note that it is never quite 100% certain!). This method of statistical experimentation, analysis and interpretation permits ongoing adaptation. It was tossed out for various reasons by the more conventional styles of probabilistic statistics to which we have become accustomed. These conventional methods require us to make a large number of observations before we can come up with answers with adequate degrees of confidence. But these conventional analyses are not often very helpful in current complex systems research. By the time we can predict with some certainty that the world is going to hell in a hand basket, it may be too late to do anything about it. Bayesian statistics, in effect, provides a sound mechanism that permits us to pay attention to early warning signs.

Interestingly, Peter Kennedy – a leading econometrician and statistician – observed in 1985 that Bayesian statistical analyses could in many ways be regarded as superior to conventional analyses for a number of reasons. He noted that a major reason that they were not being adopted, was simply because of the computational complexity of doing Bayesian statistics properly. He predicted that, as computers became faster and more accessible, Bayesian statistics could again be used. Slowly, this prediction seems to be unfolding. Bayesian methods are being employed with greater frequency, and even the venerable *Economist* magazine recently carried an article on the trend ('In praise of Bayes,' 28 September 2000). Bayesian analysis may soon emerge as a cornerstone of the analysis of adaptive systems.

Summary

Among the most promising concerted efforts to look at modelling over the next few years is that being spear-headed by the Resilience Alliance. Its programme to 2002 calls for the development of models that are capable of addressing issues within the panarchy. It will integrate ecological, economic, social, political and institutional aspects into the overall modelling efforts, using state-of-the-art techniques coupled with case studies to test and demonstrate the models.

We have often commented that, in our view, some of the economic modelling that is going on is getting somewhat ahead of itself. We have been personally involved in a series of interdisciplinary modelling efforts over the past 10 years that have shown us that it is possible to construct very complex models of complex bio-economic systems. We have modelled tropical forest and mangrove system dynamics using conventional structures (Ruitenbeek 1992, 1994); we have modelled the impacts of nuclear reactor leaks within a complex socio-economic/ environmental model using STELLA (Ruitenbeek and Cartier 1996); we have modelled coastal zone dynamics using fuzzy logic systems around an ecological dose-response function (Ruitenbeek *et al*. 1999); and we have modelled marine and coral reef biodiversity and bio-prospecting values using simulation tools and state-of-the-art information from marine ecology, political economy and economic science (Ruitenbeek and Cartier 2001). From our experience with our models and that of others, we observe that much economic modelling in this realm remains an 'art aspiring to science'. The more esoteric systems models in which we have been involved appear to many as 'magic aspiring to art'.

In that respect we must always remember why we are doing this modelling. In our view, it is to gain understanding of the systems and to inform policy. Decision-makers have historically shunned 'black-box' modelling, and we still find that our more successful efforts are those in which we have used simpler models that provide hands-on opportunities for the policy-makers and decision-makers to become involved. This places an even greater burden on the modeller as the procedure is somewhat as follows: (i) observe and understand the complex system as best as possible; (ii) construct a complex system model that helps us further understand the dynamics and adaptive capacity of that system; and, (iii) design a simplified version of that model that is accessible to decision-makers and that captures some of the main features of the complex system.[15] In moving through these realms, we probably begin to look like conjurers.

SEVEN

Policies: Pushing the Right Buttons

'If God had wanted a Panama Canal, he would have put one here.'

– King Philip II of Spain. ca. 1552.

'If it ain't broke, don't fix it.'

– Ann Landers. Newspaper columnist. 1980s.

We have pointed out at length that some aspects of ACM are emergent. We have also spoken of consciousness, noting that consciousness is itself an emergent property of complex neurological systems. We long for that consciousness to happen at a larger scale, too. We hope for a global awakening – a *prise de conscience* – around the need for preservation of our planet. We look hard for that collective consciousness in those around us. We search for *H. sustinens*, but too often we are disappointed and run into zombies.

Much of the literature on ACM looks at how we can best introduce ACM into a system; ACM is treated as a packaged strategy in such a context. Policies intend to deliver ACM, or impose it. It seems to us that the purpose of policy is two-fold, and that the delivery of an ACM package is *not* one of these purposes. The first purpose of policy should be to protect the conditions of emergence. The second purpose of policy is what we shall call dezombification.

To Intervene or Not to Intervene?

In our preface, we asked readers to suspend their disbelief and think of the possibility that it might make most sense in some instances to not intervene. Axelrod and Cohen (1999) have argued that it is possible to harness complexity through appropriate interventions, even though it may not be possible to control it. Identifying such appropriate interventions is certainly non-trivial. Policy advice to 'introduce adaptive co-management regimes', seems easy to dispense, but it can be more disruptive than productive.

In deciding whether to intervene, or not, one should ask a number of questions. These questions may seem somewhat rhetorical, but they do give insights into whether an intervention should proceed.

Will the intervention itself generate a learning experience? Minimally this requires monitoring the effects of the intervention, but it also requires introducing opportunities to change or withdraw the intervention.

Do I as a designer know more about the system than the agents in introducing this intervention? This is a common presumption in policy design, and it is often false. Fishers are notoriously good at outsmarting government regulations and bureaucrats simply because they have more information than the policy-makers.

If I as designer do know more than the agents, am I better off implementing the intervention or simply giving the information to the agents? Quite often, agents will be able to use the information more efficiently than the policy-maker can.

