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Resilience: An Annotated Bibliography

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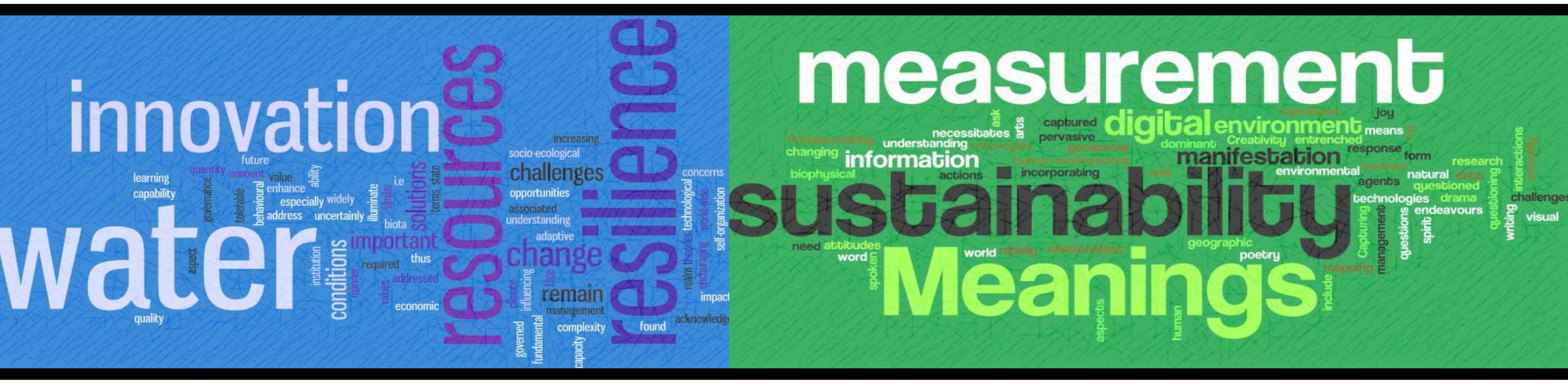

Resilience: An Annotated Bibliography

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Abstract

This annotated bibliography provides an account of the research that has been done on engineering resilience, ecological resilience, and social-ecological resilience. Undertaken as part of the WEPGN research project titled "Applying resilience analysis to a transboundary river system: Developing surrogates for institutions and governance", this annotated bibliography investigates factors that lead to greater resilience, with a focus on institutions and governance. Citations for key scholarly publications related to three types of resilience – engineering, ecological, and social-ecological – are listed in the first three sections along with a brief summary of each work. The fourth and final section of the document provides additional resources on resilience.

Keywords

Engineering resilience; ecological resilience; social-ecological resilience

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1.0. Introduction

This annotated bibliography was undertaken as part of the WEPGN research project titled "Applying resilience analysis to a transboundary river system: Developing surrogates for institutions and governance". Overall, the research project aims to: 1) conceptually explore resilience in relation to social aspects (governance of a river system), 2) conduct a resilience analysis on a transboundary river system with a specific focus on governance, and 3) identify resilience surrogates from the analysis with potential transferability to other transboundary river systems.

A search of the scholarly literature was conducted on the subject of resilience as a starting point to the research project described above. Databases of scholarly literature were searched using the term resilience, materials were carefully reviewed, and annotations summarizing the salient points were prepared. The vastness of information returned from the search is acknowledged and the annotations contained here are not exhaustive or representative of the full body of scholarship. While many types of resilience exist (e.g., social resilience, resilience engineering, resilience in the context of psychology), this annotated bibliography focuses on three types of resilience that have influenced natural resources – engineering, ecological, and social-ecological. As the search and review was intended to inform the research project, an effort was made to incorporate a reasonably comprehensive selection of sources covering different perspectives over time and in different contexts, especially beyond water. The authors acknowledge the limitations associated with using methodologies that were neither systematic nor exhaustive.

