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Complexity Science and Global Change Workshop Summary

Smithers, BC, Canada, February 13, 2009

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Abstract

Complex systems science provides an interdisciplinary framework for understanding and responding to global change phenomena. It seeks to understand the behaviour of whole systems and provides a common language and a suite of analytical tools that improve communication and integration across disciplines. Because it addresses whole-system behaviours that are beyond the scope of reductionist science, it can help to reconcile the culture clash between scientific and non-scientific approaches to understanding our world. In February 2009, the Bulkley Valley Centre for Natural Resources Research & Management (BV Research Centre) and the Natural Resources and Environmental Studies Institute (NRESI) of the University of Northern British Columbia co-hosted a half-day informal public workshop on Complexity Science and Global Change in Smithers, BC. The purpose of the workshop was to stimulate dialogue about complex systems science and how it can be applied to the challenges of maintaining sustainable ecosystems and communities in the face of global change. Presentations and lively discussion sessions focused on the relationships among complexity, diversity and resilience, genetic complexity in tree and salmon populations, restoring functional diversity in tropical forests, self-organisation in legal systems and managing natural resources under uncertainty. This document summarizes the presentations and discussion.

Introduction

On February 13, 2009 the Bulkley Valley Centre for Natural Resources Research and Management (BV Research Centre) and the Natural Resources and Environmental Studies Institute (NRESI) of the University of Northern British Columbia hosted a half-day informal public workshop at the Old Church community hall in Smithers, BC. The purpose of the workshop was to stimulate dialogue about Complexity Science and how it can be applied to the challenges of maintaining sustainable ecosystems and communities in the face of global change. Five members of the BV Research Centre volunteered to present and lead discussions on a range of topics. Thirty people, from the Bulkley Valley to Prince George, participated in the workshop. This document summarizes the presentations and discussion sessions.

The workshop consisted of five presentations, each followed by a 10- to 20-minute question and answer period, with a general discussion at the end (Table 1). A summary of each speaker's presentation and a synthesis of the questions, answers and discussion topics related to each presentation appear below. The original presentations can be downloaded from the BV Research Centre website (http://bvcentre.ca/events/detail/complexity_science_and_global_change/).

To aid in synthesis to and stimulate further discussion, more comprehensive reflections on the questions and answers were added by the editors and presenters after the workshop. Post-workshop comments are shown in italics. The speakers have added more materials, definitions, questions and references to their speaker summaries. We welcome feedback, which can be sent to haeussl@unbc.ca and will be posted on the BV Research Centre website, if the contributor agrees.

Table 1. Workshop agenda.

Time	Topic	Presenter
8:45 – 9:30 am	Introduction to Complexity Science & Global Change	Sybille Haeussler
9:30 – 10:00	Genetic Complexity	Jim Pojar
10:15 - 10:45	Functional Diversity in Tropical Forests	Marie-Lou Lefrancois
10:45 - 11:30	Self-Organisation in Legal Systems	Richard Overstall
11:30 - 12:10	Modeling and Managing under Uncertainty	Don Morgan
12:10 - 12:30	Final Discussion and Next Steps	All

An Introduction To Complexity Science And Global Change

Sybille Haeussler, University of Northern B.C. (haeussl@unbc.ca)

Global change, broadly defined, encompasses a wide range of phenomena including such things as anthropogenic climate change, the worldwide economic crisis, cultural integration and homogenization, invasive species and emerging diseases, the global food and water crises, desertification and collapse of marine fisheries. Each of these topics is related in some way to the rapid growth in human populations and even more rapid increase in human use and exchange of energy, matter and information (Costanza 2008). These global issues have proven intractable using the normal problem-solving approach of taking a problem apart and assigning its different parts to people with different skills and abilities.

Some Definitions

A **complex system** is a system with many parts that interact.

A **dissipative, non-equilibrium system** is a dynamic system that maintains its integrity (i.e., the ability to do the things it is supposed to do) while constantly exchanging matter, energy and information with the outside world.

A **complex adaptive system** is a dynamic system that is able to fix or adjust itself through self-organisation (i.e., essentially without outside help) in response to changing circumstances.

Imagine a car. According to the definitions above, a car is a complex system because it has many parts, and they interact (battery delivers a charge to the ignition which turns a cylinder which powers the wheels, etc.).[1] The sum of these interactions produces a machine that is capable of much more than a pile of individual parts in a warehouse. To a certain degree, a car – especially a vintage car – is also a dissipative non-equilibrium system because it continues to function and maintain its identity while gasoline, tires, upholstery, rusted panels, transmission and even the engine block are replaced. But a car is definitely not a complex adaptive system because it has almost no ability to spontaneously fix or adjust itself. Now imagine a forest ecosystem or a city …

An **attractor** describes the set of states of a dynamic physical system toward which the system tends to evolve, regardless of the starting conditions of the system.

Diversity refers to the number of different types (categories) of parts within a system and how evenly they are distributed within the system. Diversity is best measured as the probability that two parts of a system, selected at random, will not be of the same type.

Resilience (broadly defined) is the capacity of a system to absorb, recover from, or adapt to disturbance or stress caused by agents of change.

Vulnerability is the likelihood that a specific human-environment system will experience harm from exposure to stresses associated with alterations of societies and the environment, accounting for the process of adaptation (Schröter et al. 2004). Vulnerability incorporates not only the resilience of the system, but also the specific amount of stress and disturbance to which the system is exposed. Note also that Vulnerability is a negative concept (like sickness) whereas Resilience is a positive concept (like health).

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[1] but see Question 4 (page 10) for an alternative viewpoint

Complex systems science (also known as Complexity Science) provides an interdisciplinary framework for understanding and responding to global-change phenomena. It seeks to understand the behaviour of whole systems and emphasizes similarities among problems rather than their differences. Complexity science is rational, evidence-based, quantitative and predictive (i.e., highly scientific), but at the same time holistic and synthetic. It thus offers a bridge between the hard (reductionist) sciences (physics, chemistry and modern biological sciences) and the softer, less quantitative sciences (many social sciences and descriptive natural sciences). Complex systems science provides a common language and a suite of analytical tools that improve communication and integration across disciplines. Because it takes a predictive, analytical approach to topics and whole-system behaviours that are beyond the scope of reductionist science, it can potentially reconcile the culture clash between scientific and non-scientific approaches to understanding our world, for example between natural resource managers and environmentalists, between western medicine and holistic health practitioners, and perhaps even between science and art**.**

A complex system must have more than two components, and the components must interact (i.e., they are not independent). If the interactions among components of the system are two-way interactions (A depends on B ***and*** B depends on A) they are known as feedbacks (a negative feedback is a stabilizing or dampening interaction; a positive feedback is a destabilizing, accelerating interaction). The interactions among the component parts of a complex system cause the whole system to behave in ways that are both qualitatively and quantitatively different than the sum of its individual parts. This is known as emergent, or non-linear, behaviour, and it gives rise to the phenomenon known as self-organisation. Self-organisation refers to system-wide order or pattern that is not imposed by forces external to the system.

Defining Complexity

Although all of us are familiar with the everyday meaning of “complexity” (degree of difficulty or complicatedness), the scientific definition is more precise, because a scientific definition must be expressed in terms that are measurable. Here are three scientific definitions of complexity that at first glance may seem very different, but on closer examination turn out to be saying the approximately same thing.

(1) Complexity is the amount of information needed to fully describe an object or recreate the behaviour of a system. This is a classic definition, known as Kolmogorov complexity (Li and Vitanyi 1997), used in computer science and measured as the length of the computer algorithm needed to specify the object.

(2) Complexity refers to phenomena that arise due to the interactions among the parts of a complex (many-body) system. Hence, the degree or amount of emergent or self-organising behaviour is a measure of its complexity.

(3) Complexity is the hidden order that lies between order and randomness (Crutchfield 2003). Highest complexity is found right at the phase transition between order and chaos.

Defining Resilience

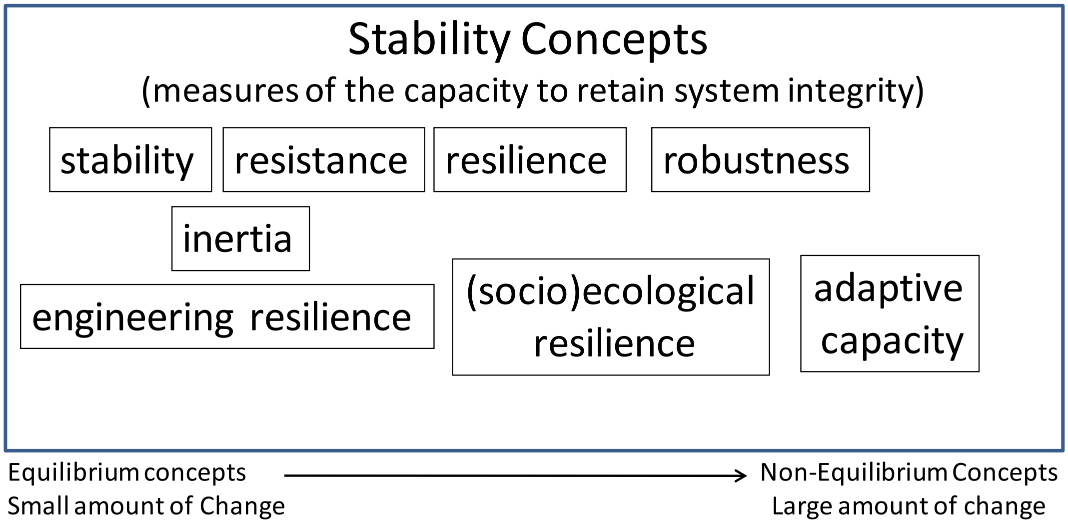
In both the natural and social sciences, and in general public discourse, there has been much recent interest in assessing the resilience of systems subject to the stresses of global change. The confusion about what resilience is and how it can be measured is related to the hundreds of different definitions of resilience (Grimm and Wissel 1997) developed by people working in different domains, and concerned with different spatial or temporal scales or scopes of inference. In the scientific literature, resilience is often narrowly defined as just one of several terms within a larger family of stability concepts (Figure 1), used to measure how a system responds to varying degrees of stress or change. When broadly defined, as in most public discourse (see Some Definitions, page 4), resilience encompasses the full breadth of these stability concepts.

