POLICY PERSPECTIVE

Conservation in a Wicked Complex World; Challenges and Solutions

Edward T. Game[1,2], Erik Meijaard[2,3,4], Douglas Sheil[4,5,6], & Eve McDonald-Madden[2,7]

[1] The Nature Conservancy, Conservation Science, West End, Queensland 4101, Australia
[2] ARC Centre of Excellence for Environmental Decisions, School of Biological Sciences, University of Queensland, St Lucia, Queensland 4072, Australia
[3] People and Nature Consulting International, Jakarta, Indonesia
[4] Center for International Forestry Research, Bogor, Indonesia
[5] Institute of Tropical Forest Conservation, Mbarara University of Science and Technology, PO Box 44, Kabale, Uganda
[6] School of Environmental Science and Management, Southern Cross University, PO Box 157, Lismore, NSW 2480, Australia
[7] CSIRO Ecosystem Sciences, Ecosciences Precinct, 41 Boggo Rd, Dutton Park, Queensland 4102, Australia

Keywords
Adaptive management; best practice; complex systems; conservation success; counterinsurgency; decision theory; feedback; leadership; monitoring; wicked problems.

Correspondence
Game Edward, The Nature Conservancy, Conservation Science, West End, Queensland 4101, Australia.
Tel: +61 7 3214 6921.
E-mail: egame@tnc.org

Received
31 January 2013
Accepted
4 July 2013

Editor
Claire Kremen

doi: 10.1111/conl.12050

Abstract

Most conservation challenges are complex and possess all the characteristics of so called "wicked" problems. Despite widespread recognition of this complexity conservationists possess a legacy of institutional structures, tools and practices better suited to simpler systems. We highlight two specific challenges posed by this mismatch: the difficulty of adaptive management where success is ambiguous and the tension between "best practice" and creativity. Drawing on research in other disciplines (including psychology, information systems, business management, and military strategy) we suggest practices that conservation could consider to better respond to complexity. These practices include, defining clear objectives, the use of scenarios, emphasis on pattern analysis, and ensuring greater scope for creative and decentralized decision making. To help illustrate these challenges and solutions, we point to parallels between conservation and military operations.

Introduction

Conservation is not rocket science; it is far more complex. Rocket flight obeys well-understood laws, is predictable, and varies in only four dimensions, thus most rockets reach their targets and, when they do not, the reasons are likely to be obvious. Most conservation actions, in contrast, cannot be assured of reaching their target. The uncertainties are large due to the fact that most conservation problems are embedded in socioecological systems possessing all the characteristics of "complex systems": numerous interacting elements lacking any central control, nonlinear interactions between elements, constant change which is seldom reversible, and no clearly defined boundaries to the system (Rosser Jr 2001; Johnson 2007; Mitchell 2009). These characteristics contribute to so called "wicked problems" (Rittel & Webber 1973). Wicked problems generally lack clear solutions because each problem is linked to other problems, and the nature and characterization of each cannot be isolated (Rittel & Webber 1973).

Complexity has profound theoretical and practical implications for conservation practice. Some implications have been recognized, for example, the need to embrace unpredictability (e.g., Holling 2001; Parrott & Meyer 2012), the importance of diverse interdisciplinary input (e.g., Liu *et al.* 2007) and the recognition that outcomes involve various types of trade-offs (e.g., Hirsch *et al.* 2011). Most conservationists are aware of the complexity of the systems they are working in; for example, the multiple, interacting links between poverty, hunger, land-use, development, policies, and politics (Meijaard

Table 1 Tips for addressing wicked conservation problems in complex systems; suggested changes relative to conventional conservation practice

Current conservation practice	Change suggested for complex systems and wicked problems
Emphasis on "best practice" in conservation approaches	Challenge "best practice"
	Responsive to competing and creative solutions
	Clearly established objectives beneath which there is flexibility in how tasks are achieved
Desire to be evidence based	Focus analysis of evidence on the search for pattern recurrence
Heavy reliance on experts and a narrow view of expertise	Reduce emphasis on "expert" opinion in favor of a more diverse set of voices and a broader view of expertise
Over reliance on feedback control or passive adaptive management as a response to complexity	Emphasis on predicting the likely impact and benefit of strategies in the context of multiple scenarios
Belief that clear measures of success and/or failure exist	Honesty about the trade-offs in any outcome
Reluctance to share information on perceived failures	Communicate transparently and constructively about perceived failures and uncomfortable truths
	Failure of a campaign or strategy is an acknowledged risk of doing business
Hierarchical leadership	Distributed responsibility for decision making
Focus on strategy or means rather than ends	Clear articulation of the outcomes we are ultimately trying to achieve