This annotated bibliography provides an account of the research that has been done on three types of resilience – engineering, ecological, and social-ecological – to illustrate how the concept has evolved and explore the links between these traditions. Engineering resilience is commonly defined as the time it takes for a system to return to equilibrium or a single steady state following some form of disturbance or perturbation. The faster the rate of return to equilibrium, the more resilient the system is considered to be. Ecological resilience, on the other hand, recognizes the existence of multiple stable states and refers to the capacity of a system to absorb disturbances and reorganize while undergoing change in order to maintain essentially the same functions. Social-ecological resilience shares similar features with ecological resilience but is more comprehensive in that it acknowledges the interconnectedness of social and ecological systems and the need to consider the two as inextricably linked. Social-ecological resilience can be defined as the amount of change a system can withstand, the degree of self-organization possible, and the ability of the system to learn and adapt. It is in the latter context where the relationship between resilience and sustainability is emphasized – "Sustainability is the capacity to create, test, and maintain adaptive capacity" (Holling, Gunderson, & Peterson, 2002, p. 76).

The remainder of this document is divided into four sections. The first three sections list citations for key scholarly publications related to the ideas of engineering resilience, ecological resilience and social-ecological resilience respectively. Each citation is accompanied by a brief summary of that work. Several of the summarized publications discuss more than one type of resilience and could therefore be placed in two or more sections. To avoid redundancy, publications appear in only one of the applicable sections. The fourth and final section of the document provides a list of links to additional resources on resilience.

2.0. Engineering Resilience

At the time several of these publications were written, the term engineering resilience was not yet adopted. The ideas and perspectives presented in these articles, for example the stability perspective, form the basis of what was later termed engineering resilience. Including these early works is purposeful as the intention of the annotated bibliography is to assist in understanding where the concept of resilience originated and how it has evolved over time.

Connell, J.H., & Sousa, W.P. (1983). On the evidence needed to judge ecological stability or persistence. *The American Naturalist, 121*(6), 789–824.

As the title suggests, Connell and Sousa's (1983) paper attempts to describe the type of evidence necessary for determining whether a natural population is stable or persistent. The authors differentiate between these two viewpoints defining stability as a quantitative viewpoint and persistence as a qualitative viewpoint dealing with questions of existence or not. Following a discussion of scales of observation, the authors critique the methods and analysis used by other researchers who have claimed to prove either stability or persistence of natural communities or the existence of multiple stable states. Connell and Sousa (1983) conclude that the methods used by these researchers lack the rigour necessary to adequately demonstrate stability, persistence, or multiple stable states.

Elton, C.S. (1958). *The ecology of invasions by animals and plants.* Chicago: University of Chicago Press.

Elton's (1958) book is the first and arguably the most influential on the topic of invasion biology. Writing from a stability perspective, Elton's (1958) work discusses the invasion of non-native species. The author provides information and examples on both the causes and spread of invasive species as well as the resulting effects on the natural environment, human societies and the economy.

Gigon, A. (1983). Typology and principles of ecological stability and instability. *Mountain Research and Development, 3*(2), 95–102.

In discussing the concept of ecological stability, the terms lability, stability, and instability are defined in this article with a focus on the latter two terms. Definitions of four different types of stability – constant, cyclic, resistant and elastic – and two different types of instability – endogenous and exogenous – are provided by Gigon (1983). In addition to emphasizing the need to differentiate between natural and anthropogenic stability and instability, plant communities in the Alps are used to illustrate that no ecological system is stable with respect to all possible disturbance factors and that more than one type of stability can occur within the same ecological system.

Hansson, S.O., & Helgesson, G. (2003). What is stability? *Synthese, 136*(2), 219–235.

As a result of a search of the natural and social sciences literature, Hansson and Helgesson (2003) identify three general types of stability concepts – constancy, robustness, and resilience. In their analysis of resilience, the authors explain that this stability concept refers to the tendency of a system to return to its original state following disturbance. Additional uses and definitions of resilience are also discussed including the use of the concept in economics and game theory. Upon further analysis, the authors conclude that robustness can be considered a special case of resilience, leaving constancy and resilience as the two basic concepts of stability.

Holling, C.S. (1996). Engineering vs ecological resilience. In P. Schultz (Ed.), *Engineering within ecological constraints* (pp. 31–41). Washington: National Academy Press.

This paper goes beyond simple descriptions of the concepts of engineering and ecological resilience and delves into details regarding the different styles of ecosystem management utilized for each type of resilience. Examples provided are numerous, thorough and effectively demonstrate the arguments being made.

MacArthur, R. (1955). Fluctuations of animal populations and a measure of community stability. *Ecology, 36*(3), 533–536.

