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A complex adaptive systems perspective of forest policy in China

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ABSTRACT

The world's forests have historically been managed as systems in which environmental health is compromised for the sake of economic efficiency and growth. China's forest policy framework has generally followed this paradigm as large-scale deforestation over the 20th century led to landscapes that, while economically productive, were made vulnerable to natural disturbances. However, in recent decades China has experienced substantial forest reforms that aim to protect important forested lands while simultaneously increasing timber outputs from plantations. Multiple green growth oriented programs have been in place to attain these objectives with the anticipation that rural poverty can be alleviated and the vulnerability towards natural disasters can be avoided. A growing body of research demonstrates the success of these reforms for improving the lives of landowners while also increasing the country's forest cover. However, these reforms have brought upon substantial change to the relationship within and between social, economic and ecological properties of the nation's forest system, and consequentially its ability to respond and adapt to change in the future. The objective of this paper is to describe the relationship between forest policy and environmental change in China during the last century using a complex adaptive systems framework. This approach demonstrates the coupled nature of policies and forest dynamics that need to be considered in future policy development. China's green growth directed policies and practices must embrace a perspective of constant change and the inevitability of perturbations and disturbances. In this way, China can begin to consider how to build resilience into its policies and management strategies so that the overall system maintains a level of flexibility that allows it to adapt to unforeseen economic and ecological change.

1. Introduction

The management of natural resources has drastically altered landscapes around the world (Steffen et al., 2006). For decades, the prevailing paradigm of natural resources policies has focused on optimization of outputs by simplifying natural ecosystems and enforcing policies with narrow objectives across diverse landscapes (Folke et al., 2004). This paradigm treats the growth of natural resources as a stable process, where inputs are controlled and outcomes are predictable (Drever et al., 2006). While this mode of governance has produced substantial social and economic wealth, there is growing evidence that the paradigm is leading to the production of social and ecological systems that are more vulnerable to economic and natural disturbances (Folke et al., 2002).

A predominant example of this paradigm has been China's forest policies over the 20th century that have exploited the countries forests for timber production in order to satisfy the country's increasing desire for wood and wood products and for supplying export market demands (Démurger et al., 2009). China has a long record of large-scale deforestation, which in recent decades helped facilitate the rise of the globalized Chinese economy and mass population growth during the second half of the 20th century (Wang et al., 2004). However, this period of exploitation has led to widespread land use change (Zhang and Song, 2006), loss of habitat for thousands of native species and created social and economic disparities between landowner farmers and those selling timber in domestic and international markets (Li et al., 2007).

While pressure for more sustainable forest policies was mounting from environmental groups in China in the late 20th century, the most significant reform to the country's forestry practices were precipitated by the 1998 floods of several major rivers including the Yangtze and Yellow Rivers (Ji et al., 2011). The flooding of the Yangtze reportedly caused 1320 deaths, affected 223 million people, and destroyed over 150,000 homes (Xu et al., 2006). While numerous causes of this flood have been reported, deforestation is often cited as the most prominent driver (Démurger et al., 2009). The direct link between deforestation and these floods prompted significant forest policy reforms at the national level that aimed to curb deforestation in key areas in order to decrease soil erosion and sandificaiton of deforested lands. At the same time, new reforestation and afforestation programs were put into place to increase China's forest cover to further assist with soil erosion problems as well as improve the livelihoods of rural farmers.

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China set forth to dramatically reform its forest policies to increase its forests across the country, but at the same time it also focused efforts on enhancing its ability to produce sufficient timber for domestic and international markets (Wang et al., 2004). This was accomplished through multiple programs that distributed land tenure and resource extractions rights to local governments and landowners, and provided subsides to farmers for transferring agricultural land to forests from which timber could be sold. Additionally, the government set aside large areas for plantations where the primary purpose is to grow fast, high-yielding species (Yin et al., 2003). This time period can be seen as one in which China invested considerably in a green growth approach to managing its forests as engaged in a more sustainable use of natural resources for assisting economic growth.