et al. 2012; Sassen *et al.* 2013). Nonetheless, the approaches, tools, and even institutional structures used in conservation are generally suited to simpler, more tractable systems. Like most conservation practitioners and scientists, we often find ourselves considering problems as if they were an engineering problem, with clear cause and effect relationships, and the ability to determine an optimal intervention.

Complex systems and the associated wicked problems have been the focus of research in various fields including mathematics, computing, psychology, ecology, social science, knowledge management, military studies, and business management. These parallel developments have generated the cross-disciplinary fields of complexity science and systems sciences. Drawing on insights from these fields we identify challenges for conventional conservation practice; specifically, the difficulty of adaptive management where success is ambiguous, and the tension between best practice and creativity. We consider how modern military conflicts embody comparable challenges, and offer suggestions for how conservation practices might change to better navigate complex systems and wicked problems (summarized in Table 1).

Success and adaptive management

Our track record for determining whether conservation investments have been successful is limited (Jepson 2005; Ferraro & Pattanayak 2006; Brooks *et al.* 2009). This assessment challenge relates to various factors such as the slow pace of conservation impact, but complexity and "wickedness" play a major role. Apparent positive change in any one element of a complex system may have unintended negative repercussions. Given that most conservation programs have multiple objectives, such as protecting biodiversity and improving livelihoods, the reality is that, unless multiple synergies dominate without any trade-offs (presumably rare), success will be subjective and difficult to characterize (Sheil & Meijaard 2010). For example, we could be effective at implementing conservation management that controls hunting of orangutans, but unless forest resources are adequate, these orangutans may negatively impact forest structure and general forest biodiversity, or antagonize surrounding communities that suffer from crop raiding (Meijaard *et al.* 2011). There is no "right" solution to wicked problems in complex systems, only trade-offs that appear more or less favorable depending on your perspective. This ambiguity also means that there is rarely any need to declare conservation actions a failure—something that might risk future support. For fundraisers this looks like a benefit, but there are downsides.

We believe that the challenge of defining conservation success negatively impacts conservation more than is typically acknowledged. The need to work in complex systems makes adaptive management (AM) highly appealing but ultimately incredibly difficult. AM—or "feedback" control as it is termed in the operations research literature—has become a standard concept among conservation agencies (Natural Resource Management Ministerial Council 2004; Walters 2007; Williams *et al.* 2007). Under an AM paradigm, decisions about interventions are based on the current state of the system and feedback about the performance and impact of any previous and ongoing interventions (e.g., Walters 1986; McDonald-Madden *et al.* 2010; Nichols *et al.* 2011). AM is frequently cited by agencies and scientists alike as an appropriate response to the uncertainty inherent in complex systems

(Williams *et al*. 2007; Nichols *et al*. 2011). Less frequently acknowledged is that AM is, at least in part, appealing because it reduces cognitive effort and resources invested in planning; changing the maxim "Ready, Aim, Fire" to "Ready, Fire, Aim" (Patton 2011) though perhaps "Ready, Fire, Aim, Fire" is more suitable. Behavioral studies of decision making suggest that in complex systems, most decision makers prefer feedback control over predictive control (where an explicit model of the system is developed and used to estimate the expected performance of different actions) because it allows them to proceed with the application of simple mental models and rules of thumb (Brehmer 1990). Although AM can be extremely rigorous (e.g., McDonald-Madden *et al*. 2010), in its more typical application in conservation it reduces upfront investment in understanding a system (a challenging task in complex systems) and instead focuses on the easier tasks of management structure and execution.

Although complex systems increase the appeal of AM, they also undermine its utility. There are two main problems. First, as mentioned above, measuring performance in complex systems is tricky. Unless a conservation solution is an unmitigated disaster (e.g., the Sumatran rhinoceros on Borneo, see Zafir *et al*. 2011), the need for, or value of, other approaches might remain unnoticed or unconvincing. In our experience, changes in strategy, even in programs that profess to be adaptive, are rare. An explanation is that the challenge of determining performance in complex systems means that regardless of outcome, the options for doing better are seldom clear or compelling, especially if funding for original strategies remains adequate.