MacArthur (1955) uses food webs to demonstrate how and why different communities are more stable than others. He explains how the stability of a community is measured stating that it is based on the "amount and choice which the energy has in following the paths up through the food web" (p. 534). According to MacArthur (1955), community stability, or the ability of a community to stay near an equilibrium state, increases as the number of links or paths increases.

May, R.M. (1974). *Stability and complexity in model ecosystems*. Princeton: Princeton University Press.

This book provides one of the first counter arguments to the idea that ecosystem complexity is directly related to population stability. Using mathematical models, May (1974) explores many important topics in his book related to the stability of populations including the non-linearity of population dynamics, limit cycles and time delays, and the study of deterministic chaos. May's (1974) arguments are a challenge to ideas put forward by some of the other authors listed in this section including Elton (1958).

McCarl, B.A., Villavicencio, X., & Wu, X. (2008). Climate change and future analysis: Is stationarity dying? *American Journal of Agricultural Economics, 90*(5), 1241–1247.

The focus of this article is the notion of stationarity in relation to yield-related analyses. The authors investigate stationarity and crop yields under projected crop climate change scenarios revealing that climate change will increase the variability of crop yield distributions. According to the authors, these findings suggest that stationarity is a dying concept and as such, there is a need for risk analysis based on distributions with nonstationarity means and variances. As with May's (1974) work, this paper is a direct challenge to the stability perspective.

McCoy, E.D., & Shrader-Frechette, K. (1992). Community ecology, scale, and the instability of the stability concept. *PSA: Proceedings of the Biennial Meeting of the Philosophy Association, 1*, 184–199.

In their work, McCoy and Shrader-Frechette (1992) discuss what they consider to be one of the foundational concepts of community ecology, the stability concept. The authors critique the stability concept pointing out the lack of consensus on what the concept actually refers to, the difficulties with measurement as well as problems of spatial and temporal scale. McCoy and Shrader-Frechette (1992) argue that despite the fact that the concept has been circulating in academic literature for several decades and that progress in community ecology relies on dealing with these issues, little effort has been made to provide conceptual clarification.

McNaughton, S.J. (1977). Diversity and stability of ecological communities: A comment on the role of empiricism in ecology. *The American Naturalist, 111*(979), 515–525.

This work is a response to the outcomes of the First International Congress of Ecology in 1974. McNaughton (1977) identifies the relationship between species diversity and ecosystem stability as the main theme of the proceedings of the congress, and further states that there exists a great deal of disagreement between experts on what that relationship is. Following a discussion of the proceedings, McNaughton (1977) presents his own empirical data on the question with findings suggesting that at the primary producer level, the diversity-stability hypothesis is true.

Milly, P.C., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., et al. (2008). Stationarity is dead: Wither water management? Science, 319, 573–574.

The central claim made by the authors of this brief paper is that stationarity – the underlying assumption for water management systems and engineering resilience more broadly – is 'dead'. In this paper, the authors clearly and succinctly define the idea of stationarity, explain the premise for their claim both in terms of the rationale and timing of the claim and offer a new basis for optimizing water systems based on adaptations to the Harvard Water Program.

Odum, E.P. (1953). *Fundamentals of ecology*. Philadelphia: Saunders.

Odum's (1953) work is aimed at introducing the field of ecology to those with little to no background knowledge in the field. The book provides a relatively straightforward discussion of the fundamental principles of ecology from a stability perspective. Covered in this book are three broad topics – basic ecological principles and concepts, the habitat approach and applied ecology.

Pimm, S.L. (1991). *The balance of nature?: Ecological issues in the conservation of species and communities*. Chicago: University of Chicago Press.

Pimm's (1991) book brings to light problems of scale and inconsistent definitions within the discipline of ecology and more specifically, in relation to stability in ecological communities. Five kinds of ecological stability are elaborated on – stability in the mathematical sense, resilience, variability, persistence and resistance. Of particular significance to this research is Pimm's (1991) chapter on resilience covering what it is, how it is defined, its relation to the life-history characteristics of individual species, and food-web and ecosystem effects on resilience.

Rutledge, R.W., Basore, B.L., & Mulholland, R.J. (1976). Ecological stability: An information theory viewpoint. *Journal of Theoretical Biology, 57*(2), 355–371.

A new measure of ecological stability is developed and presented from an information theory viewpoint in this paper. The authors use mathematical models of two example ecosystems to test the usefulness of their newly created index in measuring the ability of an ecosystem to resist changes when faced with disturbance. The findings suggest that the index is useful to a certain extent; however, it is not sufficient for all time scales.