Previous studies have revealed numerous positive outcomes from these reforms, including decreased biodiversity loss (Xu et al., 2009), increase in overall household income (Li et al., 2011), increase in carbon sequestration (Huang et al., 2012), diversification of industries (Zhang, 2006) and an increase in soil carbon stocks (Deng et al., 2014). Moreover, overall forest cover has increased in recent decades due to reforestation and afforestation efforts (see current forest land cover in Fig. 1). However, these benefits are contrasted against some of the adverse consequences of the reform programs that include a decrease in household income in some areas and in some specific parts of the forest industry (Wang and Maclaren, 2012), inappropriate site selection for specific tree species – mostly involving selecting the wrong species to be used in plantation (Trac et al., 2013) and afforestation sites (Cao et al., 2011), and continued soil erosion in managed areas (Fu et al., 2011). Several problems with administering these programs have also been noted, such as a lack of interagency cooperation and long term planning as well as the use of inappropriate technical practices in specific areas resulting from an overemphasis on a top-down administration of the programs (Xu et al., 2006).

These studies together provide an understanding of how successful the sustainable reforms have been to date. However, less attention is paid to how the management of China's forests as a dynamic natural resource system in which social and ecological processes interact over time to produce uncertain and at times adverse outcomes, such as the 1998 floods in which ecological degradation affected hundreds of millions of people. Existing critiques are largely based on quantitative metrics the measure improvements (or lack thereof) of social (e.g. income) or ecological (e.g. forest cover, carbon stocks) dimensions of the sustainable forest programs (Yin et al., 2003). While some of this work has focused around the quantification of ecosystem services (Lü et al., 2012) in which both ecological and social dimensions are collectively considered for evaluating the programs, a theoretical modeling framework is still needed that can conceptualize the forest reforms as a dynamic, interrelated system built upon the complex relationships between policies, landowners, land managers, landscapes and forests. Rarely are the programs evaluated as interacting systems in which ecological and social processes become intertwined and at times inseparable because of how income dependencies often drive management decisions that impact forest ecosystems and their connected landscapes, and likewise how specific ecological consequences of management force changes in human behavior.

The goal of this paper is to provide an alternative perspective of China's forest reforms over the last century by examining the coupled nature of economic and ecological change. This paper seeks to utilize a complex adaptive systems (CAS) framework to describe China's recent history with its forests, and to frame its current policy paradigm in order to provide a means to forecast how socioeconomic and ecological

Fig. 1. Forest cover across China.

change could potentially lead to future system disturbances. Rather than interrogate any one program, this approach is applied to the general nature of the reforms that seek to increase the nation's forest cover while alleviating rural poverty through the protection of natural forests and the reforestation of previously forested lands and the afforestation of barren landscapes. The next section uses the literatures on CAS, socio-ecological systems (SES) and socio-ecological resilience to describe the management of forests as a system that cycles through different phases of exploitation, growth, disturbance, and reorganization. This framework is then used to contextualize China's relationship with its forests since the mid-20th century, followed by a discussion on potential issues and related recommendations for China's current forest policy paradigm.

2. Forest management as a complex adaptive system

Researchers from across disciplines argue that the current paradigm of forest policies employed in many countries needs to shift away from an "ecosystem equilibrium" perspective, and towards a view of forests as complex systems in which ecosystems and resource governance evolve together (Adger, 2000; Berkes et al., 2002; Folke et al., 2005; Walker and Meyers, 2004). In these social-ecological systems, the current system of management leads to unpredictable emergent disturbance regimes that make it difficult for individuals and ecosystems to adapt to change, especially when change comes in the form of a significant disturbance. Complex systems science provides an alternative approach by offering a lens to study how systems adapt to disturbance by reorganizing in ways that allow important system components to persist over time (Holling, 2001). Specifically, complex systems science has enlightened our understanding of the *resilience* (Holling, 1973) of natural resource management systems, and social-ecological systems in general, in the presence of increasing disturbances.

Resilience, as informed by sustainability science, refers to the degree to which a system can "absorb disturbance and reorganize while undergoing change to still retain essentially the same function, structure and feedbacks" (Walker and Meyers, 2004). In resilient natural resource management systems, disturbance can create opportunity for new ways of managing landscapes by changing existing relationships among resource governance actors or creating new actors that provide alternative modes of resource governance when existing structures become ineffective (Walker et al., 2004). In contrast, non-resilient systems mute opportunity for novelty by the constraints imposed by ecosystem processes and existing governance structures.