The second way in which complex systems undermine AM is related to their wickedness. In a wicked problem, implementing any given solution will change the nature of the problem, which in turn influences the performance of the solution and so on. An example of such behavior in conservation is how the purchase of land for conservation can accelerate subsequent development and the fragmentation of the surrounding areas (Armsworth *et al*. 2006). Similarly, how stakeholders perceive a project and the way it is implemented ultimately changes conditions for the next project. One of the fundamental tenets of AM is that you have iterative decisions allowing learning from past decisions to alter future decisions (Walters 1986; Nichols *et al*. 2011). Tackling wicked problems in complex systems means you never get truly iterative decisions. Decisions in conservation seldom have identical contexts, and even small differences in context often matter, thus violating a core assumption of adaptive management—this significantly diminishes AM's utility as a management approach in complex systems.

Acknowledging the challenges does not mean that AM cannot be useful in conservation (Johnson & Williams 1999; Allen & Gunderson 2011), or that we should not make concerted attempts to learn about the effectiveness of interventions and apply this knowledge to future decisions. In some cases, there are likely to be subcomponents of larger conservation problems for which an AM approach is appropriate and effective, for example, understanding the near-term response of a single species to a set of potential management options being implemented (Nichols *et al*. 2006). The challenges highlighted here simply flag that for many conservation problems, adaptive management is more difficult than is generally acknowledged. This will be especially true as conservation gains complexity as it trends toward larger scale projects and ambitious objectives that include human well-being and ecosystem service delivery (Sayer *et al*. 2013).

Perhaps counter-intuitively, part (and only part) of the solution to working more successfully in complex systems lies in greater emphasis on predictive control, focusing on a series of scenarios rather than a single outcome (Allen & Gunderson 2011; Parrott & Meyer 2012). Using scenarios in predictive control involves forecasting the response of a system to a variety of uncertain futures. A formal approach to scenario-based predictive control involves identifying potential bifurcations in key drivers of change in a system. A predictive model is then used to explore how these bifurcations in assumptions influence the likelihood of different outcomes from a given intervention. Alternatively, a straightforward but informal approach to scenario-based predictive control, is to simply ask planners and decision makers, "what information would make you adjust your choice of actions and why?" It is helpful if qualitative storylines accompany each scenario. Alternate scenario predictions can aid in considering uncertainties and the robustness of alternate strategies to uncertainty (Peterson *et al*. 2003). Establishing alternative strategies for different scenarios facilitates rapid (but not hasty) change of tactics in response to feedback about the evolution of the problem; this is often an important missing element from attempts at AM in conservation (Lindenmayer *et al*. 2011). The use of predictive control can also accelerate learning (Hauser *et al*. 2006) and is advocated by much of the scientific literature on AM (McDonald-Madden *et al*. 2011; Nichols *et al*. 2011).

Best practice and creativity

Conservation often emphasizes "best practice." Many conservation organizations support standardized planning methods and strongly encourage partners to adopt similar approaches (e.g., Conservation Measures Partnerships 2007). There is constant pressure to leverage approaches and strategies through replication, and numerous publications are concerned with best practice (e.g., Morgan & Sanz 2007; Kühl *et al.* 2008; Hockings & Humle 2009). Apart from the fact that claims of best practice are typically unsupported by comparative evidence (and are perhaps better considered as "conventional" practice), we believe that their application to complex conservation problems has often resulted in a proliferation of what Mitroff & Silvers (2009) call a "Type III error"; finding a good solution to the wrong problem. A well-documented example of the pitfalls of best practice in complex systems is the use of integrated conservation and development projects (ICDPs) in communities with little history of natural resource care and where the main pressures were external to the community (McShane & Wells 2004).

We are cognizant of the fact that the suggestions we make here for navigating complex systems could itself be labeled as "best practice" guidance. We do not make this claim because we are not certain if they are best—though we believe that they are options that might usefully be considered. We also acknowledge the importance of capturing and sharing experience, tasks that unfortunately are often packaged, unqualified under the banner of "best practice." While there are certainly legitimate reasons for standardizing conservation approaches, best practice is, inevitably, past practice and emphasizing it too strongly may retard efforts to navigate complex systems (Ostrom & Cox 2010). Knowledge management researchers have suggested that best practice is ill suited to complex systems, and is only appropriate in known or knowable systems; those in which a predictable response could be expected from repeating an intervention (Snowden 2002). Few conservation problems relating to socioecological systems fall into this predictable category.

