PROCEEDINGS OF THE SECOND INTERNATIONAL CONGRESS OF SILVICULTURE
Florence, November 26th - 29th 2014

SILVICULTURE TO ENHANCE THE ADAPTIVE CAPACITY OF FORESTS

Klaus J. Puettmann[1]

[1]Department of Forest Ecosystems and Society, Oregon State University, Corvallis, USA;
Klaus.Puettmann@oregonstate.edu

The presentation highlights the hypothesis that viewing forests as complex adaptive systems can help forest management to enhance the adaptive capacity of forests. It provides an example, how scientific concepts derived from the complexity literature relate to forest ecosystems and can be used to develop and assess specific silvicultural practices. The threshold concept is key to understanding ecosystem dynamics and has received a lot of attention in the context of complex adaptive systems. The threshold concept can provide insights why systems are not able to change and adapt. Complex adaptive systems theory suggests that the conditions that prevent ecosystems from changing can be grouped into two sets, labeled rigidity and poverty traps. Examples of rigidity traps include old-growth forest where components are highly connected, nutrients are mostly locked up in a few shade tolerant tree species, and forests have little opportunity to change from internal processes, despite being sensitive to high intensive, large-scale disturbances. In contrast, poverty traps reflect systems right after disturbances with high diversity, but e.g., where frequent disturbances prevent high connectedness among components and do not allow succession to occur. Using an example from a thinning study, I show how the concepts of rigidity and poverty traps in conjunction with the panarchy cycle can be used to gain more conceptual understanding of ecosystems adaptability and thus provides insights in how silviculturists can evaluate practices in this context. For example, small scale management disturbances may help overcome rigidity gaps, such as creating canopy gaps or variable density thinnings. Alternatively, encouraging future seed sources, either through thinning operations or maintenance of seed bearing trees or neighboring stands, may be helpful to facility ecosystems to overcome poverty traps.

Keywords: adaptive capacity, thresholds, ecosystem dynamics.
Parole chiave: capacità adattativa, soglie, dinamiche ecosistemiche.

http://dx.doi.org/10.4129/2cis-kjp-sil

1. Introduction

Recent trends in ecological, economic, and political conditions suggest that forest ecosystems will experience novel conditions that do not have an historical equivalent (Hobbs and Hiccs, 2013). This raises the question whether traditional forest management approaches and practices are suitable in the future or whether novel management approaches are needed (Seastedt *et al.*, 2008). Several colleagues and I suggested that viewing forests as complex adaptive systems provides new unique insights that will be helpful when managing novel ecosystems (Puettmann *et al.*, 2009; Messier *et al.*, 2013).

While complex systems theory has been used in other settings, for example economics, business cycles, and transportation (Waldrop, 1992), it has received little attention in ecology (Levin, 1999) and even less in forestry (Drever *et al.*, 2006). Consequently much of the early writings are focused on concepts and theory and much work still needs to be done to work out how these theories can be utilized in forest applications (Puettmann, 2014). This presentation provides an example how a scientific concept from complexity theory may be interpreted ecological contexts, and how it can be used to provide guidance for development and assessment of silvicultural practices.

2. Background

In the past much of the work investigating how forests respond to perturbations has focused on understanding ecosystem stability, specifically on aspects of resistance and resilience (Gunderson *et al.*, 2009). Complexity theory suggests that systems continuously change and long-term developments are based on their ability to adapt to new changing conditions (Levin *et al.*, 2013), but ecologists and foresters have paid less attention to this aspect. An understanding how systems adapt (defined as the ability to adjust to changing internal and external conditions) to changes while at the same time providing all desired ecosystem goods and services (labeled “acceptable” below) appears key for future forest management (Puettmann, 2014). Specifically, this understanding can then be used to develop and implement silvicultural practices that increase the adaptive capacity of ecosystems i.e., their ability to respond to surprises in an “acceptable” way. Following, I will elaborate on thresholds; one of the key scientific concepts of complexity science that is crucial for understanding adaptive capacity and adaptation (Andersen *et al.*, 2009). My goal is to provide insights how a more formal understanding of the threshold concept can be used to develop and assess silvicultural practices that increase adaptive capacity of ecosystems.