A complex systems approach can aid in organizing ideas regarding resilience and adaptive capacity by way of the complex adaptive cycle (Fig. 2). The adaptive cycle is a concept put forth as a metaphor for conceptualizing social-ecological systems as non-linear, disequilibrium entities that are constantly in a state of flux (Gunderson and Holling, 2001). The adaptive cycle is defined by four phases: exploitation, conservation, release, and reorganization. In a natural resource management context, the exploitation represents the management of landscapes to begin efficient levels of resource growth. This is followed by the conservation phase in which biomass accumulation is maintained at a desired level for maximal resource extraction. Next is the release phase in which the system experiences disturbance resulting in biomass loss and an increase in the vulnerability of the forest management system. Finally, the reorganization phase follows, presenting opportunities for forest governance (including multiple levels of government, forestry enterprises and local landowners) to change how policies formulate the relationships between actors.

The adaptive cycle represents changes in the relationships between two system properties: on the y-axis is the amount of potential inherent in the accumulated resource, and on the x-axis is the level of connectedness in variables controlling the system (Holling, 2001). Potential is the amount of ecological (biomass) and social (economic return) capital that is accumulated over time. Connectedness is the amount of control exerted on ecological and social processes to obtain high potential. The relationship between potential and connectedness determines the phase of the adaptive cycle in which a system resides at a particular moment in time, which in turn influences future system states.

The adaptive cycle emphasizes that change is constant. The movement from the exploitation to conservation phase is guided by positive feedbacks – mechanisms that are self-reinforcing and entrench a system into rigid states. For example, increased harvesting requires higher levels of labor and infrastructure, which in turn provides more opportunities to further increase harvesting levels, and so forth. Negative feedbacks are constraints on the system, such as the ecological potential for growing timber or the social limitations for providing labor. Systems in which positive and negative feedbacks are strongly opposed are more vulnerable to different types of perturbations. The capacity of the governance structure to adapt to this disturbance is a path dependent process, meaning that the history of institutionalization of forest practices

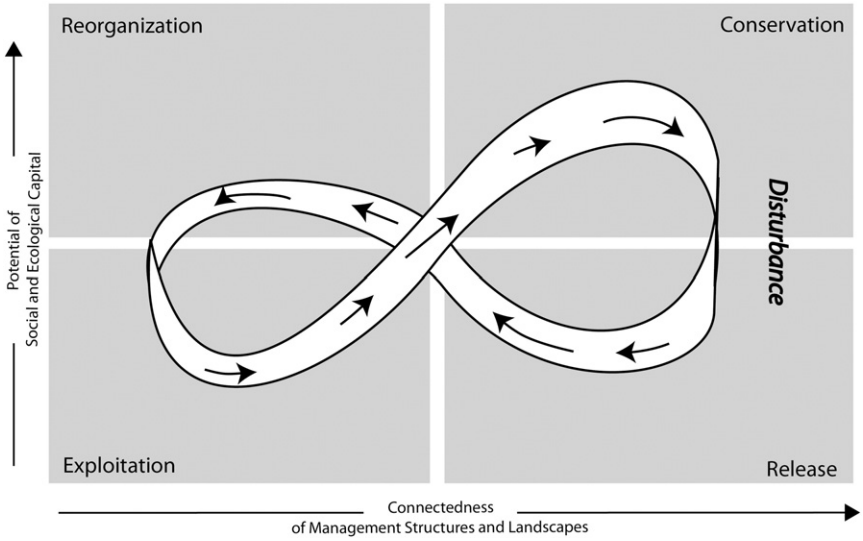

Fig. 2. The adaptive cycle depicting the movement of the system through four phases. The current state of the system is defined by the relationship between potential and connectedness.

coupled with ecological histories of the landscape constrains options for adaptation and change.

As the system moves through different phases of the cycle, decisions to increase potential by spurring greater economic activity or higher amounts of biomass can alter the shape of the adaptive cycle (from *d1* to *d2* in Fig. 3), potentially leading to more adverse consequences following disturbance. Similarly, increased connectedness in the management structure of forest resources (*d3* to *d4*) can increase the rigidity of the system, making it more difficult for the system to reorganize in a meaningful way that facilitates positive adaptive capacity. Increase connectedness can also take place by having a more connected and rigid landscape created by homogenizing forest structure over large areas. In this sense, more connected landscapes could make it easier for natural disturbances like wildfire or insect infestations to spread across large regions, in turn requiring greater levels of reorganization and capacity to adapt.

The adaptive cycle approach, and more broadly the CAS perspective, is considered a viable approach for thinking about how to manage forests at different scales (Puettmann et al., 2013). Much of the research in this field has focused on the adaptive capacity of both forests and governance systems to environmental dynamics such as climate change and natural disturbances (Johnston and Hesseln, 2012, Neill and Puettmann, 2013, Rupert and Lexer 2013, Bussotti et al. 2015, Messier et al. 2015). However, the current state of the literature is predominantly focused on applications in North America and Europe, with little attention paid to complex adaptive system perspectives in Asia, let alone China. It is therefore crucial to begin the first steps of describing China's forest policies in the context of CAS, which in future work could lead to the development and evaluation of CAS models for forecasting the potential impacts of policies on forest dynamics and environmental change.