Equilibrium concepts of system dynamics (left side, Figure 1) assume that the system will return to its original state following disturbance. Non-equilibrium concepts (right side, Figure 1) acknowledge that there may be large and unprecedented changes in the environment within which the system must function, and that the system will evolve in response to a changing environment. The set of definitions developed by C.S. Holling and the Resilience Alliance (Holling 1973, Gunderson 2000, www.resalliance.org; bottom row, Figure 1) are widely used in natural resource sciences.

By contrast, ecology field studies with a short time frame and a narrow range of spatial scales have traditionally used the resistance and resilience definitions of Pimm (1984). Robustness is a term that is widely used in computer science, engineering, statistics and genetics (Jen 2003), that lies somewhere between the definitions of ecological resilience and adaptive capacity defined by Holling and his colleagues.

Within ecology, and in some social sciences such as economics, there has long been a debate about the relationship between diversity and these stability concepts (McCann 2000). Lately, complexity has been added to this debate. It appears that many practitioners are using the terms diversity and complexity interchangeably (e.g., complexity as a newer and trendier replacement for biodiversity or cultural diversity) and that both of these concepts are often unthinkingly equated with greater resilience or stability. The current global credit crisis, which developed directly in response to the proliferation of complex financial instru-

Figure 1. The family of stability concepts showing relationships among various terms used within different disciplines and contexts to describe system stability and resilience.



ments (repackaging debt with ever greater complexity in a deregulated self-organised banking environment), should provide ample evidence that complexity provides no guarantee of stability.

In a simple world (Figure 2), a diverse system is not necessarily complex, a complex system is not necessarily diverse, and diversity and complexity may or may not be associated with higher resilience. In the real world, most diverse systems involve some interaction among their components, and thus are also complex; however, the degree of complexity is not necessarily proportional to the level of diversity.

Imagine, for example, a newly planted forest with 10 species of trees whose crowns and root systems are not yet in contact with one another. Or consider a young city with immigrants arriving from all over the world. Over time, in both the plantation and the city, interactions among the individual trees and people will inevitably occur, resulting in an increase in system complexity. But this can happen in two different ways. First, as one might expect, the degree of inter-group interaction could increase over time. Alternatively, the groups/species might instead draw apart over time and develop into separate, relatively pure, tightly-knit enclaves. Both are examples of increasing complexity

Figure 2. Simplified systems to illustrate the difference between diversity (the system contains many different kind of objects), complexity (the objects interact) and resilience (the system can withstand abuse and remain functionally intact). Subfigure (c) represents a plastic bag containing a deck of red playing cards.

a) not diverse, not complex

b) diverse, not complex

c) not diverse, slightly complex, Resilient

d) not diverse, complex, not Resilient

e) diverse, complex, not Resilient

f) diverse, complex, Resilient

(interactions among groups; interactions within groups). If an ecological or economic storm hit the system, damaging it badly, it is difficult to predict whether the system would recover more readily if the different groups/species were well dispersed and interacted with one another, or if they drew upon the strength and cohesion that lay within their own group.

Resilience will depend on the circumstances of the disturbance and the strength and variety of connections within and among the groups. It also depends on whether one's notion of recovery is limited to a system that is essentially the same as it was before, or if one is willing to accept a functioning system that has been substantially altered.

Managing for complexity is a concept that is rapidly gaining traction as an approach for increasing the resilience of systems facing global change (e.g., Puettmann et al. 2008). Many people, certainly in forestry, seem to be equating this with managing for diversity or biodiversity. The examples above were intended to show that the two are related, but still distinct, concepts and that one can manage for complexity, even within a relatively non-diverse system, by working with the system to increase the variety and strength of interactions among the components in the system. It is also possible to increase the diversity of a system (e.g., randomly planting lots of species of trees, encouraging lots of immigration) without necessarily enhancing its complexity, or its resilience.

Managing for complexity involves thinking carefully about the types of interactions (processes) that occur within the system and how they enable a system to resist stress or self-organise following disturbance. The manager intervenes in ways that are intended to strengthen favourable interactions that are likely to increase resilience and the continued provision of services, and to discourage negative interactions that are likely to disrupt system function. In the forest plantation, one might carefully consider which tree species to plant close together or in the shade of residual live trees, in order to encourage facilitative interactions such as protection from heat injury, mycorrhizal network development, and natural regeneration, and to discourage negative interactions such as allelopathy, pest problems, and excessive competition. In the immigrant city, social programs that encourage beneficial networking among cultural groups (e.g., free language and skills training and community recreation centres), while discouraging destructive interactions (e.g., mentorship programs that promote positive cultural identities and discourage gang membership or racism), are examples of managing for complexity.

Complexity science provides a wide variety of analytical tools to model these kinds of nonlinear system behaviours (Table 2). The most important differences between these tools and older linear or equilibrium models is that they explicitly allow for interactions among the components of the system and also allow the system to evolve over time rather than assuming it will stay the same. This kind of modeling is much more computationally intensive than that of older decision-aids. The rapid growth in capacity of computer systems has made it possible to begin to use such tools for real-world systems rather than merely for the highly abstract or simplified systems used by theorists.

Most of the techniques listed in Table 2 are currently being used, and were often developed within highly reductionist and disciplinary sciences. In fact, a very rapid convergence between holistic and reductionist approaches to science is occurring precisely because: (1) new computing technology allows scientists working within individual disciplines to push the boundaries of linear thinking by using progressively more complex and dynamic models; (2) the Internet allows scientists to readily learn about the approaches being used in other disciplines; and (3) increasing user-friendliness of computational tools and development of visualization software is making non-linear modeling accessible to the less-mathematically-inclined.

Questions & Discussion

1. **Adrian de Groot (AdG):** Can interaction among parts in a system cause it to behave in a way that is less (rather than more) than the sum of its parts?

Sybille Haeussler (SH): Yes, it is probably more accurate to say that the behaviour of a complex system is different (rather than more or less) than the sum of its parts.

Post-workshop Editors' Reflection (Eds): *A better word than either 'more' or 'different' is probably 'additional'. Mathematically speaking, one could either add a positive quantity or a negative quantity to an equation to describe the interactive portion of the system. Either way, it would be additional. It will often be subjective whether the additional behaviour or quality is negative (e.g., less timber production) or positive (e.g., more wildlife habitat).*

2. **AdG:** Are complex systems always dynamic?

SH: Probably yes, dynamism is a requirement of complex systems.

Eds: *On reflection, there is no absolute requirement that a complex system be dynamic (see Definitions, page 4 and the house of cards in Figure 2). Any system that is interesting enough to be studied, however, ought to have the potential to change over time. In the case of the house of cards, we are really interested only in the dynamic behaviour of the system if we add more cards, remove a card or impose a stress (i.e., will it remain stable?).*

3. **Kevin Eskelin:** The difference between diversity and complexity is that diversity is horizontal whereas complexity is vertical (i.e., complexity is vertical diversity).

Table 2. Tools and techniques used in complexity science.

Technique	**References**
Nonlinear equations	Dennis and Schnabel 1996, Khalil 2001
Cellular automata	Wolfram 1986, 2002
Agent-based models	Axelrod 1997, Gilbert and Terno 2000, Bonabeau 2002
Information theory	Cover and Thomas 2006
Network analysis	Newman 2003, Durrett 2006, Scott 2000, Barabasi and Albert 1999, Barabasi 2002
Neural networks	Bar-Yam 2003
Fuzzy logic	Klir and Yan 1995, Nguyen and Walker 2006
Fitness landscape models (adaptive walks)	Wright 1932, Kauffman 1995, Gavrilets 2004
Game theory	Shoham and Leyton-Brown 2009, Rasmusen 2006
Symbolic dynamics	Lind and Marcus 1995, Robinson 1999
Machine learning	Alpaydin 2004
Data mining	Kantardzic 2003
Statistical mechanics	McQuarrie 2000, Evans and Morriss 2008

Eds: *This is a helpful way of understanding the difference. In ecology, diversity usually refers to the number of different species, whereas complexity could refer to the number of tiers in a food web and their interconnections. The same kind of thinking can be applied to an economy where a diverse economy may have many different kinds of primary industries (mining, forestry, agriculture, fisheries) but very little secondary or tertiary industry that creates a more complex and interdependent economy. In subsequent email discussions, Kevin recommended Integral Theory (Wilber 1995, 2009, http://en.wikipedia.org/wiki/Ken_Wilber) as an alternative, more spiritual and humanistic, perspective on complexity.*

4. **Don Morgan (DM):** An important point is the difference between systems that are complicated (e.g., a car – needs command and control) versus systems that are complex, which have emergent properties.