Is the timing right? As a policy-maker one needs to consider the timing of an intervention in the context of the state of the system. Given that a complex system goes through various adaptive stages, it follows that there may be good times and bad times to introduce interventions. This point seems obvious, but it bears reiteration. What is often forgotten is that the right timing may well be years away.

Finally, does the intervention protect conditions for the emergence of adaptive management properties? If the answers to this and the other questions seem favourable, then one might attempt an intervention. If not, however, then one might be better off to let the system generate its own course. In all humility, we note that the answers to these questions have no nice metric. Much will depend on the experience of managers and policy-makers who themselves are conversant with systems thinking.

A Policy Framework

There are a number of available frameworks for addressing economic policy problems (Munasinghe and Cruz 1995; Munasinghe 2001). We shall here focus on a framework that is most directly associated with issues relating to adaptation and devolution, elaborating on a framework developed by Serôa da Motta *et al*. (1999).

A few general economic principles form the background philosophy for any economically and environmentally sustainable strategy. The two most often enunciated include the polluter pay and precautionary principles. The polluter pay (or user pay) principle assigns rights that create an incentive effect that is intended to promote proper resource use. The precautionary principle provides a mechanism for dealing with the uncertainty of impacts (Perrings 1991; O'Riordan and Cameron 1995; Perrings *et al*. 1997), and is also an underlying focus of adaptive management. The precautionary principle also has strong moral and ethical imperatives attached to it (Ruitenbeek 1997) and thus has a behavioural link that extends beyond conventional treatments of rationality within *Homo economicus*.

A number of market-based incentive (MBI) mechanisms have been developed and used to promote these principles (Tietenberg 1990, 1996; Eröcal 1991; Kreimer *et al*. 1993; Panayotou 1995). At one extreme, they include fines or sanctions that are linked to traditional command and control (CAC) regulations. At the other extreme, they include *laissez-faire* approaches that require consumer advocacy or private litigation to act as incentives for improving environmental management. In between, we find more familiar tax and subsidy approaches as well as the less familiar mechanisms relying on traded property rights. All of these approaches, in their own fashion, attempt to influence the behavioural strategies of agents.

There is a broad spectrum of instruments that might be available, all of which implicitly or explicitly have some incentive effect (see Box 3). These occur across a continuum ranging from very strict command approaches to decentralised approaches that rely more on market or legal mechanisms. Even traditional CAC regulations, with heavy fines, create a presumed incentive effect because a resource user would be compelled to comply with the regulations to avoid the sanctions. In principle, therefore, there is a wide range of methods available for attempting to regulate or manage environmental quality. Each of these intends to address a variety of goals.

One goal associated with decentralised decision-making relates to cost-effectiveness. The asymmetry of information, for example, often implies that private agents are more likely than governments to identify the most cost-effective means for achieving a given level of resource use. This forms the basis for the common theoretical result that – if one focuses entirely on private costs – strong forms of MBIs are more cost-effective than their weaker counterparts or than CAC approaches.

Another fundamental goal of most policy is to decrease externalities. Externalities exist where the agent making the production or consumption decision does not bear all of the costs or benefits of his or her decision. Externalities abound in environmental issues and within complex systems. Pollution disposed of into a waterway may be a low-cost solution to waste disposal for the polluter, but firms and individuals downstream may suffer consequences through higher costs from lost fishery production, higher water-treatment costs, lower amenity values (for recreation) or loss of critical drinking water supplies. Most economic incentive structures attempt to transfer some of this cost back to the individual responsible for the decision. A similar situation could exist with environmentally beneficial decisions. A firm that cleans polluted intake water and then discharges clean water after using it in its internal process would, in fact, be creating a positive externality. In such cases, it could be argued that it makes sense to subsidise such a firm in proportion to the value of this external benefit.

A third goal that many policy-makers have when designing an appropriate economic incentive system is that associated with revenue generation. There are, however, practical trade-offs to consider between revenue generation and incentive effects. In principle, it would be possible to levy a very high charge that effectively discourages all polluting activity. Abatement levels would be very high in such a case, but no revenue would be generated. Similarly, very low charges would generate little revenue and little abatement because there is no incentive for firms to reduce pollution. Typically, the abatement/revenue function is an 'inverted U', which maximises revenue at some intermediate level of abatement. A policy decision must be made relating to how much additional revenue (beyond the maximum) an agency is willing to give up to generate higher levels of abatement. The answer to this policy question should be related to the marginal benefits of pollution abatement, but it is in fact typically more a function of government budgetary realities that regard such taxes as a convenient means for underwriting environmental management efforts.

Finally, policy-makers are continually faced with high levels of scientific uncertainty in designing regulatory systems; one goal of intervention is to address uncertainty. This has caused some analysts (Lonergan *et al*. 1994) to recommend the use of surcharges to deal with some of the uncertainties of resource use in a complex system.

The relevant question becomes, 'Which policy options or measures are most effective in addressing specific objectives?'