3. The CAS of China's forest regimes

With the creation of the People's Republic of China in 1949, a massive economic restructuring was underway to facilitate socioeconomic development. Iron and steel production became major industrial institutions requiring significant volumes of wood for fuel (Xu et al., 2006). Simultaneously, the government initiated large-scale clear cutting across much of the country for crop production and to facilitate collectivization (Dai et al., 2013). Logging was also beneficial for the economy as it provided a major source of revenue for forest agencies (Kremen et al., 2000). As a result of deforestation practices over decades to fuel new industries and an agrarian economy, China's forest cover reached its lowest level in the early 1980s, and whatever forests remained were in poor condition as the most valuable timber (including most older age classes) had been removed (Dai et al., 2013).

Considering the adaptive cycle, this period represents an increasing potential as processes were in place to continually harvest large volumes of forest timber (i.e. economic potential). At the same time, system connectedness increased as the government facilitated growth in specific industries that became dependent on wood for fuel or the removal of forests for agriculture. Together, the increase in connectedness and potential lead to a high state of conservation in which the socioeconomic reliance on resource extraction was considerable. This system created positive feedbacks as more resource extraction and industrial growth permitted large increases in population levels that in turn provided more labor for industry and agriculture.

The growth of the system eventually hit its limit as mass deforestation coupled with population growth led to ecological and social disturbance in 1998 when torrential rain forced mass soil runoff that resulted in flooding of multiple rivers that killed over a thousand people and displaced millions more. It is possible that the potential for this disturbance was unanticipated due to national metrics of forest cover increase since the low point of forest cover in the early 1980s (Fig. 4). While more biomass was being added to China's landscapes, the floods were an evident result of the adverse consequences of overharvesting in specific ecologically and socially sensitive areas. These floods, in coordination with relatively recent environmental awareness of the ecological consequences of deforestation, forced the national government to adapt its forest policies and practices (Wang et al., 2004). The government had to reorganize itself both in terms of its policies and the responsibilities of different departments to address the socio-ecological impacts triggered by decades of economic and population growth. Having strong central control allowed the government to adapt by creating a series of forest policy reforms, which included the redistribution of land tenure to local governments and landowners in order for them to engage in forestry practices that would alleviate social and ecological problems.

At the onset of these reforms, the exploitation phase of the adaptive cycle took place in which some landowners, particularly farmers, were in the position to decide if they wanted to convert their farms to forests,

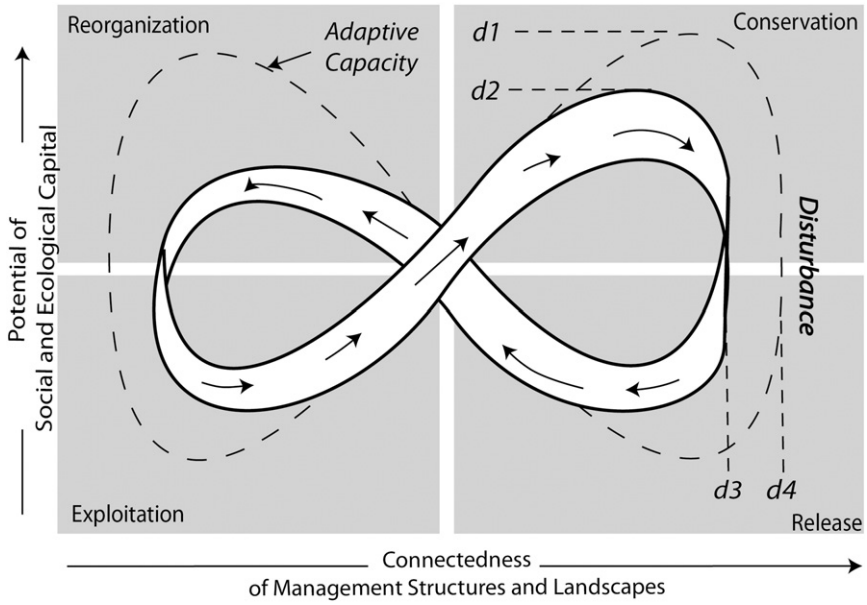

Fig. 3. The adaptive cycle modified by higher levels of potential (*d2*) and higher levels of connectedness (*d4*).