SH: *Don raised an important distinction between an engineered system that is fully reliant on outside control and a system that is able to self-organise or adapt to changing circumstances. My perspective (see Some Definitions, page 4) is slightly different. I don't think 'complicated' has a scientific definition, but if it did, I doubt it would preclude emergent behaviour. Secondly, I think a car* ***is*** *a complex system and that it does have emergent properties – most notably the ability to move against the force of gravity, which a pile of auto-parts does not possess. Third, the important difference between a car and a complex adaptive system (a special sub-group of complex systems) is that, although the car does have emergent properties, it has limited or no ability to regulate or fix itself. That would be a "smart" car and engineers are working in that direction.*

DM: *The car example is a little challenging for me given that I come across cars being used as an example of a complicated system not a complex system; however, when you drive a car it does become part of a complex system. A car has many parts, but can be taken apart and reassembled - there is a manual for assembling a car and there is only one correct form. A car can also be seen as a complex system in that it can be driven or changed, as you have argued, or in that what happens to a car can take many forms (e.g., trips to various destinations). In the words of Donald Rumsfeld (actually he was using what is called a johari window - http://en.wikipedia.org/wiki/Johari_window) complicated systems have "known unknowns" – the system is discoverable, but not necessarily immediately apparent like a simple system and a complex system has "unknown unknowns" – thus their emergence, flux and unpredictability.*

It depends on what literature you read. Organisation literature talks a lot about interacting systems. For example, Snowden (http://www.cognitive-edge.com/) developed the Cynefin framework (http://en.wikipedia.org/wiki/Cynefin) for describing systems, which is where I came across complicated versus complex. He also discusses system interaction, such as a simple system like a bureaucracy managing a complex system like a forest, leading to inappropriate decisions − simple rules on a complex system. In my scenario research I commonly cross over into the social realm, because the scenario methods I use are attempting to communicate system uncertainty to participants so that they can discover strategies that are better founded in complexity and recognize the feedbacks within and between natural and human behaviour/decision systems.

5. **Erin Hall:** How does the concept of an attractor relate to the bowl and the ball?

SH: In the bowl/ball (also known as ball-and-cup) system, the attractor (see Some Definitions, page 4) lies at the bottom of the bowl, where the system comes to rest. If the system is stressed and the ball leaves the bowl, however, it will likely come under the influence of one or more alternative attractors that lie outside the bowl.

Eds: *The ball and cup is a simple metaphor for a steady-state system in which the ball represents the current state of the system, and the cup (bowl) represents the possible state space or domain of attraction for that system (Gunderson 2000). If a disturbance to the system exceeds its ecological resilience, the ball leaves the cup, and enters an alternative state space or domain of attraction. There are limitations to the ball-and-cup metaphor: (1) it doesn't allow the attractor to shift over time. For this reason, a hurricane may serve as a better metaphor for the domain of attraction of a dissipative non-equilibrium system with the eye of the hurricane representing a shifting point attractor. (2) When a ball comes to rest at the bottom of a cup, it has maximum entropy. This is exactly the opposite of a complex adaptive system such as a forest ecosystem or city, which has maximum entropy immediately following a disturbance and gradually loses entropy (gains exergy) as the system moves towards the attractor and becomes more complex (e.g., forest succession; city development). It may be more appropriate to invert the cup and imagine the ball climbing upwards towards a peak (the attractor) as it loses entropy and becomes more complex (see fitness landscape models, Table 2). Best of all may be to imagine an upwards-pointing hurricane shifting in space (i.e., a dissipative, non-equilibrium, adaptive system.*

6. **Ruth Lloyd:** Pine plantations in Burns Lake versus those in Hazelton are an example of the difference between resilient and vulnerable. Neither is diverse, both are sensitive to mountain pine beetle, but the pine in Hazelton are more vulnerable than those in Burns Lake because they have to cope with both Dothistroma needle blight and the mountain pine beetle.

Eds: *Ruth's point was that lodgepole pine is equally resilient in Burns Lake and Hazelton, but more vulnerable in Hazelton because of the additional stress of Dothistroma needle blight. Ruth makes a good point, but one could argue that the pine ecosystems of the Hazelton area are both less resilient and more vulnerable than the pine ecosystems in the Burns Lake area because they represent a very small local 'peak' or domain of attraction, with a very much larger and stronger attractor (hemlock or mixed species shade-tolerant forest) nearby. Only a small amount of change will cause the Hazelton pine forest to shift to a different attractor, whereas in the Burns Lake area where lodgepole pine is the most abundant and best adapted species, it will take a much greater amount of cumulative disturbance and environmental change to unseat it.*

7. **Unknown Questioner (UQ):** Can complexity really be used in management? (if we don't understand the system, how can we manage it?)

SH: We should use our understanding of complexity and how different species interact in order to manage ecosystems better. We're already influencing systems whether we call it 'management' or not. The challenge is to do it better by figuring out how the system works (processes), not just by emulating how it looks (pattern).

Eds: *See also adaptive management discussion below (#9).*

8. **UQ:** Are diversity and complexity equivalent?

SH: Definitely not. For example, you can have a complex ecosystem with structural diversity but only one (tree) species.

Eds: *Imagine a black spruce peat bog forest – this system has low diversity, but is intensely self-organised. If our objective is to maintain the complexity of this system (i.e., to retain the functional integrity of the peat) the last thing we would want to do is to introduce additional non-peatland tree species that cause that highly integrated system to break down and reorganise towards some other ecological attractor (e.g., a mixedwood forest). Alternatively, imagine an isolated tribe in the Amazon rainforest. The interaction of the culture with the rainforest is incredibly complex – but the society itself lacks diversity. The only way to keep that culture intact is to protect it from outside human influences. Immigration will cause it to break down. For both of these examples, I suppose one could say that managing for complexity is the same as managing for beta-diversity (i.e., diversity across rather than within groups).*

9. **UQ:** Managing for complexity literature always talks about doing things differently in different places and seeing what happens – isn't that the same as adaptive management?

SH: No. Using complexity science in forest management is separate from adaptive management. There are ways of thinking ahead about what interactions are likely to work, what we could try – it's not only about trying every type of combination out and seeing what happens.

Eds: From a forest-management perspective there is a logical progression from (1) the early stages of managing for biodiversity (emulating the natural pattern we see on the landscape), to (2) the secondary stages of biodiversity management (beginning to emulate the processes taking place on the landscape), to (3) the early stages of complexity management (actually intervening in the processes taking place in the landscape to enhance complexity towards desired ends).

10. **DM:** I think adaptive management is management for complexity.

SH: I disagree somewhat. Complexity science involves explicitly thinking about and using the interactions and how they work. Adaptive management can, but doesn't necessarily use, complexity science.

Dave Coates: In forestry, we have to understand the interactions among species and use them. This is different than emulating natural disturbances, adaptive management, etc.

Eds: *The difference between Don's perspective and that of Sybille and Dave is that Don is a process person whereas Sybille and Dave are primarily interested in the technical content of the problem and its solution. Don thinks of the manager as part of the system, whereas Sybille and Dave tend to view the manager as being external to the system. Don is correct in that the process of adaptive management is more complex than the process of traditional command-and-control management because it involves feedbacks. The manager intervenes in the system, checks the response, then adjust the interventions and responds again. So there is always an interaction/feedback between the treatment and the response. In this way, the manager actually becomes part of the functioning system. For a more content-focused person, managing* **for** *complexity involves (1) actively thinking about and intervening in the interactions that go on within a system to achieve some desired end; and (2) intervening in the system so that it has an improved ability to self-organise or repair itself following disturbance. Thus complexity management almost certainly involves adaptive management, and adaptive management, done properly, should also involve complexity management (see also Richard Overstall discussion).*

Genetic Complexity and Climate Change

Jim Pojar, Semi-retired, (jpojar@telus.net)

Rowe's (1961) levels-of-biological-integration concept argues that the cell, the organism and the ecosystem are the only true levels of integration in an object-oriented biological hierarchy of increasing complexity (Table 3). Each true level is the total environment of all levels below and a structural and functional component of the next level above.

Species are abstractions, not real entities, thus are not part of the hierarchy. Populations and communities are real, but not "true" levels of integration in this system. Prediction at one level requires knowledge and consideration of the next true level above.