As suggested above, the concepts of adaptability and stability are directly related. Much of our understanding about what keeps systems stable, can be more or less directly translated into an understanding of what keeps systems from changing and adapting. For example, negative feedback loops have been shown to be key self-enforcing mechanisms to balance out changes in external conditions (Bonan, 2008). A more detailed analysis of such processes suggests that conditions which prevent ecosystems from adapting can be described by two distinct models as rigidity traps and poverty traps (Carpenter and Brock, 2008).

3. Rigidity and Poverty Traps

Rigidity traps are present when systems are highly connected, rigid, and inflexible (Allison and Hobbs, 2004). Mature old-growth forests can be viewed as an example of an ecosystem in a rigidity trap (Carpenter and Brock, 2008). Much of the biomass and nutrients are typically tied up in late successional tree species. Successional and stand dynamic processes had sufficient time to encourage connectedness, i.e., interactions such as competition and facilitation are dominant. Typical small scale disturbances do not lead to great modifications of structure and function. For example, mortality of single or small groups of trees typically leads to recruitment of shade tolerant trees, thus basically maintaining continuity of species composition and structural characteristics. Forests in the rigidity traps are not able to change through internal processes. However, such ecosystems are susceptible to intensive, large-scale disturbances that shift the ecosystem's structure and functioning to the point that they may compromise the ecosystem’s ability to provide desired ecosystem goods and services. In many old-growth stands in the western US, stand replacing fires are an example of such disturbances.

In contrast, poverty traps contain a high diversity of components with low connectedness. Such conditions are found e.g., in forests after recent disturbances, especially when multiple disturbances occur at high frequencies (Carpenter and Brock, 2008) and disturbance tolerant shrubs, such as chaparral dominate. Thus, the potential for change is high, but it is not realized due to e.g., frequent external disturbances that prevent succession to proceed. Similarly to rigidity traps, poverty traps cannot be easily overcome through internal processes.

4. Ecosystem Dynamics

To develop principles that allow silvicultural practices to be assessed in terms of their ability to overcome rigidity and poverty traps requires viewing these concepts in the context of larger scale ecosystem dynamics. Specifically the panarchy cycle provides useful insights in this context (Gunderson and Holling, 2002, Drever *et al.*, 2006). For example, ecosystems in the conservation phase of the panarchy cycle have characteristics typically associated with rigidity traps, such as high connectedness. In contrast, ecosystems in the later parts of the release and the reorganization phases exhibit high diversity but low connectedness and thus can be viewed as examples of ecosystems in a poverty trap (Holling, 2001). Holling and coworkers (Gunderson and Holling, 2002) suggested two principles based on cross-scale interactions that are key for “creating and sustaining adaptive capability” (Holling, 2001, page 398) and thus can be utilized as a basis for forest management practices during the conservation phase and reorganization phases (Gunderson and Holling, 2002). To overcome rigidity traps, selected small-scale interventions (“revolt” sensu Gunderson and Holling 2002) can encourage changes in ecosystems in the conservation phase that do not have the same negative impacts as intensive, large-scale stand replacing disturbances. For example, silvicultural treatments such as cutting gaps or thinning to lower densities in old forests can break up the homogeneity in terms of structure and tree species composition, especially when early successional species regenerate (Ares *et al.,* 2010). This can be viewed as reducing the connectedness and increasing the diversity during the conservation phase and thus can act as a practice that may help ecosystems overcome rigidity traps. In contrast, poverty traps, which play out during the later release and reorganization phase, can be overcome by cross-scale interactions driven by a larger-scale cycle. This can be viewed as creating a type of memory (“remember” sensu Gunderson and Holling, 2002). Specifically, practices aimed at overcoming poverty traps are encouraging the variety of ecosystem components that may be negatively influenced during the release phase, but that can maintain or regain their functions and thus be quite influential moving the ecosystems through the reorganization phase (Drever *et al.*, 2006). For example, silvicultural practice that encourage seed productions, seed banks, or the sprouting ability of plants will facilitate the reorganization of ecosystems after disturbances and accelerate successional development.