We note that Box 3 characterises a continuum according to levels of flexibility and government involvement. In principle, any of these may be useful within a co-management framework, but we note that some implicitly require a greater role by central government. In a complex systems framework, any of these potential interventions can be regarded as a method to regulate interaction. The selection of an appropriate mechanism would depend, in our view, on the nature of the system. If, for example, there were established and

Box 3. Classification of Policy Instruments (adapted from Serôa da Motta, Huber and Ruitenbeek 1999)

← MINIMUM FLEXIBILITY →		← MODERATE FLEXIBILITY →		← MAXIMUM FLEXIBILITY →
← MAXIMUM GOVERNMENT INVOLVEMENT →			← INCREASED PRIVATE INITIATIVE →	
← CONTROL-ORIENTED →		← MARKET-ORIENTED →		← LITIGATION-ORIENTED →
General Examples Regulations & Sanctions	Charges, Taxes & Fees	Market Creation	Final Demand Intervention	Liability Legislation
<u>Standards</u>: Government restricts nature and amount of pollution or resource use for individual polluters or resource users. Compliance is monitored and sanctions imposed (fines, closure, jail terms) for non-compliance.	<u>Effluent or user charges</u>: Government charges fee to individual polluters or resource users based on amount of pollution or resource use and nature of receiving medium. Fee is high enough to create incentive to reduce impacts.	<u>Tradable permits</u>: Government establishes a system of tradable pollution or resource-use permits, auctions or distributes permits, and monitors compliance. Polluters or resource users trade permits at unregulated market prices.	<u>Performance rating</u>: Government supports a labelling or performance-rating programme that requires disclosure of environmental information on the final end-use product. Performance based on adoption of ISO 14000 voluntary guidelines (e.g., zero discharge of pollutants, mitigation plans submitted, pollution-prevention technology adopts, re-use policies and recycling of wastes). Eco-labels are attached to 'environmentally friendly' products'	<u>Strict liability legislation</u>: The polluter or resource user is required by law to pay any damages to those negatively affected. Damaged parties collect settlements through litigation and court system.
Specific Examples of Applications				
• Logging standards • Licensing of activities • Land-use restrictions • Construction-impact regulations for forest roads • Environmental guidelines for road alignments or stream crossings • Fines for illegal harvesting • Bans applied to log exports	• Non-compliance pollution charges • Greening of conventional taxes • Royalties and financial compensation for forestry exploitation • Performance bonds posted for logging standards • Taxes affecting harvesting methods • Taxes to encourage re-use or recycling of problem materials • Source-based pollution charges to reduce downstream water treating requirements	• Market-based expropriation for construction, including environmental values • Property rights attached to resources potentially impacted by development (forests, lands, artisanal fish) • Deposit-refund systems • Tradable permits for water-abstraction rights, and water and air pollution emissions	• Consumer product labelling (eco-labels) relating to sustainable harvesting • Education regarding proper practices • Disclosure legislation requiring manufacturers to publish information on harvesting practices • Black-list of bad firms or locations • Voluntary self-regulation of industry	• Damages compensation • Liability on neglecting firm's managers and environmental authorities • Long-term performance bonds posted for potential or uncertain hazards from harvesting activity • 'Zero net impact' requirements for road construction and water crossings

functioning social institutions in place, decentralised instruments requiring little government involvement may be a good policy choice. Conversely, imposing strong external regulations within such a context could disrupt any positive natural evolution that might occur. Within the context of devolution, revenue sharing often becomes a volatile co-management issue and it may be that schemes that do not rely on such revenue generation will provide a more stable institutional context if participants are not accustomed to working collaboratively.

Protecting the Conditions for Emergence

A central goal of any policy must be to protect the conditions of emergence of ACM. Within a CS framework, there are a few things that can be done to contribute to this.

Foremost, the importance of social capital must not be underestimated. *Policy must ensure that social capital remains intact*. Typical threats to social capital include disempowerment of local organisations, programmed failures and imposed distribution patterns.

- *Disempowerment*. A programme that disempowers local organisations is doomed to failure, but in the process it may also damage social capital by challenging existing social structures and attitudes of social trust and respect. Local groups and their networks are indicators of social capital. If they are disempowered individually or collectively, existing social structures are in effect invalidated and undermined.

- *Programmed failure*. Programme designs that threatened the possibility of initial successes through under-funding (financially or otherwise); or ambitious implementation time frames can damage participants' mutual trust and belief in a collective effort. Programme successes in the initial stages, no matter how minor, are critical for sustaining motivation.

- *Imposed distribution pattern*. Programme designs that impose a pattern of output or input distribution (or reinforce a local power imbalance) can undermine existing norms of reciprocity, creating social conflict. Participants must determine how they will share the benefits (and tasks) of the programme to sustain collective motivation and participation.

As we noted previously, social capital takes a long time to create but can be destroyed very rapidly.

Second, policies must facilitate copying and variation. This means that options should not be unilaterally removed, and that potential avenues of investigation should not be blocked. In effect, this means that agents should not be unduly hindered in their ability to change their strategies. Strong regulations with heavy-handed rules are an obvious case in which flexibility is limited. Also, many relatively *soft* policies can be used to facilitate detection and copying of successful strategies. Simple information sharing and exchange provides a supportive function in this case.

Third, we reiterate that policy *timing* is often everything in a dynamic system. A local system may be at a stage of evolution where it might benefit from having a strong leader. But one cannot simply walk in, put someone in charge and expect good things to happen. Similarly, as we noted above, revenue sharing is often a volatile issue and it may make sense to defer the introduction of such mechanisms until the timing is right. If one is going to intervene in such circumstances, some cunning will be required.

Dezombification Etcetera

The main point of dezombification is that a policy should contribute to the consciousness of the agents within the system. We have stated that this consciousness applies to a few things. First, agents must be conscious that they are capable of learning. Second, they must be conscious that they are capable of adapting. And third, they must be aware that they are in fact part of a complex system and that simple cause-effect relationships may not apply. A part of this consciousness is also that, as agents within the system, they are not powerless. Many individuals feel disempowered when they are in a large system or collective; but the butterfly effect illustrates very well that even small perturbations can have significant effects within a complex system.