Consider the interacting set of species populations that make up a forest. If one population (say of a dominant tree species) forces a periodic or chaotic pattern by its own density dynamics, then all members of the set must develop responses to the interactive biotic environment (Namkoong 2001). Thus forest-level pattern and complexity could arise as emergent effects of the independent behaviour of lower level elements (e.g., each population or species doing its own thing), ***or*** due to strong functional interactions among the elements. Species assemblages are not random aggregations – they are selected, have positive and negative interactions (mutualism, competition, parasitism, etc.) supporting their interactive existence. Genes in individuals are not random operators that happen to produce whole trees; they are assembled because they function well together (Namkoong 2001).

Some assert that all function derives from genes, that higher levels of biological organisation are merely outgrowths bearing gene effects. Gene effects themselves could be emergent properties of molecular processes; they are also partly determined by developmental, population, and ecosystem processes. To simplify, two exaggeratedly contrasting views have arisen: (1) the genotype dictates its environment (Dawkins 1976); versus (2) genetic information becomes biologically meaningful only through its contact with the environment; in essence, there can be no genotype without an environment (Lewontin 1974).

Table 3. Levels of biological organisation. Highlighted levels are the only true levels according to Rowe (1961).

Biosphere
Ecosystem
Community
Population
Organism
Organ system
Tissue
Cell
Subcellular component
Molecules in biological systems (including genes)

In British Columbia, forest trees and salmon are two groups of organisms whose genetic structure has been studied in some detail.

BC Trees

BC trees show both clinal (continuous) and racial (discontinuous) variation that will affect their ability to adapt to climate change. Most wide-ranging forest tree species have racial variation – genetically distinct infraspecific populations. Specialist species have lots of such genetic differentiation and are finely attuned to their local environment. Generalist species are highly plastic and their physiological processes are more coarsely attuned to a broad range of environments. Plasticity refers to the ability of a genotype to adjust phenotypically to environmental heterogeneity and change (Bradshaw 1965). Phenotypic plasticity enables individuals to tolerate a certain amount of environmental change by altering their morphology, physiology, or development.

To generalise and simplify, environmental variability in the first group, which includes most BC conifers, is largely accommodated by genetic variation, whereas in the second group, which includes western white pine and yellow-cedar, it is accommodated to a greater extent by phenotypic plasticity.

Rapid climate change could have the following consequences for BC trees and forests.

The genetic specialists will respond to climate change by differential survival of the races or genotypes best suited to future conditions. But change could be happening too fast for evolution to keep up, at least in species – like trees – with long generation times. In principle, adaptation rate is negatively related to generation time (i.e., reproductive age), positively related to within-population genetic diversity (Stebbins 1971). Long-lived specialists will have to migrate to survive, moving if possible to where suitable environments exist.

Climate warming could ultimately exceed the adaptive capacity of many of our conifers for three main reasons. First, populations are locally adapted and climate change causes conditions to deteriorate throughout a species' range, not just at margins. This will push many populations beyond their physiological limits of temperature or moisture tolerances. Second, mortality induced by extreme climatic events will result in losses of genetic diversity. Third, the rate of change is too fast for an adaptive tracking response by tree species with long generation times and life-spans. These factors could lead to significant genetic erosion and forest decline for several forest generations.

Generalists with lots of phenotypic plasticity will respond to climate change by "attempting" to ride it out within the bounds of their plasticity. Individuals of highly plastic species can tolerate a wide range of environments, and could be less sensitive than specialists to climate change. But eventually – when changes become intolerable – they too will have to evolve, or migrate but maybe not as far to survive. If generalists moreover are handicapped by low levels of genetic diversity, as in western white pine and yellow-cedar, they could be more susceptible to pathogens, especially exotic pathogens (like white pine blister rust), or to things like freezing damage.

If intact ecosystems have resident species with a higher proportion of mature/old individuals and with more genetic diversity than secondary or degraded ecosystems, then both the genetically diverse species and the intact ecosystems should have greater resilience (Kelly et al. 2003, Mosseler et al. 2003, Jump and Penuelas 2005, Nelson et al. 2007).

Pacific Salmon

Among salmon, the evolutionary strategy of locally adapted populations is very dependent upon interconnected marine, freshwater and terrestrial habitats (i.e., high complexity). Environmental conditions experienced by individual salmon populations are the result of geomorphic, hydrologic and ecological factors acting as "filters" on the regional climate signal (Schindler et al. 2008). The regional diversity of salmon population responses to climate change appears to result from local adaptation of salmon populations to heterogeneity in landform and hydrological conditions. In Bristol Bay, Alaska, the "stock complex" of sockeye salmon consists of several hundred discrete spawning populations, adapted to local variations in spawning and rearing habitats in the area's streams and lakes. This "biocomplexity" (Hilborn et al. 2003) has enabled the aggregate of populations to sustain its productivity despite major climate change affecting the marine and freshwater environments during the previous century. Populations that were minor producers during one climatic regime have dominated during other climatic regimes, thus maintaining the resilience of the stock complex.

This system of population-specific variability exhibits high resilience when these linked environments vary within historical limits, but becomes vulnerable when variability exceeds limits (such as water temperature) within which local populations are adapted. The homogenization of stocks and asymmetric selection against large fish by commercial fisheries also greatly reduces resilience.

Questions & Discussion

1. **UQ:** I disagree that there's only one hierarchy of true levels of biological organisation. Maybe cell → organism → ecosystem is just one system of organisation. Gene → species → ecosystem could be another one. An individual can be a member of a few different complex systems.

Jim Pojar (JP): Species are not a very useful group to be thinking about in this context –individuals across the full range of a species often don't interact at all; populations are more important ecologically than are species. For example, consider white spruce in BC: even within the range of this single species, particular spruce ecotypes or provenances will have to migrate (north or up in elevation) to survive.

JP: *For that matter, the gene is difficult to clearly define, and gene expression is controlled at the cellular not the species level.*

2. **SH:** In B.C. we have some tree species with lots of genetic diversity, others without. But overall, are our trees genetically diverse, relative to those found in geophysically less diverse landscapes?

JP: We have conifers that span a wide range of physical environments and as a result they have developed "races". If B.C. was flat, we'd probably see less genetic diversity within our tree species.

3. **Patrick Williston:** What do we know about pre-adaptation to warmer climates in our BC species? Is the assumption behind predictions being made that trees in the population are not pre-adapted? Is it a possibility we have warm-adapted individuals present already?

JP: Yes, it's possible. But the major factors driving global change in B.C. aren't only temperature and precipitation but also land-use change, natural disturbances, invasive species, etc. and interactions among these factors. So even if species are pre-adapted, there's no guarantee that they'll persist.

4. **UQ:** How can we manage BC forests for climate change?

JP: Assisted migration is probably a good idea for some trees. Beyond such interventions, I think we should husband the forests we still have, for carbon storage and as reservoirs of biodiversity. The coastal, wet interior, and wet subalpine forests are likely to persist for hundreds of years because they're not so susceptible to wildfire and other stand-replacing disturbances. We should leave these largely alone to conserve biodiversity and ecosystem services (including carbon storage), but also because intact forests are more resilient and will serve as migration landscapes.

Additional Questions to Ponder

Jim provided some additional questions for readers to consider when reflecting upon "the ecological theatre and the evolutionary play" (Hutchinson 1965):

1. Is the complex genetic architecture of NW BC tree species an inevitable consequence of physical complexity (climate, topography, physiography, landforms)? If northwestern North America was flat, would the tree species be as genetically diverse? *See Question 2 above.*
2. Given their ecosystem role (structure & function), ecosystem services, carbon dynamics, genetics and life history characteristics, and economic significance, should most of B.C.'s tree species be of conservation concern?
3. Do genes of dominant species determine ecosystem structure and drive ecosystem —evolution (Bonn 2006)? Are ecosystems emergent properties of genetic processes? Do species-level events form the only organising principle?

Restoring Ecosystem Functions in Neotropical Forests of Panama

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Tropical and neotropical forests incarnate many characteristics of complex systems such as non-linear relationships, positive and negative feedback loops and emergent properties. Some ecosystem services (e.g., timber production, pollination, wildlife habitat) can be considered as emergent phenomena. In this project, we were not looking at reproducing a complex system per se, which might not be humanly feasible, but rather at restoring ecosystems functions initially rendered by highly complex forests.

With the current high rate of deforestation and biodiversity loss, aggravated by temperature increase and population growth, many precious ecosystem services are becoming lost or threatened. Because of the ever-increasing need for timber products at the global scale, it is of utmost importance to plan for future yield while preserving ecosystem functions. The negative effects of deforestation can potentially be mitigated by intensive forest plantations, which alleviate stress on irreplaceable primary forest systems.

In this qualitative study, we defined a rationale for re-introducing ecosystem services through native species reforestation based on species functional types. In the Republic of Panama (our area of interest), 90% of the reforested land is planted with exotic species, especially teak. Originally, these forests had both significantly high alpha- (species richness) and beta-diversity (different species found across the landscape), however, and tree species count surpassed 2000 (Condit et al. 2002). This makes the "replication" of these forests practically unattainable, hence the need for guidelines for scientifically-sound management.