Ecosystems that are considered in a rigidity or poverty trap can provide a challenge for silviculturists, specifically when external changes or trends, e.g., climate change, suggest that current ecosystem conditions are not adequate or suitable to provide the desired ecosystem goods and services in the future (Puettmann, 2011). In such situations silviculturists may be called upon to initiate or facilitate processes that initiate or encourage ecosystems to overcome the traps, while allowing ecosystems to change and adapt and at the same time provide desired ecosystem goods and services during this transition. I propose that a detailed understanding of factors and processes associated with rigidity and poverty traps and how these factors and processes are impacted by silvicultural practices is crucial in such situations.

5. Silviculture Example

Silvicultural practices to overcome rigidity traps reduce connectedness and increase species diversity include high intensity or variable thinnings and cutting small gaps to establish a wider variety of species. Other examples include introduction or fostering of new tree species through seeding or planting. Both these practices should pay special attention to establishing early successional species, thereby increasing diversity, reduce connectedness, and thus shift the internal processes that determine system behavior (Dodson *et al.*, 2014).

In contrast, silvicultural practices that stress "remember" or legacies include thinning or other practices that increase the amount and diversity of understory vegetation or encourage the establishment of advanced regeneration (Ares *et al.*, 2010; Dodson *et al.*, 2014). In this case, species are of special interest that can survive or re-establish quickly after disturbances, such as sprouting species, species that can tolerate stress, such as drought, and species with the long-lived seed bank (Neill and Puettmann, 2013). Other practices to encourage ecosystems to overcome poverty traps include treatments such as thinning or fertilization that encourage seed production of trees that may survive large-scale disturbances. Alternatively, silvicultural treatments that encourage refuge areas in the context of landscape connectivity may provide seeds or provide habitat for key plants, animals, fungi, pollination sources, etc. that can reinvade and may be crucial for ecosystems as they reassemble after disturbances (Drever *et al.*, 2006). These treatments are especially valuable, if they are designed to ensure that desired ecosystem goods and services can be provided throughout the release and reorganization phase.

Next, I highlighted an example how silvicultural practices may have to be modified to encourage conditions that overcome rigidity traps and poverty traps. Data for this example came from the Density Management Study (Cissel *et al.*, 2006), in which we modified conventional thinning approaches to increase the spatial variability in otherwise homogenous Douglas-fir stands in western Oregon, Conventional thinning operations are typically designed to achieve homogenous conditions and to encourage growth of the residual trees. If the main objective is maximizing income, residual spacing and spatial layout, as well as selection criteria for cut and leave trees, typically focus on finding the optimal balance between individual tree and stand growth (Nyland, 2002). To encourage the adaptive capacity, we left leave islands untreated and created gaps (both from 0.1 to 0.4 hectare in size) and areas with low residual densities (e.g., 50 trees per hectare) in addition to the conventional thinning areas with different residual densities. Our findings suggest that practices modified to encourage forests to overcome rigidity and poverty traps can be applied successfully on an operational basis and be profitable (Cissel *et al.*, 2006; Dodson *et al.*, 2012). Our treatments increased the spatial variability of overstory and understory vegetation and established natural regeneration of a variety of trees and other plants, including early successional species (i.e., increasing diversity and reducing connectedness). The higher amount of understory vegetation (Ares *et al.*, 2010) can act as a stabilizing force during the release and reorganization phase when, for example, overstory trees are killed by insects or windstorm (i.e., act as "remember" agents). Further detailed investigation highlighted that our treatments increased selected amount and diversity of understory species that are key for provision of food for wildlife and insects and at the same time are tolerant to drought and higher temperatures or able to re-sprout after disturbances. Thus, our treatments favoured elements that will allow forest ecosystems to adapt to various aspects of climate change, while providing various food sources for wildlife (Neill and Puettmann, 2013). Consequently, we concluded that the treatments, as applied in our study, were successful in facilitating mature *Douglas-fir* forests overcome rigidity and poverty traps and thus increased the adaptive capacity of the ecosystems to react to perturbations.