This deliberate consciousness raising can be done using various policy instruments. The first of these is obvious: education and awareness-building. This involves simply explaining the ideas of complex interactions to people. Many will be able to draw on examples from their own experience.

Second, economic incentives can be adjusted to link more directly to social aims, as opposed to personal aims. Similarly, incentives can be re-oriented away from blatant economic criteria, towards other criteria that reflect social values. As we noted earlier, people respond to more than just self-interest, and people feel rewarded by things other than money. Incentives based on non-monetary social values will therefore also remind people that there are common social goals and that they are part of a broader system. The use of narrow monetary instruments focusing on self-interest merely tends to reinforce the view that people live in a very simple and limited cause-effect world. Instead of just fining illegal tree felling we can be giving out green prizes for innovative land-reclamation techniques.

Third, we should use policies to reinforce basic ideas of complex systems management. One example of this is promoting redundancy. Another example is promoting failsafe methods. As people experience the benefits of redundancy and failsafe systems, they will also appreciate that they live within a complex system. Too often we are still in Mark Twain's world where he counselled, 'put all your eggs in one basket and watch that basket'. We need to move away from that. Having more than one basket can make sense. It is not inefficient. It is sensible policy in a complex world.

What Next? A Panarchist's Cookbook

In 1971 a book was published that was immediately banned in many countries. It was a practical guide to living in a complex and chaotic world. It counselled what to do in the face of civil strife, and what strategies would work best to protect oneself in a hostile society. It gave advice on how to wield information in useful strategic ways. It was banned because it also showed explicitly how to do a few things that were not in favour with civil society of the day. It showed how to set wiretaps. It showed how to make a grenade launcher out of a shotgun. It showed how to manufacture hallucinogens and explosives. It showed how to question authority. The book was written by William Powell and is entitled *The anarchist's cookbook*. The author believed at the time that the book showed people how to participate meaningfully in a world that needed to change. It showed how to create chaos.[16]

Thirty years later we are in a somewhat different situation. We still want to participate meaningfully in a world we think needs to be changed. But we are not trying to create chaos. Quite the contrary; we want to harness the complexity and reduce the chaos. But we lack a policy manual. We need a Panarchist's Cookbook. Alas, there is no such thing. We shall have to collectively write it.

On that note, we will comment on one final potential role for policy. Our god Pan was, as we now know, somewhat of a devious character ... at times a prankster. We also know that complex systems can seemingly stagnate, and that positive changes and adaptation often occur in response to a crisis. It thus seems plausible that one role of policy might be that of Pan the prankster: introduce a crisis to a stagnating or wallowing system. Sometimes we need a wake-up call. Sometimes it makes sense to release stress in a continuous series of small short crises, rather than wait for an unmanageable crisis. The small crises help us learn and prepare for what lies ahead. Think of it as living on the slopes of a volcano. A small rumbling every few years prepares us, teaches us how to adapt and makes the volcano less dangerous. Long periods of inactivity, followed by cataclysmic eruptions, leave us complacent, unprepared and, quite possibly, dead.

EIGHT

Pedagogy: A Brief Research Agenda

'I AM TIRED OF ALL THIS THING called science. We have spent millions in that sort of thing for the last few years, and it is time it should be stopped.'

– Simon Cameron. US Senator from Pennsylvania. 1861.

DEAN, TO THE PHYSICS department. 'Why do I always have to give you guys so much money, for laboratories and expensive equipment and stuff. Why couldn't you be like the math department – all they need is money for pencils, paper and waste-paper baskets. Or even better, like the philosophy department. All they need are pencils and paper.'

– Anon. 20th century.

BY THE EARLY TWENTIETH CENTURY, contemporary science had effectively banished the word 'purpose' from its vocabulary (Koestler 1959). Falling stones were no longer trying to find their Aristotelian home or *telos*. The stars no longer had the purpose of serving as chronometers to profiting man. The tentative Galilean scientific revolution had come its full distance; the space-spirit hierarchy was replaced by the space-time continuum. At one time, this realm of investigation was called the philosophy of nature. Now it is called science.

But in defining the panarchy, in studying complex systems, and in looking at adaptive co-management we cannot help but notice that the terms *goal*, *purpose* and *objective* continually creep into the discussion. Indeed, the formal complex systems framework we use in this paper explicitly calls for *measures of success*, linking these in some fashion to human well-being and sustainability. Does science indeed have a role to play in all of this?

Basic and Applied Research within a Complex Systems Framework

In a nutshell, our research agenda must permit us to move consciously into a realm of systems thinking, rather than relying solely on our deterministic roots. As a starting point, that will require a thorough review of past work to see if its prescriptions are still consistent with the broader ideas of panarchy and systems thinking.

More specifically, within the arena of ACM, we feel that much work is still needed that revisits the notion of whether ACM is an emergent property or a legitimate policy tool. The arguments in this paper focus on the idea that ACM is emergent, and that policy's primary role is one of supporting the conditions for emergence. But the hypothesis remains on thin ice at this stage because there has not been a lot of opportunity for empirical testing. The judgements and skills of investigators in many disciplines working in many different bio-economic systems will be needed to address this research question.

Within the area of modelling, we generally believe that the modelling priorities and directions being followed by the Resilience Alliance are on the right track. They work within the conceptual framework of a panarchy and grapple with both the intersectoral linkages and the complex systems dynamics that will need to be addressed. Specifically, we see the increased use of Bayesian techniques and rule-based modelling as promising.