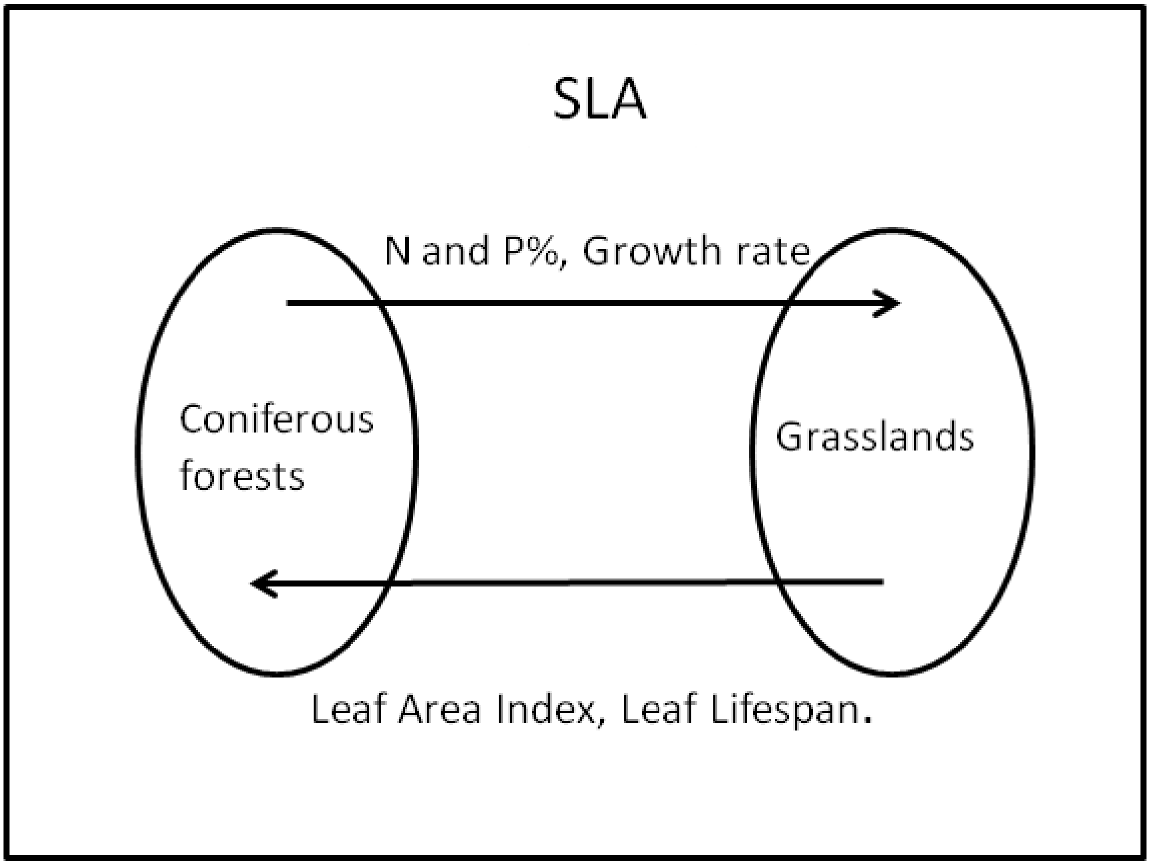
In order to restore ecosystem functions through mixed-species plantations, we advocated that functional diversity should be favored over species richness or diversity. Species are often grouped together according to their functional traits to allow studies of complex systems (Hooper et al. 2005) such as forest systems. In this study, we proposed a general approach to plan, establish, and manage mixed-species plantations based on the functional grouping of tree species. We advocated that such management can help to maintain or restore important ecosystem functions.

We found that in order to exploit the ability of species to restore multiple ecosystem functions simultaneously, differences between ecological strategies should be enhanced. Functional groups of species were defined by the ecosystem service they provide and species were grouped together because they respond in a similar way to the environment and have similar effects on ecosystem functioning. For example, different groups of trees with varied crown shapes will create vertical heterogeneity in the stand, potentially enhancing wildlife habitat and optimizing the use of the light resource. Stand productivity can be increased through resource-use complementarity. Kelty (2002) illustrated this approach with an example in which the slender crowns of shade intolerant species in the overstory benefited the fuller crowns of shade tolerant trees in the understory.

Tree species selection is pivotal when planning for mixed-species plantations since it greatly influences stand productivity. Productivity is often associated with species diversity (Erksine et al. 2006), but other factors, such as temperature (Firn et al. 2007), may have more influence on stand production. In fact the biodiversity-productivity relationship has been challenged lately and studies shows that productivity is extremely dependent on the dominant species of the stand (Erksine et al. 2006, Firn et al. 2007). Therefore, much attention has to be given to species selection in mixed-species reforestation initiatives. To better understand this, we need to address species "strategy dimensions" and thresholds in species richness, or redundancy within functional groups.

Species "strategy dimensions" (Westoby et al. 2002) is an insightful approach for exploring possible trade-offs. This can be expressed by simple traits, such as specific leaf area (SLA; leaf area to dry mass ratio). On an axis where SLA increases, growth rates also increase, but leaf lifespan decreases (Figure 3). At larger scales, typical ecosystems with species exhibiting low SLA versus high SLA from low to high productivity (Figure 3). Thus, to ensure functional diversity within a forest we would probably want to vary species SLA. Recent meta-analyses of plant traits (Westoby et al. 2002, Wright et al. 2007) have highlighted other tradeoffs, for example leaf size, which is generally positively correlated with fruit size but negatively correlated with wood density.

Figure 3. Specific leaf area (SLA) is an example of a "strategy dimension" with associated tradeoffs at different scales. Higher SLA is associated with higher levels of nitrogen and phosphorus uptake and higher plant growth rates, but at the cost of lower leaf area indices and shorter leaf lifespans (adapted from Wright et al. 2007).



Thresholds in species richness, or redundancy, within functional groups also need to be addressed. A very interesting study by Mayfield et al. (2005) showed that for the same number of species, there can be different mechanisms at play, either ecological filtering which produces lower functional diversity, or differentiation which produces more functional diversity. To restore ecosystem functions, we aim to maximize functional diversity. How many species do we need in each functional group to achieve the full variety of necessary traits? That will depend on the ecosystem service or function. For example, to reproduce the full range fruit sizes found in a given tropical forest, it will require a very large number of tree species (Figure 4). In the same forest, however, if we look at tree growth forms, redundancy might be achieved with fewer species.

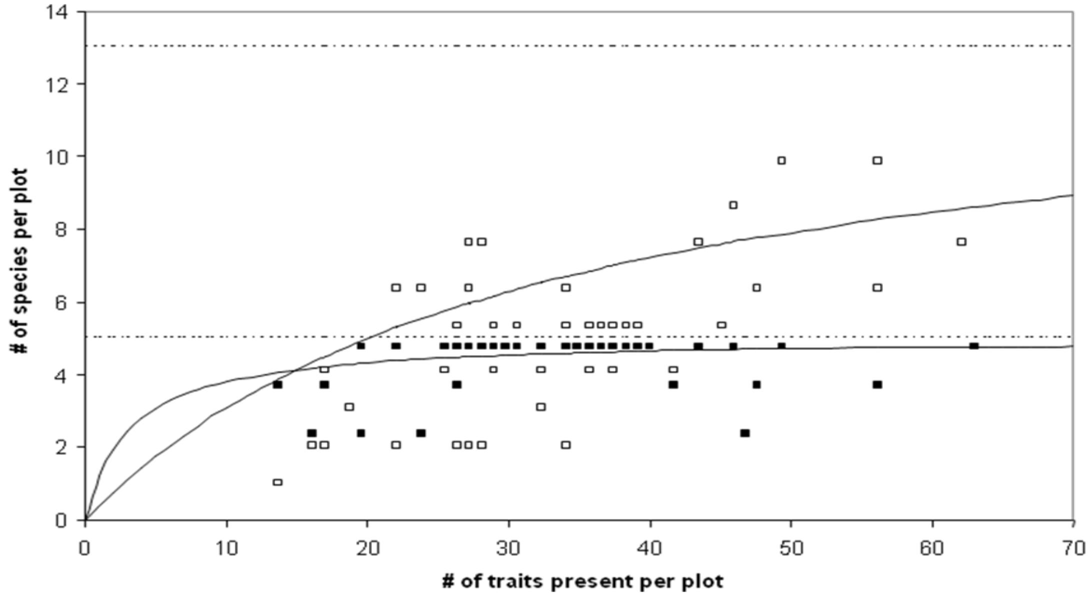
To address the problem of species selection we propose a baseline approach that aims to include trees of different successional stages (e.g., pioneering species, mid-successional species, late successional stages). Differences in traits should be optimized because strategies of the trees found across these successional stages will vary. Additional species can then be selected if other ecosystem functions are a priority (e.g., slope stability, pharmaceutical use, timber supply).

Current projects are looking at functional diversity and species interactions worldwide by using tree plantations and other experiments (grassland trials). Most of these experiments were initially implemented to test the diversity/productivity paradigm, but they also provide a good knowledge basis for the design of intensive mixed-species plantations, that would contribute to timber supply and restore other ecosystem functions.

