CORRESPONDENCE

Pyrogeography, historical ecology, and the human dimensions of fire regimes

ABSTRACT

In our 2011 synthesis (Bowman *et al.*, *Journal of Biogeography*, 2011, **38**, 2223–2236), we argued for a holistic approach to human issues in fire science that we term 'pyrogeography'. Coughlan & Petty (*Journal of Biogeography*, 2013, **40**, 1010–1012) critiqued our paper on the grounds that our 'pyric phase' model was built on outdated views of cultural development, claiming we developed it to be the unifying explanatory framework for all human–fire sciences. Rather, they suggest that 'historical ecology' could provide such a framework. We used the 'pyric transition' for multiple purposes but did not offer it as an exclusive explanatory framework for pyrogeography. Although 'historical ecology' is one of many useful approaches to studying human–fire relationships, scholars should also look to political and evolutionary ecology, ecosystems and complexity theories, as well as empirical generalizations to build an interdisciplinary fire science that incorporates human, ecological and biophysical dimensions of fire regimes.

Keywords Ecosystems ecology, evolutionary ecology, historical ecology, human–fire dynamics, political ecology, pyric transition, pyrogeography.

INTRODUCTION

We recently highlighted the place of human behaviours within larger issues of fire regime variability and change (Bowman *et al.*, 2011). We called for greater integration of the natural sciences, social sciences and humanities to produce a more holistic view of human–fire relationships across space and through time, an approach we term 'pyrogeography'. Coughlan & Petty (2012, 2013) also champion the development of an integrated human–natural fire science, arguing that this is best achieved by 'historical ecology', presumably referring to an anthropological paradigm that posits particular relationships between human agency and environmental change (Balée, 1998, 2006; Coughlan & Petty, 2012). In making their case they were critical of our synthetic approach, which seeks to blend a diversity of intellectual traditions and approaches, and in making their case appear to have misunderstood our ethos and some specific examples. Specifically, Coughlan & Petty (2013) criticize our use of the 'pyric phase' model as simplistic, deterministic and based on long discredited anthropological theories. They conflate our use of pyric phases with modes of economic organization and interpret our use of the 'pyric transition' as a unifying theory of human–fire relationships. In their interpretation of our framework, Coughlan and Petty have also misunderstood our reference to human–fire–climate relationships in tropical forests. Here we take the opportunity to elaborate on our approach to remedy any misapprehensions of our earlier work.

Our adaptation of Pyne's (2001) 'pyric transition' was intended to highlight underappreciated interconnections among organic evolution, the biosphere, and human economies, ecologies and ideologies, as well as the connections among the traditional academic disciplines that study them. We do not advocate it as a universal explanatory framework for all human–fire research. Nor do we suggest that human–fire relationships develop in a predictable, deterministic stage scheme. We welcome Coughlan and Petty's suggestion to identify existing theoretical frameworks in which to situate interdisciplinary human–fire science, and indeed we believe that a much broader consideration of social-ecological theories is in order, one that encompasses but is not restricted to historical ecology.

HUMAN PYROGEOGRAPHY IN A COMPLEX WORLD

A major foil for our paper (Bowman *et al.*, 2011) was the enduring polemic between the 'natural' and 'anthropogenic' fire paradigms. Despite recent evidence that hominin use of fire stretches back more than 1 million years (Berna *et al.*, 2012) and that fire became a regular technology for many (if not all) hominin populations between 400 and 300 ka (Roebroeks & Villa, 2011) the polemic continues. Although distinguishing unambiguous evidence for human-caused fire activity in palaeoenvironmental records is difficult with existing methods (e.g. Fulé *et al.*, 2011) – a point that we emphasized in our original paper (Bowman *et al.*, 2011, pp. 2224–2225) – our inability to parse human from non-human impacts may simply reflect the inadequacies of current palaeohistorical research methods for dealing with the inherent complexities of human–fire relationships. If climate and culture are not mutually exclusive explanations of changes in past fire regimes (e.g. Holz & Veblen, 2011), we must develop more meaningful research questions. To accomplish this goal, we need a fuller appreciation of the human dimension of fire regimes – a key point in our 2011 paper.