Rather than adhering to nominal best practice, studies into successful management and leadership in complex situations consistently emphasize a willingness to disrupt existing behaviors and to be open and responsive to competing and creative options (Snowden & Boone 2007; Uhl-Bien *et al.* 2007). We believe that a relatively unacknowledged tension exists between creativity and best practice in conservation. Fostering creativity requires leadership that is open to diverse inputs, and encourages discussion, dissent, and diversity (Regine & Lewin 2000; Marion & Uhl-Bien 2002). One reason this has been challenging in conservation is the reliance on "experts." In conservation, expertise is typically conferred through lengthy engagement with the system in question. It has been argued that the very development of expertise inevitably leads to entrained thinking (Snowden 2002). The view of expertise and the weight given to it in conservation are in sharp contrast to business ventures that have successfully navigated complex systems through a disruptive and decentralized model of innovation. Google, a good example of such practices, places great emphasis on distributed leadership and a wide diversity of skills and opinions in its workforce (Levy 2011). Research in the field of environmental conservation decision making suggests that perceived level of expertise is poorly correlated with the accuracy of advice and that accuracy was most easily improved by taking a more broadly defined view of expertise (Burgman *et al.* 2011).

However, distributed leadership alone is not enough to break the hold of "best practice"; the freedom to innovate also comes from the confidence of clearly established objectives beneath which there is flexibility in how tasks are achieved (Uhl-Bien *et al.* 2007; Gregory *et al.* 2012). This is akin to planning and decision-making processes that focus broadly on what needs to be achieved rather than the means of getting there—as recommended in the previous section. If a conservation program manager knew they could approach forest protection by any legal means, this flexibility might lead to unorthodox but potentially effective solutions such as the legal use of tree spiking to prevent illegal logging (Meijaard & Sheil 2011). Similarly, complexity science has revealed that complex systems are managed most efficiently when clear rules-of-the-game are established beneath which system components can self-organize (that is adopt structures responsive to local conditions) without extensive top-down control (Helbing 2013).

An institutional approach to harnessing creativity might involve restructuring the systems of funding and rewards. Examples of this can be seen in both the United States Agency for International Development (USAID) and United Kingdom Department for International Development (DFID) which have established funding programs that focus exclusively on novel and creative practices rather than application of existing practices (USAID 2013). Creativity is promoted through provision of a large number of relatively small grants with the recognition that many will not be successful enough to warrant further funding. Rather than rewarding a project for its application of some nominal best practice, this approach rewards innovation and diversity of practice. Such experience is also likely to make an organization both more robust and more flexible and responsive to the surprises that are inevitable in complex systems.

Acknowledging complexity does not mean abandoning the analyses required to learn what tends to work and what does not, and in what contexts. Even in the most complex systems, patterns can emerge that can guide interventions. As such, it remains profitable to focus analysis of current evidence on the search for particular cause–effect relationships that often occur in different contexts. For example, Johnson *et al.* (2011) illustrate a simple, consistent pattern of violence escalation in terrorist and insurgent activities. In complex counterinsurgency operations, the U.S. military considers "event-pattern analysis" to be the basic element of their analysts' work (Petraeus 2006). Similarly, knowledge management research suggests that in complex systems, effort should be directed to the recognition and management of patterns rather than best practice (Snowden 2002). Repeated patterns are likely to exist in conservation work, such as the predictable impact of dams on environmental flows, that could flag places or events for which replication of particular interventions might be appropriate.

What can we learn from the military?

For over a decade the United States and its allies have conducted a military campaign in Afghanistan. The protracted nature of this campaign is generally seen as a reflection of an earlier underestimation of the complexity of the task (AP 2011). The challenges that complexity pose for military engagement in Afghanistan are often similar to those that arise in conservation. The Afghanistan campaign suffered from unclear objectives—"freedom" means different things to different people—and aims have been expanded and linked to humanitarian outcomes and development achievements. Defining success has been difficult; for example, was it a success to replace the Taliban with a corrupt government allowing opium exports to flourish (Debusmann 2009)? In response to such challenges, the U.S. military has altered its structure and tactics. The shared characteristics between military and conservation challenges and approaches provide potential lessons, suggestions, and opportunities for conservation tactics and practice.