Questions & Discussion

1. **Liz Osborn:** Has any of this been characterized from the perspective of energy cycling? Perhaps the better the cycling, the less energy that's leaving the system,

Figure 4. Species/trait relationships for growth form and fruit type in a forested tropical plant community (adapted from Mayfield et al. 2005).



and the more resilient the system is.

SH: Yes, they do look at this concept a lot in ecosystem ecology and ecological economics, though in the former it's more often about nutrient rather than energy cycling. But I don't think you can equate efficient cycling with resilience; they're not the same thing. I am thinking of the example of Burns Lake, where they had a local, black market money lending system in the 1990s that recycled money very effectively within the community, but when the system collapsed, it had a substantial, cascading economic impact on the local community – I don't think that was particularly resilient because the system relied so heavily on the one fellow at the centre of the scheme (house-of-cards scenario).

Eds: *Complexity, on the other hand can be related to the efficiency of energy and nutrient cycling and perhaps this is what Liz was referring to. There has been considerable theorizing-starting with Odum (1953), and empirical work (e.g., the famous Hubbard-Brook Forest study (Bormann and Likens 1979), showing that as a system moves from a state of high entropy (e.g., newly disturbed, reorganising) to a state of high exergy (older, established and highly 'developed' system), that there is more internal recycling and less energy/nutrient leakage. In ecological economics that would describe a system where resources, income and jobs remain in the community and are recycled through local value-added production rather than draining out of the community. Jane Jacobs (2000) provides an entertaining, non-technical introduction to this topic.*

Additional Questions to Ponder

Marie-Lou Lefrancois: If we were to dream of such an experiment here in Smithers, what would we like to investigate? (1) Climate change-adaptation? (2) Species interactions? (3) Wildlife habitat?

Legal Orders as Complex Systems: Applying Kauffman's NK Networks

Richard Overstall, Buri, Overstall, Barristers and Solicitors (richard.overstall@burioverstall.com)

The legal orders of the Tlingit, Tsimshian and Gitxsan peoples of northwestern America, and those of the Irish, Icelandic and Anglo-Saxon peoples of early medieval northwestern Europe are strikingly similar, both in general form and in many of their details. This raises the probability of a common, emergent, implicit constitutionalism that is in contrast, and often in opposition, to the explicitly constructed constitutionalism of more recent nation states.

On the northern Northwest American Coast, groups defined by kinship and contract have migrated, interacted with other and interacted with the land in the 10,000 years since the last ice age. In the process, a number of distinct but compatible legal orders have emerged, three of which are those of the Tlingit, Tsimshian and Gitxsan peoples. The Tlingit occupy what is now the Alaskan panhandle, the Tsimshian the lower Skeena River and adjacent coast, while the Gitxsan occupy the upper Skeena and upper Nass River watersheds. All of them depend on intensive processing and storage of seasonally available fish, mainly salmon and eulachon, and other resources.

In northwest Europe, the introduction of writing during the first millennium AD enabled records to be made of a number of peoples. Here too, groups defined by kinship and contract migrated and interacted with each other. In Ireland, what has been called a Celtic culture existed until the early 17th century. In England, the Celtic inhabitants were displaced in a 5th century conquest by migrating Germanic groups who later called themselves Anglo-Saxons. In Iceland, an unoccupied and relatively unproductive land was populated by Scandinavians in the late 9th century in a seemingly unorganised migration. All of these peoples depended on intensive processing and storage of seasonally available food products from livestock, mainly cattle, and crops.

None of the peoples in the northwest American or the early medieval northwest European culture area had an overarching governance or legal system. Instead, various kinship and corporate groups contracted with each other and with supernatural beings to form clustered and nested networks maintained by delicately balanced duties and privileges. Although certain individuals and their relatives had the legal capacity to embody a group and to represent its decisions to other groups, they were generally not given the power of command over others within their group. Rather, they needed to demonstrate superior moral, physical and management abilities to encourage others to contract with them.

Contracts were variously for access to goods and services such as land, livestock, legal services, and raiding and trading opportunities. In return, contractors obtained access to the group's collective food production and storage capacity, as well as legal and military protection.

Each group and individual had an explicit level of legal capacity (generally categorised as "royalty," "nobles," "commoners," and "slaves") and a ranked status that mediated its contractual relationships and guided the amount needed to satisfy a wronged party with material compensation or with retaliation in a feud. For example: in medieval Ireland, a person's status and rank constrained the value of his contracts and sureties; in England, it established the legal weight of his oaths; and in the Pacific Northwest, it established the weight of his participation in the feast or potlatch (Tables 4 and 5).

The legal orders are incompletely recorded in oral histories and sagas, early written law codes and charters, and ethnographies and histories. As such, they tend to be records of an emerging leadership class as influenced and reported by ecclesiastical, civil and academic bureaucrats. Relations among so-called commoners and slaves are less well documented. Nevertheless, it is possible to show that the legal entities tended to be groups rather than individuals. The legal orders reflect the tension between maintain-

Table 4. Northern Northwest Coast terms for a person's legal capacity (19th Century)

Legal capacity	Tlingit	Coastal Tsimshian	Gitxsan/Nisga'a/ Inland Tsimshian
Embody a tribe[1] (and its leading lineage) …and their heirs ("Royalty")	[weakly present?]	*smgyigyet k'abawaalksik* or *alugyigyet*	[not present]
Embody a clan[2] (and its leading lineage) …and their heirs ("Royalty")	*łingit łlen* or *na cade hani* *anyadi*	[not present]	[not present]
Embody a property-owning lineage[3] or group of lineages …and their heirs ("Nobles")	*hit sati* [not distinguished]	*manlik'agyigyet* *lik'agyigyet*	*simgiget* *laxgiget*
Full legal capacity ("Commoners")	*k'anac kide'h*	*k'algyigyet*	*liksgiget* or *amgiget*
Temporarily with no or reduced legal capacity ("Debt- and Penal-slaves")	*xat'aq qu'u*	*wah'a'ayin*	*gagweey'*
Permanently with no legal capacity ("Slaves")	*Gux*	*łałuungit*	*łiłingit*

[1] Tribe: a local group that is the widest group to host a feast, or be one party to a feud/compensation process; made up of corporate groups that are defined by reference to identified ancestors (descent groups).

[2] Clan: a unilineal descent group descended from a known ancestor with unknown genealogical connections.

[3] Lineage: a unilineal descent group descended from a known ancestor with known genealogical connections over a limited number of generations.

ing group cohesion and benefiting from the competition among its constituent elements, be they individuals or smaller nested groups.

The two culture areas' mutual isolation precludes conquest, migration or cultural diffusion as a convincing explanation of their similarity. Instead, it is suggested that under certain conditions an inherent human sociability constrained by similar external factors allowed parallel legal orders to emerge. The process by which these inherent and external aspects interacted may be usefully compared with the behavioural biology and evolution of other social animals.

Complexity theory is one theoretical framework that links social systems and biological systems. This theory comes from the dis-

Table 5. Northwest Europe terms for a person's legal capacity

Legal capacity	**Ireland (7C[1] – 12C)**	**Anglo-Saxon (7C – 9C)**	**Iceland (10C – 13C)**
Embody a local group[2] (and its leading lineage)	*rí*	*cyning*	(not present)
…and their heirs ("Royalty")	*tánaise rí* *rigomna*	*aethling* *cynecynn*	
… and their retainers ("Companions")		*eorl* (7C Kent) *ealdorman* (7C Wessex – 10C) *gesith* (7C – 9C) *cyninges thegn* (10C)	
Holds contracts with a number of clients ("Lords")	*flaithe* (economic) *aire*	*hlaford* (military & legal)	*godi* (legal)
…and their clients	*cleili*	*hlafeater*	*thingmenn*
Embody a property-holding lineage[3] or group of lineages ("Nobles")	*conn fine*	*gesith* (8C – 10C) *thegn* (9C - 10C)	*fyrirmad*
Full legal capacity ("Commoners")	*féni*	*ceorl*	*bóndi*
Temporarily with no or partial legal capacity (including debt- and penal-slaves)	*fuidir* *deorad*	*laeti* (Kent) *wealh*	*skógarmadr* *skuldarmadr*
Permanently with no legal capacity ("Slaves")	*mug* (m) *cumal* (f)	*theow*	*thrall* (m) *ambátt* (f)

[1] C = century AD

[2] A local group is the widest group of lineages to be one party to a feud/compensation process.