Sivapalan, M., & Samuel, J.M. (2009). Transcending limitations of stationarity and the return period: Process-based approach to flood estimation and risk assessment. *Hydrological Processes, 23*(11), 1671–1675.

Recognizing that traditional flood frequency analysis and estimation is based on the concepts of stationarity and the return period – concepts no longer appropriate in today's environment – the argument is made in this paper that there is a need for a major paradigmatic change to flood estimation and management practices globally. The authors present their new flood frequency analysis framework and offer several examples of its use. While not radically different from existing frameworks, the authors highlight that their proposed framework is more process-based and overcomes the limitations of the assumption of stationarity.

3.0. Ecological Resilience

Alberti, M., & Marzluff, J.M. (2004). Ecological resilience in urban ecosystems: Linking urban patterns to human and ecological functions. *Urban Ecosystems, 7*, 241–265.

With a focus on urban ecosystems, Alberti and Marzluff (2004) offer a stimulating discussion of ecological resilience. In their paper, the authors propose a conceptual model linking urban patterns to ecological resilience in urban ecosystems. The authors use a study of the impact of urban patterns on bird and benthic macroinvertebrate diversity in the Puget Sound region to further explore this model and highlight the complexity of these interactions.

Brand, F. (2009). Critical natural capital revisited: Ecological resilience and sustainable development. *Ecological Economics, 68,* 605–612.

Brand's (2008) work provides a concise yet informative exploration of ecological resilience in relation to the concept of critical natural capital. Critical natural capital as defined by Brand (2008) refers to the part of natural capital that performs important and irreplaceable environmental functions and as such, ought to be maintained for present and future generations. The author asserts that ecological resilience can be used in combination with other criteria to improve the assessment of the specific 'ecological criticality' of natural capital stocks.

Côté, I.M., & Darling, E.S. (2010). Rethinking ecosystem resilience in the face of climate change. *PLOS Biology, 8*(7), 1–5.

In this article, Côté and Darling (2010) present a very interesting perspective on resilience-focused management and its ability to influence the vulnerability of a system to climate change induced impacts. Using coral reefs as a model, the authors argue that the strategy of reducing local stressors as a means of enhancing the resilience of coral reefs may actually be increasing vulnerability.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., et al. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics, 35*, 557–581.

The argument is made in this article that rather than having one steady state, ecosystems have multiple stable states or domains of attraction. Examples are provided of how various ecosystems undergo transition from one state to another and how human involvement has and continues to influence those transitions. Biodiversity's role in ecosystem renewal and reorganization is also explored with explicit mention of functional-group and functional-response diversity. More specifically, the authors suggest that the degree of functional-group diversity together with the degree of functional-response diversity within an ecosystem determines the ability of the ecosystem to remain within a desired state.

Gunderson, L.H. (2000). Ecological resilience – in theory and application. *Annual Review of Ecology, Evolution, and Systematics, 31*, 425–439.

Gunderson's (2000) work provides a detailed description of ecological resilience by contrasting it with the concept of engineering resilience. The description of ecological resilience provided is enhanced through the use of many examples of ecosystems that undergo transitions between stable states. The examples provided also demonstrate the influence of human populations on the resilience of systems both through active attempts to manage ecosystems, as well as unintentional effects of human activities such as farming.

Gunderson, L.H., & Allen, C.R. (2010). Introduction: Why resilience? Why now? In L.H. Gunderson, C.R. Allen, & C.S. Holling (Eds.), *Foundations of ecological resilience* (pp. xiii–xxv). Washington: Island Press.

This introductory chapter provides the reader with a brief background on resilience before getting into more complex topics relating to resilience in later chapters. Incorporated in this overview is an examination of different definitions of resilience including those that consider return times or time of recovery to a designated state of equilibrium as well as popular definitions of ecological resilience such as Holling's (1996) dealing with multiple equilibria and shifts between steady states. Adaptive management is also discussed in this chapter as this approach to natural resource management was developed based on theories of resilience and is cognizant of the great deal of complexity and uncertainty associated with natural systems.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4*, 1-23.

Written by the 'father of resiliency theory', this article documents the initial ideas regarding multiple stability domains or multiple basins of attraction in ecological systems. The distinct differences between the concepts of engineering resilience and ecological resilience – including differences in what defines a desirable system, the relationships among system elements, how each concept is measured and management approaches – are discussed for the first time in this article. The significance of this article is glaringly obvious as it continues to be cited 40 years after being published.