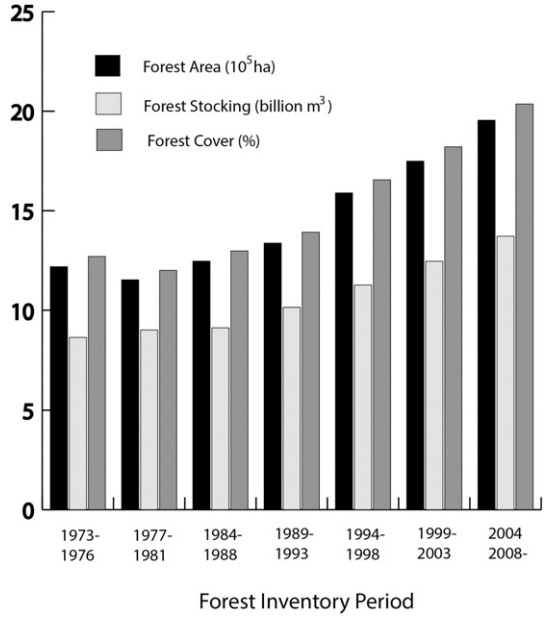

Fig. 4. Forest area, stocking and cover as measured during different periods of China's Forest Industry.
Source: The 7th National Forest Industry.

while others were forced to change practices in areas where forest harvesting became prohibited. Furthermore, the government hastened efforts to distribute resource ownership rights of some collectively managed forests to individual farmers in hopes that they would replant degraded lands for generating income (Dai et al., 2013). This reorganization of policies and the exploitation of new land tenure opportunities present perhaps one of the greatest modern-day adaptive responses of a resource economy after disturbance.

The new era of Chinese forest policies since the turn of the 20th century has once again led to increasing connectedness and potential in the forest system, albeit in a very different way. Landowners who abandoned agriculture needed to invest in new technologies, resources and training for managing timber resources, while larger enterprises needed to establish institutional infrastructure to employ workers and sustain desired output. In this light, increasing connectedness took place between the vast network of landowners, enterprises and workers, which faciliated the recently emerged market economy that was driving domestic and foreign demand for wood. At the same time, the system's potential increased due to increase in forest biomass resulting from the various new forest programs that focused on reforestation and afforestation throughout the country, and the economic return generated from these activities. According to the adaptive cycle perspective, a tightly connected network and high biomass and economic potential could be vulnerable to a disturbance of some kind. While it is not possible to foresee what such a disturbance will look like or when it will occur, we can utilize the adaptive cycle to see what potential impact certain types of disturbances will have on the system.

From an ecological perspective, China's forest reforms have led to an increase in overall forest biomass through producing high-yield timber as well as through reforestation and afforestation efforts. With regards to the adaptive cycle, the increase in biomass can be seen as an increase in potential of the forest as a greater amount of energy is contained in the system. At the same time, large-scale plantations aimed to provide sustained yields over time represent homogenized landscapes of single species (i.e. monocultures), most notably in the form of eucalyptus, poplar, rubber and Chinese fir plantations. (Although it is a non-native plant to China, the country accounts for approximately 13% of the world's eucalyptus total (Ji et al., 2011)). This has led to greater connectedness within the landscape due to the homogenization of the forest oppose to a less connected forest with uneven age forest stands and diversified species.

The focus on generating timber to meet domestic and international markets has placed plantations in the conservation phase of the adaptive cycle and forced the country to reconsider management practices in order to protect forests to ensure sustainable yields over time. As a result, China has recently adopted technologies and operational processes to minimize the risk of natural disturbances that could eliminate timber resources. A primary example of this is China's recent fire suppression efforts that mirror those in some western countries such as the United States.

Wildfires are the most common natural disturbance to forests in many parts of China (Wang et al., 2007), and increased fire suppression in recent decades on many plantations has led to an increase in fuel accumulation that is altering the nature of how fires take place. As has been noted in the United States, large scale suppression of naturally occurring wildfires serves as a positive feedback because fuel accumulation can lead to more frequent and intense fires over time, consequentially require heightened suppression efforts (Calkin et al., 2015). Therefore, suppressing disturbance from Chinese forest plantations could further increase the amount of potential in the system by allowing forests to grow beyond naturally occurring disturbance intervals. Similarly, as wildfires can act to increase tree age diversity in forests, suppressing forest fires can lead to homogenization of age structures, thereby increasing the forests connectedness.