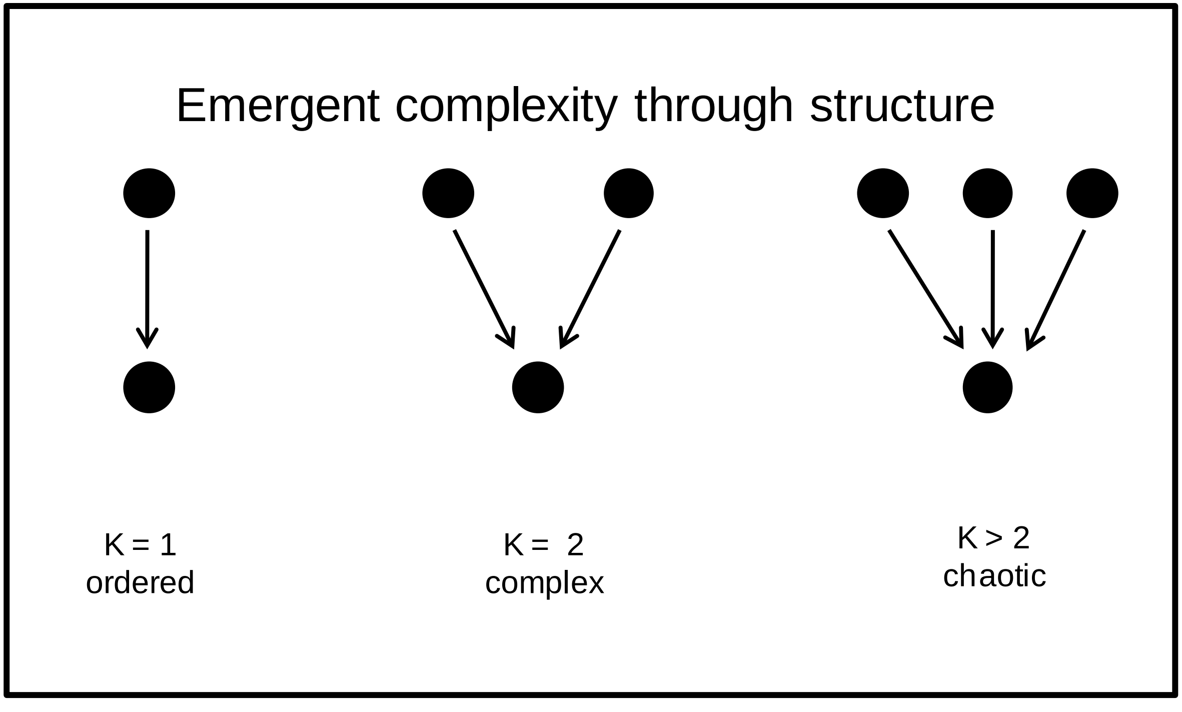
[3] Lineage: a unilineal descent group descended from a known ancestor with known genealogical connections.

covery that order may spontaneously emerge from the most complex of systems according to a few simple rules. Rules and process are the very stuff of legal orders. Therefore, if complexity theory is to explain how human societies very distant from one another in time and space are so similar, one might expect to detect it in the law.

Stuart Kauffman is a pioneer of complexity theory. In the 1970s, Kauffman began experimenting with virtual networks – computer simulations that he analogises as a finite set of lightbulbs, each wired to one or more other lightbulbs. Each lightbulb receives random, Boolean ("and", "not", "or", etc.) inputs from others to switch it on or off (Kauffman 1995). He calls these NK networks, where N is the number of elements (lightbulbs) and K is the number of connections (wires). Kauffman and his colleagues found that when the average such input per lightbulb was one, the system very quickly fell into a single pattern of illumination. It "freezes up, saying the same thing over and over for all time." On the other hand, when each lightbulb received many inputs, up to the number of lightbulbs in the network, the illumination pattern did not settle to any order but continued twinkling away, seemingly forever. This is chaotic behaviour.

But when each lightbulb receives an average of about two Boolean inputs, the system converges into a steady pattern around a basin of attraction. This pattern is independent of initial conditions and when the system is perturbed, it returns to its steady state. The pattern is, in effect, a virtual new entity with properties that can be measured and behaviour that can be predicted (Figure 5). Since NK networks have been discovered, numerous variations have been investigated.

Figure 5. Kauffman's NK network model, where N is the number of elements (circles) in a network, and K is the average number of inputs (arrows) to each element from other elements. (Adapted from Kauffman 1995).



These include introducing a bias into K>2 connections, which still enable ordered states to emerge, allowing two networks to co-evolve, and looking at the effect of network structure, such as clumping the connections around hubs.

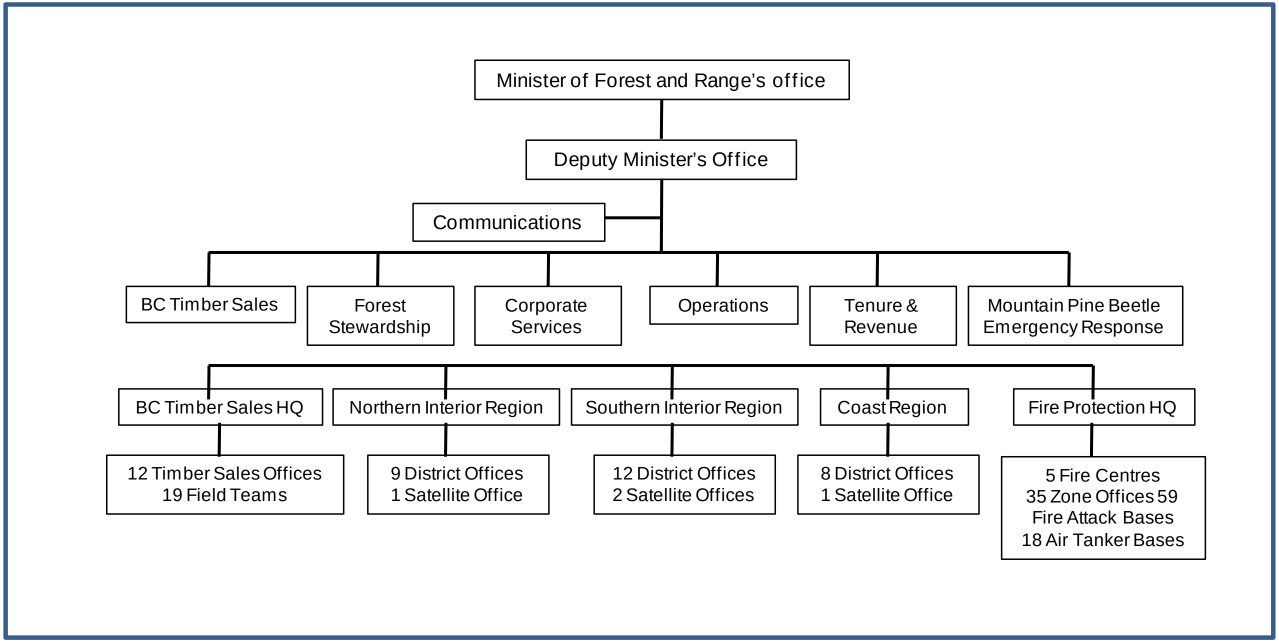
Applying these findings to human societies has been controversial. Many are troubled by the idea that institutions and behaviours might be emergent properties and not the result of individual free will. But in fact such implicit orders are part of our everyday lives. An example is the local economy. All of us participate in it – we make contracts, buy and sell goods and services, make investments, and so on. But few, if any, of us know how it really works.

In the first part of this presentation, I described each of the Northwest American and Northwest European cultures as having no overarching government or individual controlling peoples' lives. Yet the various kinship and corporate groups interacted intensely in highly structured societies to take advantage of rich but intermittent resources. This suggests that such clustered and nested networks might be analogous to Kauffman's K = 2 lightbulb networks, where the order emerges from the relationships and is not dictated by authorities.

On the other hand, societies in modern states are largely structured on each individual receiving just one input – as a command down the chain within corporate, government or military hierarchies. The organisational chart of the BC Ministry of Forests (Figure 6) is one such command and control system. Similar to Kauffman's K = 1 lightbulb networks, these systems cannot learn and adapt.

Command and control social systems are good at dealing with near-term crises -- war, revolution, epidemics, technological development, financial meltdowns, and so on. They appear much less able to deal with long-term threats such as intergenerational equity, loss of natural diversity and, above

Figure 6. Organisational chart for the BC Ministry of Forests and Range (Source: BC Ministry of Forests and Range).



all, climate change. To deal with global change that may occur beyond a ten-year horizon, we may need to pay attention to the complexity inherent in society as well as in geological, atmospheric and natural systems. We may have to tap into new, implicit ways of organising ourselves – allowing an adaptive, learning society.

Questions & Discussion

1. **UQ:** What do you think about the Internet?

Richard Overstall (RO): I worry because there are no bounds on the Internet. I don't think you can expand a decentralized system infinitely – it's too horizontal at the moment.

2. **UQ:** How can we look at these things (like societal organisation) objectively?

RO: This is why complexity theory is a science. You think of questions/hypotheses and then you have to test them formally. Complexity theory work to date has been a lot of analogy – it's important to start moving towards more formal testing.

3. **UQ:** When you were talking about the Smithers economy, were you saying that if we had groups of 150 people with a leader like your examples of other societies we could create a complex society?

RO: I wasn't saying that the Smithers economy is complex, just that its rules are implicit. I don't know whether it's ordered, complex or chaotic, only that it's implicit. I don't know if and how the economy would be changed if we organised ourselves into groups of 150.

4. **UQ:** Can a system be somewhat complex or is it a binary sort of thing? (complex versus not complex)

RO: Generally, it's not a binary thing – there can be elements of chaos in a complex system, elements of complexity in an ordered system, etc.

RO: But at a particular scale, the switch from complex to ordered or to chaotic is a quite rapid phase change – what is often called a tipping point.