Another goal of our paper was to highlight that human contributions to fire regimes extend beyond ignitions and active fire suppression. Humans can affect fire regimes via changes in ignitions, fuel loads, fuel continuity and miroclimates, all of which can have significant impacts on fire regimes (e.g. Laris, 2011). Human dimensions of fire regimes are embedded in complex ecological, economic, political, technological and social relationships. However, it would be as much a mistake to assume that any of these cultural interconnections are *necessarily significant*, as it has been a mistake to assume that climate and culture are mutually exclusive explanations.

The next generation of hypotheses in pyrogeography should evaluate the relationships among human demographic, economic, technological, land-use and political variables with fire regimes in testable ways.

One way that this can be approached is by focusing on the biophysical properties of known fire regimes to identify vulnerabilities to changes that can be triggered by various forms of human activity. This is the strategy that Whitlock, McWethy and colleagues (Whitlock *et al.*, 2010; McWethy *et al.*, 2013) have used to build a set of generalized, testable models about anthropogenic fire regimes based on fire, fuel (vegetation), ignition and climate relationships. These hypotheses can then be evaluated in palaeorecords, modern fire regimes or through simulation studies (e.g. Krawchuk *et al.*, 2009).

An alternative approach is to re-formulate ideas about fire–culture relationships that have developed in the humanities and social sciences in ways that can be tested with empirical evidence. This is the approach that we took in our 2011 paper. In our thought experiment, we focused on adapting Pyne's (2001) 'pyric transition' because it highlights the relationship between combustion and human–environment interaction across space, time, economy and culture. We put forward the 'pyric phase' concept as a way to formalize these ideas as testable general hypotheses about the relationship among economies, technologies and combustion.

Our inspiration for the 'pyric phases' were not the outdated developmental schemes of 19th and early 20th century cultural evolutionism (Laland & Brown, 2011), although we could see how readers might interpret our Figure 3 in that way (Bowman *et al.*, 2011, p. 2229). Rather, we found inspiration in the phase concept used in complex adaptive system studies that is akin to basins of attraction or alternative stable states (Beisner *et al.*, 2003). Phase diagrams (or ball-in-cup diagrams) can be used to provide simplified representations of the range of conditions (in *n*-dimensional space) in which a range of socio-economic and technological arrangements may be likely to result in similar or analogous human–fire relationships because of similar feedback loops within these fire–society systems. In this way, the pyric phases emphasize nonlinearities and key entanglements among human populations, technologies, economies and pyrogeographies, even as change is not assumed to be unidirectional. Although our adaptation is conceptual rather than quantitative, the complex adaptive system analysis of social and ecological systems with multiple basins of attraction is an emerging area of interest for anthropologists and other social scientists (Lansing *et al.*, 1998; Lansing, 2003; Lansing & Downey, 2011).

The pyric phase hypotheses also reiterate the interconnectedness among wildland fires, fossil fuel combustion and climate change – a point that we highlighted in our earlier paper (Bowman *et al.*, 2009) and that we illustrated with an example of fire in tropical rain forests. Here, we did not advocate total fire suppression in tropical forests with disregard for the livelihood of local populations, many of whom rely on fire use as part of agricultural strategies (cf. Coughlan & Petty, 2013, p. 1011). Our point is that landscape fire-use for economic activities, industrial combustion and carbon emissions are all interconnected in ways that will require difficult compromises to devise sustainable solutions. If reducing carbon emissions is an agreed upon societal or global goal, then anthropogenic fires in the tropics should probably be reduced, but this cannot be done without dramatic restructuring of local economies. If those economies are to be preserved, it must be done at the expense of reducing emissions through REDD-like schemes (e.g. Aragão & Shimabukuro, 2010), which are rife with their own set of complications and controversies. Regardless of the priority chosen, there will be trade-offs among these human dimensions of tropical fire regimes and the outcomes will depend upon anthropogenic climate change, economic, political and social dynamics operating at varying scales.