Within the area of economic incentives, research must look at what constitutes incentive, measures of success and credit at the local level. ACM seems to emerge or work most effectively where there is high dependence on a bio-economic system, homogeneity of vision and high penalties for failure. Incentive policies should rely less on simple cause-effect models of monetary reward and punishment, and research should look to incentive structures that may more clearly link system effects into individual behaviour. Policies that promote redundancy or failsafe strategies are also in order.

Research is also still needed in the role of consciousness within an adaptive system. This aspect has been, in our view, under-represented in recent work and remains absent from many research programmes. In this respect, we should welcome more philosophers onto our research teams. If our policies are to promote dezombification, as we define the policy role of consciousness raising, then we will need philosophers to tell us if we are, indeed, ridding the world of the zombies.

Finally, we see a somewhat different role for ongoing research into criteria and indicators (C&I). Historically, the treatment of such indicators has been very reductionistic, and some analysts (Colfer and Byron 2001; Prabhu *et al*. 2001) have questioned what the role of C&I might be if we re-orient our work in a complex systems framework. But these indicators still have some key roles to play within adaptive management. First, C&I remain powerful tools for learning and awareness building if they are used by those agents and individuals directly involved in forest management; they contribute directly to dezombification. Second, we must remind ourselves that some components of a complex system are, in fact, quite simple and may in fact be described very well by simple cause-effect relationships; C&I remain important within this context. Finally, and as a research priority, C&I research should also be directed to look for short-term, finer-grained criteria of success that can usefully stand in for longer-run, broader goals. This is a central prescript of CS analysis, and this 'stand-in' function is what most agents in fact do within complex systems when they identify and copy successful behaviour.

Recap

Where were we? In Galileo's time, at the University of Pisa, philosophers were revered and paid more than anybody. Natural scientists were tolerated but those on the frontiers were banished or jailed. There were probably some economists around, but history is oblivious to them.

Where are we now? Three hundred years later, it seems that the economists are most revered and highly paid. The plight of natural scientists has not changed much; those on the frontiers still have a tough time, although they are usually not imprisoned for their views. The world now seems oblivious to its philosophers.

Where should we be heading? We probably need to borrow some from the old and try to re-invent science, once again. The recipe seems straightforward: pay the philosophers more, become more tolerant of those scientists on the frontier, and perhaps banish some of the economists.

NINE

A Grain of Salt: ACM Revisited

'I THINK THE WORLD IS GOING TO BLOW UP in seven years. The public is entitled to a good time during those seven years.

– Henry Luce, publisher of *Time*, *Life* and *Fortune*, explaining why he would publish *Sports Illustrated*. ca. 1954.

THE SORROWS AND HOPES OF OUR TIME undoubtedly stem from material causes, economic and technical factors which play an essential role in the course of human history, but even more profoundly they stem from the ideas, the drama in which the spirit is involved, the invisible forces which arise and develop in our minds and hearts. History is not a mechanical unfolding of events into the midst of which man is simply placed like a stranger. Human history is human in its very essence; it is the history of our own being, of miserable flesh, subject to all the servitudes imposed by nature and by its own weakness, which is, however, inhabited and enlightened by the spirit and endowed with the dangerous privilege of freedom. Nothing is more important than the events which occur within that invisible universe which is the mind of man. And the light of that universe is knowledge. If we are concerned with the future of civilization we must be concerned primarily with a genuine understanding of what knowledge is, its value, its degrees, and how it can foster the inner unity of the human being.

Jacques Maritain, French philosopher. Early 20th century.

'It's the work of a madman.'

–Ambroise Vollard. French art dealer, viewing a Picasso painting. 1907.

SOMETIMES WE MAKE MISTAKES. That is, after all, the point of experimentation and learning. This also implies, however, that we must be prepared to revisit concepts and ideas and perhaps to discard some of those ideas if they are found to be wanting. Many hold up the idea of adaptive co-management as a panacea, hoping to solve all sorts of problems within forestry, fisheries or other bio-economic systems. While this is an exciting prospect, we must be careful in how we interpret and implement our ideas around ACM.

We are Part of the Process

In particular, we must acknowledge that sub-subsystems exist within subsystems, which exist within systems. It is tempting to look back to how people historically looked at epicycles of planetary motion, lunar motion, earth's rotation, and how these all interlinked to influence other circles of motion on our earth. Economic systems, ecological systems, social systems and the political and institutional settings in which they find themselves are all among these circles. We may now call these earthly circles the panarchy.

But we are all part of that panarchy, and how we see ourselves within it will influence our actions and our overall outlook. We can consider ourselves as being in any one of at least three potential roles. As *observers*, we can attempt to describe how the panarchy works, how agents behave within it, and the prospects for its sustainability and perhaps even its betterment. In that role of observer, we remain in a relatively isolated place. Our second potential role is that of *designer* or *policy-maker*. In this role, we are an active agent within a slightly larger system that includes us within that system. The specific role we have to play is that of monitor, analyst and, ultimately, that of one who might prescribe how to influence the entire system. This role has attached to it some fairly onerous responsibilities. Third, however, and perhaps most realistically, we must regard ourselves as *players* in multiple roles within the overall system that is this panarchy. We are, each and every one of us, a researcher, a consumer, a producer, a polluter, a diplomat, a philosopher, a citizen, a teacher and a student. We test out strategies in each of these roles, as we play this game of life. We can hope only that we do this consciously, conscientiously and heedful not just of our own interests, but of the interests of others and of the society at large.