The potential result from wildfire suppression is the risk of greater disturbance that would require different kinds of reorganization and adaptation than previously experienced. It is unclear how recent forms of forest governance and ownership will be able to respond if wildfire regimes change in ways that see more intense fires across the landscape. As Calkin et al. (2015) notes with regards to fire suppression policies in the United States, the level of suppression needed to adapt to the intensity and frequency of today's fire regime has become unsustainable, and only a cultural shift in forest policies will be able to adequately address this challenge.

4. Discussion

The management of the world's natural resources is a major force in altering landscapes and ecosystems. Forest policies in countries across the globe have long aimed to simplify ecosystems by minimizing the presence of non-timber species in order to create efficient landscapes that can optimize economic returns. This view of forests assumes they exist in a steady, predictable state in which timber resources can be extracted on convenient schedules. Natural disturbances are seen as a threat to timber growth and extraction, and as such, management strategies and the policies go to great lengths to minimize disturbance frequency and intensity. However, in a growing number of cases, this natural resource management paradigm is pushing forest landscapes past a threshold of disturbance resistance. It is at these moments that natural resource management needs to learn to adapt by reshaping policies and reorganizing the relationships between individuals and institutions in order to maintain the ability to persist as a viable system. In other words, a paradigm shift is needed in how we understand forests as a natural resource in order to be able to implement green growth strategies in the face of disturbance.

The complex adaptive systems approach described here offers a means of contextualizing China's forest practices past and present. This study set forth to examine China's forest management as a CAS in hopes to provide insights into potential disturbances and the capacity of the system to adapt to changes in order to maintain its desired functions. It is clear that the structure of how forests are managed are different from the pre-reform era, and as such careful consideration will need to be given to how government, enterprises and landowners should respond today when specific types of disturbances take place.

This study puts forth the following recommendations as things to consider for deploying sustainable forestry in China under a CAS perspective:

- Assess the degree to which private landowners can respond to fluctuations in demand for timber and timber products.
- Evaluate if private landowners can easily diversify how they make their income from forest services and products.
- Determine the capacity of local, regional and national governments to work together to assist landowners when timber demand quickly declines. That is, does their exist opportunity for government to initiate new programs that can assist landowners during periods of substantial change in demand?
- Consider abrupt changes to the economy could lead to adverse ecological consequences. For example, will market or policy changes intensify levels of harvesting in specific areas that could potentially increase ecological degradation to the point where adverse consequences take place?

There are also multiple recommendations to be considered from an ecological perspective:

- Consider the adverse consequences of continued fire suppression in the long-term with regards to changing overall fire regimes. Reduce fire suppression if possible in order to limit the amount of built-up energy in the system.
- Diversifying plantations both in terms of species and age distributions in order to withstand disturbance.
- Manage plantations to avoid overly connected landscapes that can be more at risk to larger natural disturbances.
- Examine the possible threat of multiple natural disturbances that could impact plantations simultaneously (e.g. wildfire and insect infestations), thereby exacerbating the economic implications for individuals and enterprises that depend on forestry as a mean source of income.

These recommendations will require a change in how China approaches strategies for natural resource management by considering the dynamic nature in which the social and ecological dimensions of forests interact over time. The adaptive nature of China's forests informs us that we must embrace a perspective of constant change and the inevitability of perturbations and disturbances. In doing so, regional differences in both bioclimatic constraints and economic constraints need to be considered. As Cheng and Zhang (1999) demonstrate, China's climate and socioeconomic variability across the entire country requires detailed consideration of how policy implementation may vary from one place to another. In this way, China can begin to consider how to build resilience into its policies and management strategies so that the overall system maintains a level of flexibility that allows it to adapt to unforeseen economic and ecological change at both local and regional scales.

Other countries in the surrounding region would also benefit from adopting a CAS approach for understanding the consequences of forest policies within their own borders. South Korea, for example, exhibits a parallel history with China with regards to periods of substantial deforestation followed for policy reforms aimed at reforesting and protecting landscapes (Bae et al., 2012). Currently, South Korea is facing questions about the balance between sustaining a domestic timber supply versus restoring biodiversity and recreation opportunities for its growing urban populations (Tak et al., 2007). In doing so, it has to contend with disturbances such as wildfire that are driven by forests characteristics at large scales that are a consequence of policy reforms (Lee et al., 2009). Can a CAS theoretical modeling approach for understanding and forecasting social and ecological change be useful in a South Korean context as well as in other countries in the region? Can lessons and experiences form China be applied in South Korea and other countries to assist in forecasting economic and ecological disturbances? How can a CAS approach help us understand the interaction of economic, social and ecological systems across this region? These questions should be considered together as part of an effort to improve the development of policies directed towards the sustainable management of forest resources in China and its neighboring countries.