Resources alone cannot tame complexity. In Afghanistan, the United States has discovered that it cannot spend its way to a solution. Although conservationists routinely bemoan the lack of funds for their activities (McCarthy *et al.* 2012), there is little evidence that bigger budgets make conservation easier or more effective. Having the money to buy oil palm plantations does not resolve issues around employment, development, secondary industries, and trade agreements (Venter *et al.* 2008). If conservation and warfare were simply about available funds they would be straightforward; work out what we are willing to pay for and get the job done. Working effectively in complex systems requires a redesign of how we interact with them.

Complex systems demand distributed leadership (Uhl-Bien *et al.* 2007) and a decentralized approach to strategic analysis (Petraeus 2006). Rather than relying on a central intelligence body, the United States now emphasizes local analyses. This has required increased analytical expertise among field units, and decentralized decision making to allow for a rapid response. The military's hierarchical structure has had to be modified to support these decision-making processes. Distributed leadership can be facilitated through a clear set of objectives and principles which provides local leaders the confidence to explore novel solutions rather than worry about compliance with best practice (Uhl-Bien *et al.* 2007). The militaries of the United Kingdom and Israel have found it effective to establish clear mission objectives at a high level but then devolve tactical decisions to local commanders (Moffat 2002). A related point is the need to listen to diverse voices during decision making. Recognizing that good strategies in complex systems are as likely to come from subordinates as from the higher ranks, the army encourages leaders to explore challenges and solutions with a broad group (Petraeus 2006). General Petraeus recognized that the break with conventional practices would be a shock to many—in a statement attached to the guidance he told his staff: "If this sounds un-military, get over it."

We do not claim that these changes within the United States and other militaries have resulted in improved military or humanitarian outcomes in Afghanistan. However, we have reported them here for three reasons: (1) they are the result of carefully considering problems similar to those faced in conservation; (2) there is some convergence in these recommendations across quite disparate fields and literature; and (3) many of the tools we use in conservation planning (for example, optimization routines and the Delphi approach to expert information), were originally developed for military applications and yet have made important contribution to conservation practice.

Conclusion

Acknowledging the systems we work in as complex and plagued with wicked problems allows us to learn from other fields facing similar challenges. Opportunities for progress lie in how we define and share objectives, how we use scenarios, and in our willingness to distribute leadership and engage diverse views to promote creativity. Borrowing concepts from other fields will not solve all our problems, but it broadens our range of options.

Acknowledgments

We thank Peter Kareiva, Michael Bode, Claire Kremen, and three anonymous reviewers for constructive input that greatly improved this manuscript. We thank Kirsten Evans for introducing us to some of the literature on management of complex systems.

References

Ahmad Zafir, A.W., Payne, J., Mohamed, A. *et al.* (2011). Now or never: what will it take to save the Sumatran rhinoceros Dicerorhinus sumatrensis from extinction? *Oryx*, **45**, 225-233.

Allen, C.R. & Gunderson, L.H. (2011). Pathology and failure in the design and implementation of adaptive management. *J. Environ. Manage.*, **92**, 1379-1384.

AP. (2011). U.S. had 'frighteningly simplistic' view of Afghanistan as war began, Retired Gen. McChrystal says. NY Daily News. http://www.nydailynews.com/news/national/u-s-frighteningly-simplistic-view-afghanistan-war-began-retired-gen-mcchrystal-article-1.960480 (visited Oct. 6 2012).

Armsworth, P.R., Daily, G.C., Kareiva, P. & Sanchirico, J.N. (2006). Land market feedbacks can undermine biodiversity conservation. *Proc. Nat. Acad. Sci. U.S.A.*, **103**, 5403-5408.

Brehmer, B. (1990). Strategies in real-time, dynamic decision making. Pages 262–279 in R.M. Hogarth, editor. *Insights in decision making: a tribute to Hillel J. Einhorn*. University of Chicago Press, Chicago.

Brooks, T.M., Wright, S.J. & Sheil, D. (2009). Evaluating the success of conservation actions in safeguarding tropical forest biodiversity. *Conserv. Biol.*, **23**, 1448-1457.