6. Conclusion

The presentation concludes that the hypothesis was supported that concepts from complexity science like rigidity and poverty traps and the panarchy cycle can be useful when developing and assessing silvicultural practices in regards to their influence on adaptive capacity. As a next step, researchers and foresters need to test this hypothesis further by evaluating whether these principles are useful in a wider variety of ecosystems and management situations. Furthermore, researchers and foresters should assess their current suite of practices in this context, specifically whether silviculture practices influence specific factors associated with rigidity and poverty traps, and how these practices may have to be modified to facilitate that ecosystems overcome such traps. If such efforts are successful, the application of the trap and the associated threshold concepts can provide an example, how scientific theories from complexity science can be applied to develop silvicultural treatments that encourages the adaptive capacity of ecosystems.

Table 1. Selected characteristics of poverty trap and rigidity traps (modified from Carpenter and Brock, 2008).

Rigidity Trap	*Poverty Trap*
Highly connected, self-reinforcing inflexible	Heterogeneity/diversity is high
Nutrients locked up few species	Connectedness is low
Little opportunity to change from endogenous process	Potential for change is high, but not realized
Susceptible to high intensity, large-scale disturbances	Frequent changes or disturbances do not allow succession to occur

Table 2. Examples of vegetation characteristics that can facilitate forest ecosystems to overcome rigidity and poverty traps.

Rigidity Trap	*Poverty Trap*
Canopy gaps or low density areas	Understory vegetation
Tree regeneration of a variety of species	Advanced tree regeneration
Early seral vegetation	Refuges, legacies (at stand and landscape scales)
New, introduced species	Landscape connectivity

RIASSUNTO

Selvicoltura e aumento della capacità adattativa delle foreste

Questo contributo evidenzia come l'ipotesi di considerare le foreste sistemi complessi e adattativi possa aiutare la gestione forestale ad aumentare la capacità adattativa delle foreste. Viene presentato un esempio di come i principi scientifici derivati dalla letteratura sulla complessità possano essere applicati agli ecosistemi forestali e usati per sviluppare e valutare specifiche pratiche selvicolturali. Il concetto di soglia è un concetto chiave per capire le dinamiche degli ecosistemi e ha ricevuto molta attenzione nel contesto dello studio dei sistemi complessi e adattativi. Qui si esamina il concetto di soglia e la sua utilità per spiegare perché certi sistemi non sono in grado di cambiare e adattarsi. La teoria dei sistemi complessi e adattativi suggerisce che le condizioni che impediscono agli ecosistemi di cambiare possono essere divise in due categorie, definite rispettivamente trappole della rigidità e trappole della povertà. Esempi di trappole della rigidità includono le foreste vetuste dove i componenti sono strettamente connessi, i nutrienti sono bloccati in poche specie tolleranti, e le foreste hanno poca opportunità per cambiare a seguito di processi interni, pur essendo sensibili ai disturbi. Al contrario, le trappole della povertà rappresentano sistemi con alta diversità ma disturbi frequenti che impediscono una elevata connessione tra i componenti del sistema e non consentono il verificarsi di successioni. Usando un esempio da uno studio sui diradamenti, spiego come i concetti di trappole della rigidità e della povertà, insieme al ciclo della panarchia, possano essere usati per ottenere una comprensione più concettuale della adattabilità degli ecosistemi e così dare alcune indicazioni ai selvicoltori su come valutare le pratiche selvicolturali in questo contesto. Per esempio, una gestione che emuli regimi di disturbo a piccola scala, come creare *gaps* nella copertura arborea, oppure diradamenti che rilasciano densità diversificate, possono aiutare a superare le trappole della rigidità. In alternativa, incoraggiare la disponibilità futura di seme attraverso diradamenti, oppure mantenendo alberi o popolamenti portaseme, può essere utile per aiutare gli ecosistemi a superare le trappole della povertà.

REFERENCES

Allison H., Hobbs R., 2004 – *Resilience, adaptive capacity, and the lock-in trap of the western Australian agricultural region*. Ecology and Society, 9.