The adoption of a CAS perspective of China's forest policies will foster additional research that will lead to variations or entirely different models of China's forests as complex socio-ecological systems. The current lack of research in this area presents challenges with being able to compare the model framework put forth in this paper, but the framework herein is a starting point for a new perspective that can be adopted and critiqued in future work, thereby providing a body of literature that includes dialogue surrounding suitable formations of the CAS approach in this context. In addition, future research could provide a systematic comparison of the CAS perspective to other approaches for contextualizing China's forest policies.

References

Adger, W.N., 2000. Social and ecological resilience: are they related? Prog. Hum. Geogr. 24, 347–364.

Bae, J.S., Joo, R.W., Kim, Y.S., 2012. Forest transition in South Korea: reality, path and drivers. Land Use Policy 29, 198–207.

Berkes, F., Colding, J., Folke, C., 2002. Navigating Social-ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press.

Bussotti, F., Pollastrini, M., Holland, V., Brüggemann, W., 2015. "Functional traits and adaptive capacity of European forests to climate change.". Environ. Exp. Bot. 111, 91–113.

Calkin, D.E., Thompson, M.P., Finney, M.A., 2015. Negative consequences of positive feedbacks in US wildfire management. For. Ecosyst. 2 (1), 1.

Cao, S., Chen, L., Shankman, D., Wang, C., Wang, X., Zhang, H., 2011. Excessive reliance on afforestation in China's arid and semi-arid regions: lessons in ecological restoration. Earth Sci. Rev. 104, 240–245.

Cheng, J.Y.-s., Zhang., M., 1999. Regional differences and sustainable development in China. J. Chin. Polit. Sci. 5 (no. 1), 1–50.

Dai, L., Zhao, W., Shao, G., Lewis, B.J., Yu, D., Zhou, L., Zhou, W., 2013. The progress and challenges in sustainable forestry development in China. Int. J. Sustain. Dev. World Ecol. 20, 394–403.

Démurger, S., Yuanzhao, H., Weiyong, Y., 2009. Forest management policies and resource balance in China an assessment of the current situation. J. Environ. Dev. 18, 17–41.

Deng, L., Liu, G., Shangguan, Z., 2014. Land-use conversion and changing soil carbon stocks in China's "grain-for-green" program: a synthesis. Glob. Chang. Biol. 20, 3544–3556.

Drever, C.R., Peterson, G., Messier, C., Bergeron, Y., Flannigan, M., 2006. Can forest management based on natural disturbances maintain ecological resilience? Can. J. For. Res. 36, 2285–2299.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. AMBIO: J. Hum. Environ. 31, 437–440.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C.S., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annu. Rev. Ecol. Evol. Syst. 35, 557–581.

Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour. 30, 441–473.

Fu, B., Liu, Y., Lü, Y., He, C., Zeng, Y., Wu, B., 2011. Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. Ecol. Complex. 8, 284–293.

Gunderson, L.H., Holling, C.S., 2001. Panarchy: Understanding Transformations in Human and Natural Systems. Island Press.

Holling, C.S., 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 1–23.

Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4, 390–405.

Huang, L., Liu, J., Shao, Q., Xu, X., 2012. Carbon sequestration by forestation across China: past, present, and future. Renew. Sust. Energ. Rev. 16, 1291–1299.

Ji, L., Wang, Z., Wang, X., An, L., 2011. Forest insect Pest management and Forest Management in China: an overview. Environ. Manag. 48, 1107–1121.

Johnston, M., Hesseln, H., 2012. Climate change adaptive capacity of the Canadian forest sector. Forest Policy Econ. 24, 29–34.

Kremen, C., Niles, J.O., Dalton, M.G., Daily, G.C., Ehrlich, P.R., Fay, J.P., Grewal, D., Guillery, R.P., 2000. Economic incentives for rain Forest conservation across scales. Science 288, 1828–1832.