Burgman, M.A., McBride, M. & Ashton, R. *et al.* (2011). Expert status and performance. *PLoS ONE*, **6**, e22998.

Conservation Measures Partnerships. (2007). Open Standards for the Practice of Conservation, Version 2.0.

Debusmann, B. (2009). Afghanistan imperative: taming the narco-state. The New York. http://www.nytimes.com/2009/2001/2030/world/americas/2030iht-letter.2001.19805304.html (visited Jan. 30, 2009).

Ferraro, P.J. & Pattanayak, S.K. (2006). Money for nothing? A call for empirical evaluation of biodiversity conservation investments—. *Plos Biol.*, **4**, 482-488.

Gregory, R., Failing, L., Harstone, M., Long, G., McDaniels, T. & Ohlson, D. (2012). *Structured decision making: a practical guide to environmental management choices*. Wiley-Blackwell, Oxford, UK.

Hauser, C.E., Pople, A.R. & Possingham, H.P. (2006). Should managed populations be monitored every year? *Ecol. Appl.*, **16**, 807-819.

Helbing, D. (2013). Globally networked risks and how to respond. *Nature*, **497**, 51-59.

Hirsch, P.D., Adams, W.M., Brosius, J.P., Zia, A., Bariola, N. & Dammert, J.L. (2011). Acknowledging conservation trade-offs and embracing complexity. *Conserv. Biol.*, **25**, 259-264.

Hockings, K. & Humle, T. (2009). *Best Practice Guidelines for the Prevention and Mitigation of Conflict Between Humans and Great Apes*. IUCN SSC Primate Specialist Group, Gland, Switzerland.

Holling, C.S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, **4**, 390-405.

Jepson, P. (2005). Governance and accountability of environmental NGOs. *Environ. Scie. Pol.*, **8**, 515-524.

Johnson, F. & Williams, B.K. (1999). Protocol and practice in the adaptive management of waterfowl harvests. *Conserv. Ecol.*, **3**, e8.

Johnson, N., Carran, S., Botner, J. *et al.* (2011). Pattern in escalations in insurgent and terrorist activity. *Science*, **333**, 81-84.

Johnson, N.F. (2007). *Two's Company, Three is Complexity: a simple guide to the science of all sciences*. Oneworld, Oxford.

Kühl, H., Maisels, F., Ancrenaz, M. & Williamson, E.A. (2008). *Best practice guidelines for surveys and monitoring of great ape populations*. IUCN SSC Primate Specialist Group (PSG), Gland, Switzerland.

Levy, S. (2011). *In the plex: how Google thinks, works and shapes our lives*. Simon and Schuster, New York.

Lindenmayer, D.B., Likens, G.E., Haywood, A. & Miezis, L. (2011). Adaptive monitoring in the real world: proof of concept. *Trends Ecol. Evol.*, **26**, 641-646.

Liu, J.G., Dietz, T., Carpenter, S.R. *et al.* (2007). Complexity of coupled human and natural systems. *Science*, **317**, 1513-1516.

Marion, R. & Uhl-Bien, M. (2002). Leadership in complex organizations. *Leadership Quart.*, **12**, 389-418.

McCarthy, D.P., Donald, P.F. & Scharlemann, J.P.W. *et al.* (2012). Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. *Science*, **338**, 946-949.

McDonald-Madden, E., Probert, W. & Hauser, C.E. *et al.* (2010). Active conservation of threatened species in the face of uncertainty. *Ecol. Appl.*, **20**, 1476-1489.

McDonald-Madden, E., Runge, M.C., Possingham, H.P. & Martin, T.G. (2011). Optimal timing for managed relocation of species faced with climate change. *Nature Climate Change*, **1**, 261-265.

McShane, T.O. & Wells, M.P. (2004). *Getting biodiversity projects to work: towards more effective conservation and development*. Columbia University Press, New York.

Meijaard, E., Buchori, D., Hadiprakoso, Y. *et al.* (2011). Quantifying killing of orangutans and human-orangutan conflict in Kalimantan, Indonesia. *PLoS One*, **6**, e27491.

Meijaard, E. & Sheil, D. (2011). A modest proposal for wealthy countries to reforest their land for the common good. *Biotropica*, **43**, 544-548.

Meijaard, E., Wich, S., Ancrenaz, M. & Marshall, A.J. (2012). Not by science alone: why orangutan conservationists must think outside the box. *Ann. N. Y. Acad. Sci.*, **1249**, 29-44.