5. **UQ:** It appeared in your talk that there were some implicit rules about carrying capacity (if the group is >150, it splits up; if it is <150, they join with another group). Do you think this has application for current issues (human population/environment)?

RO: The societies I talked about change very slowly. For example, when the geographic range of cedar trees expanded northwards on the American west coast, cultures were able to adapt and change because the species' migration occurred slowly. The speed of our society is much faster – things happen faster, decisions are made faster. This is because our decision-making institutions have changed from using processes that emerge implicitly from horizontal social relations to using processes that are explicitly commanded through hierarchical social relations. In a more conservative society, institutions and technologies change more slowly, and so it's easier to keep up with and adapt to most environmental change.

Modelling and Planning for Uncertainty

Don Morgan, BC Ministry of Forests and Range (Don.Morgan@gov.bc.ca)

Natural resources planning over the past Century has relied on assumptions of increasing certainty through data collection, analysis and predictive modelling, and increasing efficiency by maximizing supply and minimizing regrets (Rustichini 1999). Timber-supply and habitat-supply analysis in BC are two examples of this approach. Both have adopted a Newtonian world-view for problem solving that can be described as linear (cause-and-effect), mechanistic and reductionistic. This approach emphasizes prediction and managing toward a mean outcome. In fact, predictions about the future have generally been incorrect (Table 6).

A new way of forecasting the future involves coming to terms with and planning for uncertainty, recognizing incomplete knowledge and the inherent lack of predictability of the behaviour of complex systems. In contrast with the Newtonian view, the Complexity world view is non-linear, adopts a systems perspective, recognizes the phenomenon of emergence, and understands that small changes can result in large effects. The focus shifts to managing for variability and for plausible, rather than certain, futures.

Scenarios are a new tool used to manage for uncertainty. They describe a set of reasonably plausible, but structurally different conjectures about what might happen in the future (Duinker and Greig 2007). Their main purpose is to stimulate thinking about underlying assumptions, as well as the opportunities and risks of alternative courses of action. Scenario analysis typically involves four steps: (1) identifying the important social and ecological drivers of the system; (2) defining the critical uncertainties in the system; (3) describing the major characteristics of each scenario, (4) developing logical paths forward. The result is a bounded range of plausible futures.

Consider a matrix of four land-use management scenarios that bound the range of low to high environmental change on the vertical axis and reactive to proactive management response on the horizontal axis (Figure 7). Managers working through these scenarios must consider many possible futures rather than a single desired future state.

Table 6. Past success at forecasting the future (adapted from P. Duinker 2009 unpublished slide).

Forecast	Source
"The phonograph is of no commercial value."	Thomas Edison (1880)
"There is no reason for any individual to have a computer in their home."	Ken Olsen, President of DEC (1977)
Internal sales forecasts for PCs for the 1980s: 295,000. Actual sales: 29,000,000+	IBM (1979)
"Anyone who thinks the ANC is going to run South Africa is living in cloud cuckoo land."	Margaret Thatcher (1987)
"The concept is interesting and well-formed but in order to earn better than a 'C', the idea must be feasible."	Yale University professor's response to Fred Smith, founder of Federal Express
"They couldn't hit an elephant at that dist…"	Last words of General Sedgwick (1864)

Further information on the use of scenarios to manage for uncertain futures can be found on websites of the Habitat Supply Research Network (HSRN 2009), the Milennium Ecosystem Assessment (MEA 2009), the Future Forests Project (SFMN 2009) or in Morgan et al. (2008a, b).

Questions & Discussion

1. **JP:** If we abandon command and control, how would that affect common-property resources like forests and salmon? Do we need to go to the opposite extreme of deregulation?

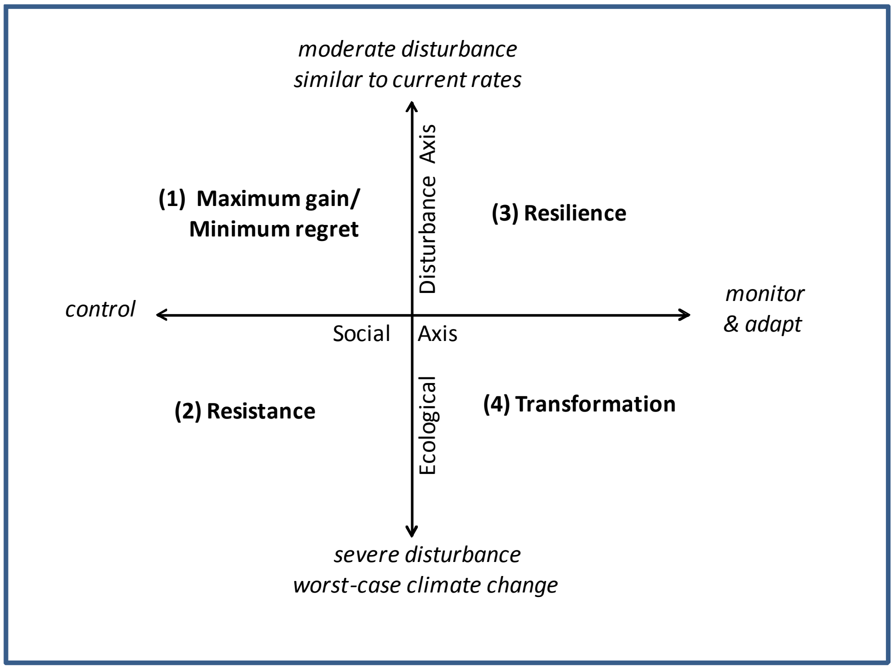
DM: I'm advocating for more regionalization, not abandonment of governments and rules.

2. **UQ:** How do you plan for uncertainty in the face of uncertainty? How do you know in your models how much is known and how much is unknown?

DM: There are some ways to plan for uncertainty that are clear. For example, maximizing timber production is probably not a good idea in the face of climate change – it doesn't allow us enough of a buffer; to hedge our bets.

DM: *Different sources and types of uncertainty can be characterized, and the management of ecosystem services can be structured to acknowledge them. For example, one breakdown of uncertainty is to split it into knowledge or epistemological uncertainty (those things we can come to know about a system through further study, species use of a particular habitat type, for example) versus inherent uncertainty (those aspects of the system that cannot be predicted, such as the likelihood of a large regional fire next year). Further characterization of uncertainty may include uncertainty due to natural variation, uncertainty about functional relationships, uncertainty generated by excluding deliberately or inadvertently key variables,*

Figure 7. A land use-management scenario matrix for southeastern British Columbia illustrating a range of moderate to severe ecological disturbance on the vertical axis, command-and-control versus adaptive societal response on the horizontal axis, and appropriately-themed management scenarios (1) to (4) in each quadrat.



and unknowables, such as a volcanic eruption. A Johari window (Luft and Ingram 1955) provides a taxonomy of uncertainty with four quadrants: 1)Known knowns – things such as cause and effect that are known through empirical work and data analysis of known relationships; 2)Known unknowns –outstanding questions that require further data collection and analysis, but can be addressed; 3) Unknown knowns – issues that are known to others, but not known or accepted by the investigator, such as First Nations traditional knowledge; and 4) Unknown unknowns –aspects of a system that are unknowable. By identifying different types and sources of uncertainty a more robust planning system can be constructed that can leverage what is known, identify research gaps that can be further pursued, provide flexibility to adapt to those aspects of the system that are unknown or unknowable. The framework highlights the need to apply different decision making approaches depending on the certainty or type of uncertainty that is being managed (Snowden and Boone 2007).

3. **UQ:** Generally, is planning for and modeling uncertainty a matter of increasing error parameters around your predictions?

DM: Yes, but there are also new model components. Instead of having static decisions, we’re now able to incorporate adaptive decision-making into models.

RO: We’re a risk-embracing society – militarization and capitalism, for example, are risk-embracing systems. Part of managing for uncertainty means moving towards more risk-averse scenarios.

Concluding Remarks and Next Steps

There was wide-ranging discussion during the individual presentations and breaks, but insufficient time for a formal synthesis session at the end of the half-day workshop. Participants expressed enthusiasm about the breadth of perspectives offered at the seminar and were motivated to learn more. Although several participants wanted a follow-up session dedicated to a hands-on application of Complexity Science to their domain of interest (forestry and/or wildlife management), a show of hands indicated that the participants overwhelmingly wanted the next session to be broad and interdisciplinary.

A second Complexity Workshop is planned for Smithers on February 19, 2010. Our objective will be to involve participants more directly, and to expand the range of interests and perspectives. Two possibilities under discussion are: (1) to have participants take part in a local global change scenario exercise; and (2) to allow participants to play with interactive models. An invited speaker from outside the Bulkley Valley is another option. Our intent is to also keep the second workshop informal and low-cost.

The idea of adding a Complexity discussion group or blog on the BV Research Centre Complexity Workshop webpage was investigated, but was not possible with the existing website structure. With website upgrades underway in May 2009, this may be possible after the second workshop. In the interim, general complexity discussion items can be sent to haeussl@unbc.ca and will be posted on the BV Research Centre workshop webpage, if the contributor wishes.

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