Lee, S.W., Lee, M.B., Lee, Y.G., Won, M.S., Kim, J.J., Hong, S.K., 2009. Relationship between landscape structure and burn severity at the landscape and class levels in Samchuck, South Korea. For. Ecol. Manag. 258, 1594–1604.

Li, H., Aide, T.M., Ma, Y., Liu, W., Cao, M., 2007. Demand for rubber is causing the loss of high diversity rain forest in SW China. Biodivers. Conserv. 16, 1731–1745.

Li, J., Feldman, M.W., Li, S., Daily, G.C., 2011. Rural household income and inequality under the Sloping Land Conversion Program in western China. PNAS 108, 7721–7726.

Lü, Y., Fu, B., Feng, X., Zeng, Y., Liu, Y., Chang, R., Sun., G., Wu, B., 2012. A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the Loess Plateau of China. PLoS ONE 7, e31782.
Messier, C., Puettmann, K., Chazdon, R., Andersson, K.P., Angers, V.A., Brotons, L., Filotas, E., Tittler, R., Parrott, L., Levin, S.A., 2015. From management to stewardship: viewing forests as complex adaptive systems in an uncertain world. Conserv. Lett. 8 (no. 5), 368–377.
Neill, A.R., Puettmann, K.J., 2013. Managing for adaptive capacity: thinning improves food availability for wildlife and insect pollinators under climate change conditions. Can. J. For. Res. 43 (no. 5), 428–440.
Puettmann, K.J., Messier, C., Coates, D.K., 2013. In: Messier, C., Puettmann, K.J., Coates, D.K. (Eds.), Managing Forests as Complex Adaptive Systems." Managing Forests as Complex Adaptive Systems: Building Resilience to the Challenge of Global Change. *Routledge*, New York, NY, pp. 3–16.
Rupert, S., Lexer, M.J., 2013. Forest management under climatic and social uncertainty: trade-offs between reducing climate change impacts and fostering adaptive capacity. J. Environ. Manag. 114, 461–469.
Steffen, W., Sanderson, R.A., Tyson, P.D., Jäger, J., Matson, P.A., M. III, B., Oldfield, F., Richardson, K., Schellnhuber, H.J., Turner, B.L., 2006. Global Change and the Earth System: A Planet Under Pressure (Springer Science & Business Media).
Tak, K., Chun, Y., Wood, P.M., 2007. The south Korean forest dilemma. Int. For. Rev. 9, 548–557.
Trac, C.J., Schmidt, A.H., Harrell, S., Hinckley, T.M., 2013. Environmental review and case studies: is the returning farmland to Forest program a success? Three case studies from Sichuan. Environ. Pract. 15, 350–366.
Walker, B., Meyers, J.A., 2004. Thresholds in ecological and socialecological systems: a developing database. Ecol. Soc. 9, 3.
Walker, B., Holling, C.S., Carpenter, S.R., Kinzig, A., 2004. Resilience, adaptability and transformability in social–ecological systems. Ecol. Soc. 9, 5.
Wang, C., Maclaren, V., 2012. Evaluation of economic and social impacts of the sloping land conversion program: a case study in Dunhua County, China. Forest Policy Econ. 14, 50–57.
Wang, S., Cornelis van Kooten, G., Wilson, B., 2004. Mosaic of reform: forest policy in post-1978 China. Forest Policy Econ. 6, 71–83.
Wang, X., He, H.S., Li, X., 2007. The long-term effects of fire suppression and reforestation on a forest landscape in Northeastern China after a catastrophic wildfire. Landsc. Urban Plan. 79, 84–95.
Xu, J., Yin, R., Li, Z., Liu, C., 2006. China's ecological rehabilitation: unprecedented efforts, dramatic impacts, and requisite policies. Ecol. Econ. 57, 595–607.
Xu, H., Tang, X., Liu, J., Ding, H., Wu, J., Zhang, M., Yang, Q., Cai, L., Zhao, H., Liu, Y., 2009. China's progress toward the significant reduction of the rate of biodiversity loss. Bioscience 59, 843–852.
Yin, R., Xu, J., Li, Z., 2003. Building institutions for markets: experiences and lessons from China's rural forest sector. Environ. Dev. Sustain. 5, 333–351.
Zhang, Z., 2006. Review of the 10th five-year plan and perspective on the 11th five-year plan in relation to natural forest conservation program. For. Econ. 1, 49–52.
Zhang, Y., Song, C., 2006. Impacts of afforestation, deforestation, and reforestation on forest cover in China from 1949 to 2003. J. For. 104, 383–387.

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