Mitchell, M. (2009). *Complexity: a guided tour*. Oxford University Press, New York.

Mitroff, I. & Silvers, A. (2009). *Dirty rotten strategies: how we trick ourselves and others into solving the wrong problems precisely*. Stanford Business Books, Stanford University Press, Palo Alto, CA, pp. 1-29.

Moffat, J. (2002). *Command and control in the information age: representing its impact*. Renouf Publishing Company Limited, New York.

Morgan, D. & Sanz, C. (2007). *Best practice guidelines for reducing the impact of commercial logging on great apes in Western Equatorial Africa*. IUCN SSC Primate Specialist Group (PSG), Gland, Switzerland.

Natural Resource Management Ministerial Council. (2004). *National biodiversity and climate change action plan 2004–2007*. Australian Government, Department of Environment and Heritage, Canberra, ACT.

Nichols, J.D., Koneff, M.D. & Heglund, P.J. *et al.* (2011). Climate change, uncertainty, and natural resource management. *J. Wildlife Manage.*, **75**, 6-18.

Nichols, J.D., Runge, M.C., Johnson, F.A. & Williams, B.K. (2006). Adaptive harvest management of North American waterfowl populations—recent successes and future prospects. *J. Ornithol.*, **147**, 28-28.

Ostrom, E. & Cox, M. (2010). Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis. *Environ. Conserv.*, **37**, 451-463.

Parrott, L. & Meyer, W.S. (2012). Future landscapes: managing within complexity. *Front. Ecol. Environ.*, **10**, 382-389.

Patton, M.Q. (2011). *Developmental evaluation*. Applying Complexity Concepts to Enhance Innovation and Use The Guilford Press, New York and London.

Peterson, G.D., Cumming, G.S. & Carpenter, S.R. (2003). Scenario planning: a tool for conservation in an uncertain world. *Conserv. Biol.*, **17**, 358-366.

Petraeus, D.H. (2006). *Counterinsurgency*. Vol Field Manual No. 3-24. Department of the Army, Washington, DC.

Regine, B. & Lewin, R. (2000). Leading at the edge: how leaders influence complex systems. *Emergence*, **2**, 5-23.

Rittel, H.W.J. & Webber, M.M. (1973). Dilemmas in a general theory of planning. *Pol. Sci.*, **4**, 155-169.

Rosser Jr, J.B. (2001). Complex ecologic-economic dynamics and environmental policy. *Ecol. Econ.*, **37**, 23-37.

Sassen, M., Sheil, D., Giller, K.E. & ter Braak, C.J.F. (2013). Complex contexts and dynamic drivers: understanding four decades of forest loss and recovery in an East African protected area. *Biol. Conserv.*, **159**, 257-268.

Sayer, J., Sunderland, T., Ghazoul, J. *et al.* (2013). Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *Proc. Nat. Acad. Sci.*, **110**, 8349-8356.

Sheil, D. & Meijaard, E. (2010). Purity and prejudice: deluding ourselves about biodiversity conservation. *Biotropica*, **42**, 566-568.

Snowden, D. (2002). Complex acts of knowing: paradox and descriptive self-awareness. *J. knowledge manage.*, **6**, 100-111.

Snowden, D.J. & Boone, M.E. (2007). A leaders framework for decision making—wise executives tailor their approach to fit the complexity of the circumstances they face. *Harvard Bus. Rev.*, **85**, 68-74.

Uhl-Bien, M., Marion, R. & McKelvey, B. (2007). Complexity leadership theory: shifting leadership from the industrial age to the knowledge era. *Leadership Quart.*, **18**, 298-318.

USAID. (2013). Development Innovation Ventures.

Venter, O., Meijaard, E. & Wilson, K. (2008). Strategies and alliances needed to protect forest from palm-oil industry. *Nature*, **451**, 16.

Walters, C.J. (1986). *Adaptive management of renewable resources*. Blackburn Press, Caldwell, New Jersey.

Walters, C.J. (2007). Is adaptive management helping to solve fisheries problems? *Ambio*, **36**, 304-307.

Williams, B.K., Szaro, R.C. & Shapiro, C.D. (2007). *Adaptive management: the U.S. department of the interior technical guide*. U.S. Department of the Interior, Washington, DC, USA.