Holling, C.S. (1987). The resilience of terrestrial ecosystems: Local surprise and global change. In W.C. Clark & R.E. Munn (Eds.), *Sustainable development of the biosphere* (pp. 292–320). New Rochelle: Cambridge University Press.

In this chapter Holling (1987) discusses the dynamics of ecosystems with special attention paid to the contrasting concepts of resilience and stability. An in-depth explanation of each of the four stages of the adaptive cycle is also provided here.

Holling, C.S., & Gunderson, L.H. (2002). Resilience and adaptive cycles. In L.H. Gunderson & C.S. Holling (Eds.), *Panarchy: Understanding transformations in human and natural systems* (pp. 25–62). Washington: Island Press.

The material in this chapter builds on the idea of different worldviews or myths of nature presented in chapter one of the same book. More specifically, the fifth worldview – nature evolving – is explored in further detail. The authors explore key features of ecosystem structure and function and discuss the organization and dynamics of complex adaptive systems in order to present 'nature evolving' as the most accurate – although not perfect – view of nature that currently exists.

Holling, C.S., & Meffe, G.K. (1996). Command and control and the pathology of natural resource management. *Conservation Biology, 10*(2), 328–337.

The idea of the pathology of natural resource management is defined in this article. The authors make a compelling case against the command-and-control style of resource management alluding to the many ways in which this style of management creates further, more serious issues regarding natural resources and ecosystems as a whole. The urgency of implementing an alternate form of natural resource management is made apparent and the authors suggest a new 'conceptual underpinning for management'.

Peterson, G., Allen, C.R., & Holling, C.S. (1998). Ecological resilience, biodiversity, and scale. *Ecosystems, 1*(1), 6–18.

This article examines the debate over how biological diversity relates to ecological resilience, more specifically, whether or not an increase in the biological diversity of an ecosystem corresponds to an increase in ecological resilience. The authors review four models each proposing different explanations of how diversity of species increases the stability of an ecosystem – species richness-diversity, idiosyncratic, rivet and drivers and passengers. Following this review, the authors provide their own model called cross-scale resilience which incorporates species richness and ecological resilience as well as scale.

Reice, S.R., Wissmar, R.C., & Naiman, R.J. (1990). Disturbance regimes, resilience, and recovery of animal communities and habitats in lotic ecosystems. *Environmental Management, 14*(5), 647–659.

A review of literature pertaining to the role disturbance plays in determining community structure and resilience in lotic systems is provided in this article. In contrast to the intermediate disturbance hypothesis which states that disturbance of an intermediate frequency leads to maximum species richness and system stability, the authors argue that greater exposure to fairly frequent disturbance enhances adaptability and thus, resilience of a community.

4.0. Social-Ecological Resilience

Adger, W.N. (2000). Social and ecological resilience: Are they related? *Progress in Human Geography, 24*(3), 347–364.

Adger (2000) discusses the concept of social resilience and emphasises the fact that a link exists between social and ecological resilience. This link is explored in the paper in terms of if and how ecological resilience influences social resilience. The author uses a case study of mangrove conversion in a community in coastal Vietnam to assess how ecological change impacts the social resilience of resource dependent communities.

Adger (2000) found that ecological change negatively impacted social resilience of the community.

Adger, W.N., Hughes, T.P., Folke, C., Carpenter, S., & Rockstrom, J. (2005). Social-ecological resilience to coastal disasters. *Science, 309*, 1036–1039.

This article presents two brief case studies illustrating the linkages between coastal ecosystems and social systems and highlights how better understandings of these linkages can enhance resilience. Notably, the authors identify the priority in more marginalized coastal communities to be the reduction of perverse incentives that destroy natural capital and make communities more vulnerable to both short- and long-term impacts of hurricanes, tsunamis and other natural disasters.

Anderies, J.M., Walker, B.H., & Kinzig, A.P. (2006). Fifteen weddings and a funeral: Case studies and resilience-based management. *Ecology and Society, 11*(1), 21.

This paper summarises the important insights brought to light in a special issue titled "Exploring Resilience in Social-Ecological Systems". In addition, the authors discuss the future of social-ecological systems theory and management practise listing ten key messages. Managing at multiple scales, attending to slow variables, recognizing windows for transformation and understanding underlying mental models are just a few of the messages presented by the authors.