A Reality Check

In this paper we seek primarily to look at how various aspects of ACM might be considered from an economic perspective. The main message that we want to drive home is that ACM is not just some strategy that one can impose externally on any group of innocent bystanders. ACM is potentially something that emerges naturally from a complex bio-economic system. There may well exist an invisible wand, driven by individuals' altruistic dispositions to the common good, that causes ACM to emerge as a property of the system.

If it does so emerge, then it has some important implications for analysis and policy-making. Chief among these is that the role of policy is no longer simply to try to introduce ACM into a system. The role of policy is now to protect the conditions under which emergence may occur. Also, policy has a strong education and enabling function that we call dezombification. In this context, it implies that policies should attempt to introduce consciousness into the ACM regime. The consciousness and awareness revolve primarily around the fact that agents are working within a complex system, that they are capable of learning within that complex system, and that they can adapt their strategies as a result of such learning. Finally, these agents should be fully aware that they are capable of changing the rules of the system if necessary.

Systemic Cultural Change

We opened this paper on the theme that we may be on the verge of a major change in scientific paradigm. The science of complexity is gaining some currency, and deterministic science is limited to addressing problems of simpler systems. It is tempting to prescribe the use of complex systems science in all areas of human experience. But prescribing such scientific frameworks will likely not lead us very far. The new science will emerge in its own way, in its own good time. There still remain too many cultural barriers that will continue to work against the adoption of complexity as a leading scientific paradigm.

The barriers to such cultural change are manifold. First, reductionist science is well entrenched within our current learning institutions and within standard educational curricula. We are still taught, for the most part, to think inside a box rather than to think creatively outside of the box. It will take at least one generation to overcome this. Second, the cause-effect model of all interactions is omnipresent. Many parts of our society would cease to function if we discarded it. Legal responsibility falls within a cause-effect framework. Monetary rewards are dispensed according to a cause-effect framework. Punishment is doled out according to a cause/effect framework. But complex systems science requires that we downplay such interactions in many of the more problematic areas that currently confront us. It thus seems unlikely that the transition will be swift.

On the other hand, the adoption of complexity as a viewpoint is itself a potential strategy that any of us as agents are free to adopt within our broader panarchy. Just as there may be forces that prevent such adoption, there are also forces at work that implicitly promote such adoption. The evolution of the Internet has been such that it has given rise to what is being called the Net Generation (Don Tapscott 1997: *Growing Up Digital*). This ‘N-Gen’ of children and youth are all learning, playing, interacting and adapting within a digital world that still remains a mystery to most people. This generation will be very much a product of complexity. It may also be easier for it to absorb the implications of complexity as a way of thinking and as a way of solving problems and facing the future. We should not be surprised if this generation, in one fell swoop, overcomes all of the presumed barriers that have been set before it. Complex systems do, after all, generate surprises. And if there is one thing that history has taught us, it is that cultural change can be very swift. Especially when that culture faces a crisis.

> There are grounds for cautious optimism that we may now be near the end of the search for the ultimate laws of nature.
>
> Stephen W. Hawking, *A brief history of time*. 1988.

Notes and Sources

Acronyms

ACM	Adaptive Co-Management
BACH	Acronym constructed from the names of the original members of the complex systems research group at the University of Michigan: Arthur Burks, Robert Axelrod, Michael Cohen, and John Holland.
C&I	Criteria and Indicators
CAC	Command and Control
CIFOR	Center for International Forestry Research
CS	Complex System
ICZM	Integrated Coastal Zone Management
IDCI	Integrated Development and Conservation Initiative
IDP	Integrated Development Project
MBI	Market-based Instrument
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Cooperation and Development
P-A	Principal-Agent [problem]
RA	Resilience Alliance
WTA	Willingness-to-Accept [Compensation]
WTP	Willingness-to-Pay

Citations

The citations at the chapter heads of this paper are derived from various sources. In all cases attribution is certain, although the sources are at times not clear. The following provide further clarifications for those with incomplete or secondary sourcing.

Chapter One

Kingwell, Mark. This quote comes from a live CBC radio broadcast in early January 2001, during an interview regarding futurism. Kingwell is author of *Dreams of millennium* (1996).

Sagan, Carl. From Sagan (1994).

Supertramp. This is the name of one of the group's hit albums.

Chapter Two

Anonymous Saudi fisherman. The story was recounted during the presentation of Callum Roberts' paper at the International Coral Reef Symposium, Bali, Indonesia 23-27 October 2000. See Roberts (2000).

Chapter Three

Duell, Charles. This quote by Charles Duell is often repeated and the usual rumour is that he resigned his duties in the patent office because he thought nothing was worth inventing anymore. But most current historians find that this story is, itself, a myth, and that nothing of the sort was ever said, even though it was widely attributed to Duell. For more information, see Sass (1989). For more discussion around this point, see: http://www.ideafinder.com/resource/archives/wow-duell.htm.

Warner, H.M. Harry Warner did indeed say this and it is plastered all over Hollywood. It is also documented all over the Internet. In early January 2001, there were 1400 citations of this found using a typical Internet search engine.