Andersen T., Carstensen J., Hernandez-Garcia E., Duarte C., 2009 – *Ecological thresholds and regime shifts: approaches to identification*. Trends in Ecology & Evolution, 24: 49-57. http://dx.doi.org/10.1016/j.tree.2008.07.014

Ares A., Neill A., Puettmann K., 2010 – *Understory abundance, species diversity and functional attribute response to thinning in coniferous stands*. Forest Ecology and Management, 260: 1104-1113. http://dx.doi.org/10.1016/j.foreco.2010.06.023

Bonan G., 2008 – *Forests and climate change: forcings, feedbacks, and the climate benefits of forests.* Science, 320: 1444-1449. http://dx.doi.org/10.1126/science.1155121

Carpenter S., Brock W., 2008 – *Adaptive capacity and traps*. Ecology and Society, 13: 40.

Cissel J., Anderson P., Olson D., Puettmann K., Berryman S., Chan S., Thompson C., 2006 – *BLM Density Management and Riparian Buffer Study: Establishment Report and Study Plan,* pp. 151.

Dodson E., Ares A., Puettmann K., 2012 – *Early responses to thinning treatments designed to accelerate late successional forest structure in young coniferous stands of western Oregon, USA.* Canadian Journal of Forest Research, 42: 345-355. http://dx.doi.org/10.1139/x11-188

Dodson E., Burton J., Puettmann K., 2014 – *Multiscale controls on natural regeneration dynamics after partial overstory removal in Douglas-fir Forests in western Oregon, USA.* Forest Science, 60: 953-961.

Drever C., Peterson, G., Messier C., Bergeron Y., Flannigan M., 2006 – *Can forest management based on natural disturbances maintain ecological resilience?* Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 36: 2285-2299. http://dx.doi.org/10.1139/x06-132

Gunderson L., Holling C., 2002 – *Panarchy: Understanding transformations in human and natural systems*. Island Press, Washington, DC., pp. 507.

Gunderson L., Allen C., Holling C., 2009 –*Foundations of ecological resilience*. Island Press, pp.466.

Hobbs R., Hiccs E., 2013 – N*ovel Ecosystems: Intervening in the new ecological world order.* Wiley-Blackwell, pp. 368.

Holling C., 2001 – *Understanding the complexity of economic, ecological, and social systems.* Ecosystems, 4: 390-405. http://dx.doi.org/10.1007/s10021-001-0101-5

Levin S., Xepapadeas T., Crépin A., Norberg J., de Zeeuw A., Folke C., Hughes T., Arrow K., Barrett S., Daily G., Ehrlich P., Kautsky N., Mäler K., Polasky S., Troell T., Vincent J., Walker B., 2013 – *Social-ecological systems as complex adaptive systems: modeling and policy implications*. Environment and Development Economics, 18: 111-132. http://dx.doi.org/10.1017/S1355770X12000460

Levin S., 1999 – *Fragile Dominion.* Helix Book, Perseus Publishing, Cambridge, MA. Pp. 250.

Messier C., Puettmann K., Coates D., 2013 – *Managing forests as complex adaptive systems: Building resilience to the challenge of global change.* The Earthscan Forest Library. Earthscan from Routledge, London, pp. 353

Neill A., Puettmann K., 2013 – *Managing for adaptive capacity: Thinning improves food availability for wildlife and insect pollinators under climate change conditions*. Canadian Journal Forest Research, 43: 428-440. http://dx.doi.org/10.1139/cjfr-2012-0345

Nyland R., 2002 – *Silviculture: Concepts and Applications (2nd edition).* McGraw-Hill, New York., pp. 682.

Puettmann K., 2011 – *Silvicultural challenges and options in the context of global change: Simple fixes and opportunities for new management approaches*. Journal of Forestry, 109: 321-331.

Puettmann K., 2014 – *Restoring the adaptive capacity of forest ecosystems*. Journal of Sustainable Forestry, 33: S15-S27.

Puettmann K., Coates D., Messier C., 2009 – *A Critique of Silviculture: Managing for Complexity*. Island Press, Washington, DC., pp. 188.

Seastedt T., Hobbs R., Suding K., 2008 – *Management of novel ecosystems: are novel approaches required?* Frontiers in Ecology and the Environment, 6: 547-553. http://dx.doi.org/10.1890/070046

Waldrop M., 1992 – *Complexity: The emerging science at the edge of order and chaos*. Simon & Schuster, New York, pp. 380.