Bennett, E.M., Cumming, G.S., & Peterson, G.D. (2005). A systems model approach to determining resilience surrogates for case studies. *Ecosystems*, *8*(8), 945–957.

In this paper, Bennett, Cumming and Peterson (2005) introduce the idea of resilience surrogates as "proxies that are derived directly from theory for use in assessing resilience in a social-ecological system" (p. 946). The authors describe a four step approach for using simple systems models to identify resilience surrogates. The four steps include assessment and problem definition, identifying feedback processes, designing a systems model, and using the systems model to identify resilience surrogates.

Berkes, F., Colding, J., & Folke, C. (Eds.). (2003). Navigating social-ecological systems: Building resilience for complexity and change. Cambridge: Cambridge University Press.

Edited by Berkes, Colding and Folke (2003), this book draws on the work of leading researchers from the natural sciences, social sciences and humanities in exploring the concept of resilience. Case studies from around the world highlighting different resource types and cultures are utilized in exploring four interrelated themes that divide the chapters of the book – perspectives on resilience; building resilience in local management systems; social-ecological learning and adaptation; and cross-scale institutional response to change. In its 14 chapters, this book covers a great deal of information and various perspectives on resilience as a conceptual frame for understanding the dynamics of social-ecological systems.

Berkes, F., & Folke, C. (Eds.). (1998). *Linking sociological and ecological systems: Management practices and social mechanisms for building resilience*. New York: Cambridge University Press.

Using a case study approach, this book explores social and ecological linkages in a variety of ecosystems with the purpose of investigating sustainable ecosystem management. Written by a collection of different authors, the book's 16 chapters are broken into four parts – learning from locally devised systems; emergence of resource management adaptations; success and failure in regional systems; and designing new approaches to management. In the final chapters the editors provide an excellent overview of the lessons learned from the case studies and summarize guiding principles for building resilience in social-ecological systems.

Berkes, F., & Jolly, D. (2001). Adapting to climate change: Social-ecological resilience in a Canadian Western Arctic community. *Conservation Ecology, 5*(2), 18.

Berkes and Jolly (2001) evaluate social-ecological resilience in the northern Canadian community of Sachs Harbour in terms of how the community is able to cope with and adapt to impacts of climate change. The key findings of this research show that living in the Arctic – a highly variable environment – has allowed the people to become quite adept at dealing with change thus far. However, with increasing uncertainty and complexities brought on by climate change, the authors assert that further co-management and new institutional linkages will increase the resilience of the social-ecological system by improving both the community's capability for self-organization and capacity for learning.

Berkes, F., & Seixas, C.S. (2005). Building resilience in lagoon social-ecological systems: A local-level perspective. *Ecosystems, 8*(8), 967–974.

In this article, Berkes and Seixas (2005) provide an exploration of various factors that help build resilience at a local level and speculate on resilience surrogates. More specifically, the authors look at lagoon social-ecological systems in semi-tropical developing countries and use a framework based on four categories of factors for building resilience. The authors explain the difference between factors that help build resilience and resilience surrogates. They do this by stating that identification of factors that help build resilience is a critical first step in operationalizing resilience and actually turning these factors into measurable surrogates is its own separate step requiring additional research not addressed in this paper.

Carpenter, S.R., Westley, F., & Turner, M.G. (2005). Surrogates for resilience of social-ecological systems. *Ecosystems, 8*, 941–944.

As the introduction to a special feature on resilience surrogates, this article provides a succinct explanation of what resilience surrogates are, how and why they are developed, and the importance of advancing the state of knowledge on the topic. The authors assert that in moving from resilience theory to resilience practice, it is necessary to complete an assessment or estimation of resilience. However, with the direct measurement of resilience being as difficult as it is, in many cases aspects of resilience must be indirectly inferred as opposed to directly observed. Although this introductory article is brief it does an exceptional job of illuminating the idea that resilience surrogates, as a means of indirectly inferring resilience, provide a way to bridge the gap between theories of resilience and practical field experiences.

Cumming, G.S., Barnes, G., Perz, S., Schmink, M., Sieving, K.E., Southworth, J., et al. (2005). An exploratory framework for the empirical measurement of resilience. *Ecosystems, 8*(8), 975–987.