Chapter Four

Sizzi, Francisco. Professor Sizzi was one of Galileo's contemporaries at the time that the moons of Jupiter were first seen through the newly invented telescope. This citation is documented both in Amabel Williams-Ellis' (1930) work and again in a Congressional Research Report by Nancy Gamarra (1969) dealing with erroneous predictions. If future technology is of interest to you, we refer you to the work of the Foresight Institute, which is a non-profit organisation dedicated to the use of emergent technologies associated with nanotechnology development. 'The Foresight Institute's goal is to guide emerging technologies to improve the human condition. Foresight focuses its efforts upon nanotechnology, the coming ability to build materials and products with atomic precision, and upon systems that will enhance knowledge exchange and critical discussion, thus improving public and private policy decisions.' See also http://www.foresight.org/

Carlyle, T. Documented in Fitzgibbons (1995).

Chapter Five

Drexler, Erik. Drexler founded the MIT Nanotechnology Study Group and now serves as Chair of the Foresight Institute. This citation comes from Chapter 5 of his book *Engines of creation*, originally published by Anchor Books in 1986. The entire manuscript with an updated introductory section is now available on the Internet, with permission of the copyright owner, at: http://www.foresight.org/EOC/index.html. Related work may also be found at the web site of the Institute for Molecular Manufacturing at: http://www.imm.org/

Chalmers, David. His observation relating to zombies is a self-published item on his web page dedicated to zombies entitled 'Zombies on the Web'. http://www.u.arizona.edu/~chalmers/zombies.html.

Chapter Six

Bohr, Niels. Attribution is certain if not exactly documented. The first documentation of Bohr's statement was in early 1986 at a dinner meeting in London, when historian Simon Collier used it while venturing some opinions on democracy in South America. Anne C. Peterson, Deputy Director of the National Science Foundation, so cited the Danish physicist in her address to the national Association of State Universities and Land Grant Colleges, Chicago, November 1994. She supplies a partially satisfactory ascription: Speechwriters' Newsletter, 7 October 1994.

Éluard, Paul. Precise wording is likely a translation from French, and the original source is unknown to us even after much research. The quote was originally provided to us by Ken White an econometrics professor at UBC and author of the Shazam modelling software. See White (1987).

Minsky, Marvin. Cited by: Wolf, M.T. 1994. Science fiction. Educom Review 29 (1). Educause. http://www.educause.edu/pub/er/edreview.html.

Chapter Seven

King Philip of Spain. Cited by Cerf and Navasky (1998).

Landers, Ann. Ann is the most widely syndicated columnist in the world with an estimated readership of 90 million, and appears in more than 1200 newspapers. Her advice about unbroken things appears regularly in her column.

Chapter Eight

Cameron, Simon. Cited by Cerf and Navasky (1998).

Anon. Anybody who has spent any time in any of the these departments (physics, mathematics or philosophy) will have likely seen this pinned to a wall.

Chapter Nine

Luce, Henry. Cited by Cerf and Navasky (1998).

Maritain, Jacques. From his work *Range of reason* republished in 1994 by University of Notre Dame.

Vollard, Ambroise. Vollard was referring to Picasso's paintings as the work of a madman; we again thank Ken White (1987) for this reference. But we like this quote for quite a different reason that is not covered in White's notes, and in fact has a lot to do with economics and with complex systems. The quote is in a long tradition of French references to 'madmen' that dates back to revolutionary France. The first such reference that we can find dates to the writings of Edme-François Darigrand. In two volumes in particular – *l'Anti-financier* (1763) and *l'Antropophagie, ou les antropophages* (1764) – Darigrand painted particularly gruesome pictures of the corruption within the French tax system, and the resultant oppression of the French farmers; such corruption, of course, eventually contributed to the uprisings in the French Revolution. Darigrand was imprisoned for publishing his views in 1763, and the latter volume was cited as the 'Work of a Madman' among his contemporaries. Lesson 1: Tax collectors have never been popular, but neither have been their critics. Lesson 2: Madmen may be harbingers of substantial systemic change.

Hawking, Stephen. Cited in Hawking (1988: 157).

Endnotes

[1] Acronym constructed from the names of the original members of the complex systems research group at the University of Michigan: Arthur Burks, Robert Axelrod, Michael Cohen and John Holland.

[2] An example of such a long-term adaptive management planning model is provided by Faucheux and Froger (1995), who advocate a decision-making process of *procedural rationality* as an appropriate means to address many long-range environmental problems that involve uncertainty or irreversibility. O'Connor (1993,1996) expands on the treatment of economic values within such a long-term framework.

[3] Strictly speaking, the matrix of various actors is more usually a web of numerous individuals or agents and we use the 'two actor' model as a simplification for discussion purposes. Mandy Haggith (pers. comm. 2001) describes the real-life situation as a *collaboration configuration* and argues that such a 'co-co' treatment of co-management more accurately describes the web of interactions than a simple 'co' definition would entail. In such a case, some vector or matrix l can be said to characterise these interactions. The central conclusion remains the same: an ACM structure could see ongoing variations within l as the system evolved.

[4] Some of these concepts regarding consciousness reach back to the writings of Machiavelli. They find currency in modern writings because of work surrounding

artificial intelligence; for a current review, the reader is referred to the work of David Chalmers, Director at the Center for Consciousness Studies (http://www.u.arizona.edu/~chalmers/). There remains, for example, a significant question as to whether consciousness is in fact necessary for learning to occur. Chalmers' (1996) seminal work in *The conscious mind* reviews some of these issues.

[5] See Tognetti (1997) and Colfer and Byron (2001) for reviews.