Recognizing that the concept of resilience had not yet been directly operationalized, Cumming et al. (2005) developed an exploratory framework as a step towards operationalizing resilience concepts for empirical studies. In this article the authors present their framework which is based on an alternative view of resilience. Cumming et al. (2005) define resilience as the ability of a system to maintain its identity in the face of endogenous and exogenous forces where system identity is determined by the components that make up the system, relationships between components, and the ability of components and relationships to maintain themselves through space and time. An example application of this new framework is provided and its strengths and weaknesses are outlined.

Cumming, G.S., Cumming, D.H., & Redman, C.L. (2006). Scale mismatches in social-ecological systems: Causes, consequences, and solutions. *Ecology and Society, 11*(1), 14.

This article takes an in-depth look at the issue of scale in relation to social-ecological systems. Spatial and temporal scales are noted as being important considerations along with ideas about representation and organisation. The paper proceeds logically starting with an explanation of scale mismatch followed by how they are created, what the consequences of scale mismatches are and how they can be resolved. Examples are used throughout to aid in getting this information across.

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change, 16*(3), 253–267.

Highlighted in this article is the transition of the resilience perspective from its roots in ecology and a focus on stability and equilibrium to new ideas of instability, non-linear dynamics and its inclusion in multiple disciplines. While emphasis is placed on social-ecological systems, Folke (2006) incorporates useful information on ecological and engineering resilience perspectives as well.

Garmestani, A.S., Allen, C.R., & Cabezas, H. (2008). Panarchy, adaptive management and governance: Policy options for building resilience. *Nebraska Law Review, 87*(4), 1036–1054.

The authors of this paper assess the efficacy of the current law and policy framework in the United States for dealing with present and future environmental challenges. Garmestani, Allen and Cabezas (2008) describe several incompatibilities between the nature of complex socio-ecological systems and the characteristics of traditional environmental policy. The authors assert that while the resulting challenges of these incompatibilities are indeed daunting, there are ways to begin addressing them. Suggestions for ways forward are offered by the authors.

Holling, C.S., Gunderson, L.H., & Ludwig, D. (2002). In quest of a theory of adaptive change. In L.H. Gunderson & C.S. Holling (Eds.), *Panarchy: Understanding transformations in human and natural systems* (pp. 3–22). Washington: Island Press.

This book chapter outlines several examples of efforts to manage systems and points to the common theme among the examples – initial success is followed by crisis. The authors explain that incomplete views of nature are responsible for repeated failure in the management of systems. They provide explanations of these views termed nature flat, nature balanced, nature anarchic, nature resilient and nature evolving. Despite the numerous examples of failed systems management throughout history, the authors refer to the resilience of natural ecological systems and the human capacity for learning and creativity as the underlying reasons for the continued existence of ecological systems.

Leach, M. (Ed.). (2008). *Re-framing resilience: A symposium report, STEPS working paper 13*. Brighton: STEPS Centre.

This report outlines the main points of discussion and arguments raised during a day and a half symposium in 2008 that brought scholars from the Resilience Alliance together with researchers from a variety of different backgrounds. During the symposium, over 50 researchers engaged in an examination of resilience centred around five main questions. These questions prompted the consideration of resilience in much broader terms than it is usually explored. The report concludes with a brief discussion of themes that emerged from reflections on what was learned during the symposium and the challenges and opportunities requiring further investigation.

Lebel, L., Anderies, J.M., Campbell, B., Folke, C., Hatfield-Dodds, S., Hughes, T.P., et al. (2006). Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society, 11*(1), 19.

Addressed in this paper are attributes of governance and their ability to enhance resilience in social-ecological systems. The attributes considered are participation, representation, deliberation, accountability, empowerment, social justice, and organizational features including being multi-layered and polycentric – all attributes considered to be part of ‘good governance’. Using several regional case studies, Lebel et al. (2006) illustrate how each of these attributes can to some extent contribute to improved resilience.

Lundholm, C., & Plummer, R. (2010). Resilience and learning: A conspectus for environmental education. *Environmental Education Research, 16*(5-6), 475–491.

A succinct yet informative overview of the concepts of engineering resilience, ecological resilience and social-ecological resilience is provided in this article. Additionally, as the focus of this paper is environmental education, the importance of learning in relation to social-ecological resilience is clearly outlined by the authors.

Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharwani, S., Ziervogel, G., et al. (2010). Resilience and vulnerability: Complementary or conflicting concepts? *Ecology and Society, 15*(3), 11.

This paper provides and in-depth look at the concepts of resilience and vulnerability. The authors demonstrate how these concepts represent two different approaches to understanding the response of social-ecological systems to change but at the same time exhibit areas of convergence and linkages in theory, methodology and application. Ways in which resilience and vulnerability research can come together in order to enhance the ability to solve pressing world problems are also expressed.

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive comanagement for building resilience in social-ecological systems. *Environmental Management, 34*(1), 75–90.

Using examples from Sweden and Canada in which local groups responded to a sequence of environmental events by developing adaptive comanagement systems, the authors explore two linked themes in this paper. First, the authors identify and discuss social features that both support and facilitate the emergence of adaptive comanagement systems. Second, Olsson, Folke and Berkes (2004) illuminate the potential of these social features to build social-ecological resilience in order to deal with inherent uncertainty.

Plummer, R. (2010). Social-ecological resilience and environmental education: Synopsis, application, implications. *Environmental Education Research, 16*(5-6), 493–509.

Plummer (2010) outlines the transition from ecological resilience to social-ecological resilience and identifies the difficulties associated with understanding and measuring this complex new concept. Furthermore, social-ecological resilience is analysed in terms of how it can be applied to social systems including environmental education.

Stokols, D., Lejano, R.P., & Hipp, J. (2013). Enhancing the resilience of human-environment systems: A social ecological perspective. *Ecology and Society, 18*(1), 7.

The conceptual framework of social ecology emerged in response to the realization that understanding societal problems strictly in ecological terms presents considerable limitations. Social ecology, as described in this paper by Stokols, Lejano, and Hipp

(2013), refers to the study of communities from an interdisciplinary perspective with attention given to bioecological and macro-economic concerns as well as the social, psychological, institutional, and cultural contexts of people-environment relationships. The authors describe the core principles of social ecology and explain how they build on those found in much of the resilience scholarship by placing greater emphasis on social-symbolic aspects of complex systems, ultimately resulting in a broader conceptualization of resilience.

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., et al. (2002). Resilience management in social-ecological systems: A working hypothesis for a participatory approach. *Conservation Ecology, 6*(1), 14.

Building on the work of other scholars, Walker et al. (2002) present a framework for analyzing resilience in regional scale social-ecological systems. Following a fairly thorough explanation of important concepts related to this framework, the authors provide an excellent description of the four step process starting with the development of a conceptual model of the system ('resilience of what'). The second step addresses 'resilience to what' through visioning exercises and scenarios. The third step explores the interactions between the information generated in steps one and two using modeling and non-modeling methods. The final step is one of reflection in which the entire process is evaluated and the implications for policy and management are discussed.

Walker, B., Gunderson, L., Kinzig, A., Folke, C., Carpenter, S., & Schultz, L. (2006). A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society, 11*(1), 13.

In this paper, Walker et al. (2006) present fourteen propositions about resilience in social-ecological systems. The propositions are the outcome of two workshops comparing the dynamics of fifteen regional case studies. The authors stress the fact that these propositions are tentative statements based on their current understanding of social-ecological systems and future changes to the described propositions are both likely and encouraged.

Walker, B., Holling, C.S., Carpenter, S.R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society, 9*(2), 5.

As the title suggests, the focus of this article is the examination of three complimentary attributes – resilience, adaptability and transformability. The authors suggest that these are the attributes from which the stability dynamics of all social-ecological systems emerge, yet their imprecise nature makes the application of these concepts quite difficult. In order to offer more precise definitions of the attributes, the concepts of basins of attraction and stability landscapes are used along with an interpretation and explanation of how the attributes are reflected in the adaptive cycles of social-ecological systems.

5.0. Additional Resources

For additional resources please refer to the following helpful links.

http://www.ecologyandsociety.org/

http://www.resalliance.org/index.php/key_concepts

http://www.resalliance.org/index.php/resources

http://www.stockholmresilience.org/21/news/latest-videos/whiteboard-seminars.html

http://www.stockholmresilience.org/21/publications.html

References

Holling, C.S., Gunderson, L.H, & Peterson, G.D. (2002). Sustainability and panarchies. In L.H. Gunderson & C.S. Holling (Eds.), *Panarchy: Understanding transformations in human and natural systems* (pp. 63–102). Washington: Island Press.