[6] The game theory literature provides a great deal of modelling experience on the presumed rational behaviour of individuals. Building on various Prisoner's Dilemma scenarios, such game theory applications have been used to attempt to explain both competitive and cooperative behaviour. The work also leads to the definition of what Hofstadter (1985) terms the 'super-rational human', one who realises that, if everybody is in the same situation with the same information, then everybody should make exactly the same decision, which will be the decision that supports the greater common good. As we note later in this paper, however, experimental evidence has never yet detected such super-rational behaviour, and even the presumed rational behaviour is somewhat elusive.

[7] There is some empirical evidence for this hypothesis. Brown and Ashman (1996) compare the relative successes of 13 projects of intersectoral cooperation between government, grassroots organisations and international donors. Successful patterns of cooperation were characteristically NGO-mediated where the NGOs had credibility across sectors; or they were grassroots-centred where grassroots organisations were well established. Programmes categorised as clear successes were those with medium to high degrees of social capital and high levels of resources for sustainability (which included government support.) The degree of social capital is measured by the number of local organisations and by the extent of their networks. A high degree of social capital along with a dense network of social interaction coupled with relationships across sectors (grassroots to universities to business leaders to international NGOs) was characteristic of the clear successes. Regarding the degree of decentralisation being an emergent property: it seems that decentralisation is enabled by greater system complexity. Where there is little social capital there is little means or inclination for local populations to participate in management decisions. The clear successes were those with the medium to high levels of effective participation or, in other words, with substantial influence in the cooperative programmes.

[8] We are grateful to Carol Colfer for pointing this out to us.

[9] Social capital is broadly defined as the structures and patterns of social interactions. It is the extent to which relationships are grounded in structures of voluntary association with commonly understood rules, norms and sanctions. It is the network of social connections. Within such structures people come together for various purposes including health, education, protection, commerce, resource management or prayer. Less broadly Ostrom (1994) defines social capital as 'the shared knowledge, understanding and patterns of interactions that a group of individuals brings to any productive activity … [It] is created when individuals learn to trust one another so that they are able to make credible commitments and rely on generalized forms of reciprocity rather than on narrow sequences of specific quid pro quo relationships'.

[10] Their paper entitled 'Zombies and the function of consciousness' is published via the Duke University and is available at http://www.duke.edu/~twp2/zombies.html Owen Flanagan is with the Departments of Philosophy, Psychology, and Neurobiology and Thomas Polger is with the Department of Philosophy. They elaborate: 'We might have been zombies. We are not. But it is notoriously difficult to explain why we are not. This problem, the problem of the evolution of consciousness, is a problem for biologists, cognitive scientists, and philosophers of mind with interest and expertise in evolutionary theory. We need theoretical cooperation from such people plus comparative psychologists, ethnologists, paleontologists, zoologists, and neuroscientists, among others. It is hard to see how the artificial intelligentsia will contribute to the next stage of work. They have helped enormously already, setting the agenda by creating zombies in our midst. They have also shown us that the problems of intelligence and consciousness divide to a point. To solve the two hard problems: how consciousness supervenes on states of matter and why it evolved in the first place requires close study of systems that are conscious, biological creatures that have evolved to be subjects of experience. Us.'

[11] Bromley (1989, 1991) covers a large number of issues within the realm of tenure that are of relevance to the general field of ACM but are beyond the scope of this paper. We generally believe that tenure is a crosscutting issue in all sustainable forest-management problems (Ruitenbeek and Cartier 1998) and many ACM issues closely parallel tenure issues. Transaction costs are one such area, but there are numerous others. For more discussion on the modelling of tenure within the context of a complex adaptive system, we urge the reader to review the Resilience Alliance planned programme to 2002, which has a research component dedicated to tenure (http://www.resalliance.org/).

[12] OECD (1999) shows that revenue sharing and collection is a primary concern in effective biodiversity protection. Huston (1999) treats mining and forestry sector linkages during a period of devolution in Ghana. Serôa da Motta *et al*. (1999) study revenue-sharing issues during devolution in Brazil. World Bank (2001) provides a

detailed analysis of such issues in Indonesia's forest and other natural resource sectors during the country's devolution of political and fiscal authority that was enacted in 1999 and came into effect in January 2001.

[13] Ruitenbeek (1998) provides a detailed review of models available for sustainable forest management. The review was a supplementary research note to the CIFOR-sponsored effort on Rational Exploitations (Ruitenbeek and Cartier 1998). The model review comprises some 32 types of models that are categorised into the following model approaches: preference description, structural description, impact description, impact evaluation, risk assessment, distributional analysis, non-linear system modelling and qualitative. These papers are available at the author's web site: http://www.island.net/~hjr, or upon request to hjr@island.net.

[14] An excellent thorough review of the standard neo-classical maximisation and rationality assumptions is provided by van den Bergh *et al*. (2000). Their article also looks at different modelling approaches and theories such as prospect theory and regret theory.

[15] An example of this is the coastal zone modelling effort sponsored by the World Bank Research Committee reported in Gustavson *et al.* (2000). The complex system modelling efforts were eventually simplified and included on a CD-ROM that is distributed with the book. The CD-ROM provides a simulation model that has been used in the training and sensitisation of policy-makers involved in various coastal zone co-management schemes in Jamaica.

[16] *The anarchist's cookbook* is no longer banned in most countries. It is available through regular Web-based book-ordering channels. In January 2000, however, the author William Powell posted a message that is attached to all book sales. The message is that he no longer believes or supports what he wrote in the book, he does not endorse the contents of the book and he feels that the book should be taken out of print.

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