PYROGEOGRAPHY AND SOCIAL-ECOLOGICAL THEORIES

Coughlan & Petty (2013, p. 1011) suggest 'historical ecology' as a guiding framework for human pyrogeography. However, it is not entirely clear what they mean by this. 'Historical ecology' can refer to very different paradigms. For example, in some anthropological circles 'historical ecology' refers to a school of thought that is heavily influenced by the French *annales* school of history and by Marxist social theory (Balée, 1998, 2006). In this paradigm, scholars assume that all landscapes are 'humanized' and that all research questions are necessarily anthropocentric (Balée, 2006, pp. 80–81). For other scholars, 'historical ecology' might simply mean an 'epistemological commitment to the temporal dimension in ecological analysis' (Winterhalder, 1994, p. 40), and include concepts that are more generally associated with complex systems theories, such as resilience and multiple meta-stable states (Winterhalder, 1994, pp. 36–39). 'Historical ecology' can also have a definition based on applied practice, in which historical observations and dynamics provide a science-based framework for supporting ecological conservation and restoration policies and activities (Swetnam *et al.*, 1999). A key concept in this paradigm is the 'historical range of variability' (HRV) that is used to identify modern excursions from 'natural' conditions as well as to provide targets for restoring healthy ecosystems (Keane *et al.*, 2009). Although Coughlan & Petty (2013) leave their definition of 'historical ecology' nebulous, elsewhere they appear to favour the narrow anthropological use of the term (Coughlan & Petty, 2012).

We favour the more inclusive and general definitions of historical ecology and believe that it is obviously important to human–fire research. Many of the authors of this paper are historical ecologists, although we (and others) have also found great utility in other bodies of social, evolutionary or ecological theory. For example, political ecology has been used successfully as an explanatory tool to understand the role that power differences can play in the implementation and enforcement of fire policy and fire use (Kull, 2004). Evolutionary ecology provides a framework for generating predictive, testable hypotheses about human decision-making and behaviour within the context of particular social and natural environments (Winterhalder & Smith, 2000). Indeed, some of these hypotheses have been extended to human–fire relationships and are being evaluated by anthropologists today (Bird *et al.*, 2012).

Additional important sources for theory and testable hypotheses include ecosystem ecology and complex adaptive systems theory (Lansing *et al.*, 1998; Holling, 2001; Beisner *et al.*, 2003; Lansing, 2003; Scheffer & Carpenter, 2003). Empirical and simulation studies are beginning to identify nonlinearities and novel dynamics in human–fire relationships (e.g. Archibald *et al.*, 2012). Hypotheses about the resilience and vulnerability of different fire–climate–culture couplings may yield important insights about pyrogeography that have tangible implications for mitigation, adaptation and restoration in a global warming future.

CONCLUSIONS

There are many topics on which we agree with Coughlan and Petty. We agree that current fire history methods may be inadequate to distinguish human contributions to ancient fire regimes. We agree that social, economic and political changes are likely to result in changes in human–fire relationships (Coughlan & Petty, 2012, p. 481), although we would add technological, land-use, climate and demographic changes to this point. In fact, this point is not dissimilar from the suggestion inherent in our formal treatment of the pyric phases (Bowman *et al.*, 2011). We agree that too much attention has been paid to human impacts on ignitions to the detriment of all other dimensions of human–fire relationships. We agree that our goal should be to identify and explain the diversity of human–fire relationships. Although we offered our adaption of the pyric phases as one avenue to stimulate future research and to frame thinking about sustainable fire management (Bowman *et al.*, 2013), we think that it will be important to seek inspiration from a broad range of empirical, historical and theoretical sources and should not be limited to any particular paradigm.

We hope that more natural scientists, social scientists and humanists will engage the complexity of these issues and with each other. We recognize that cross-disciplinary communication and research partnerships will be a major challenge for pyrogeography (Pyne, 2007). Our research group has been fundamentally interdisciplinary from its inception and we recognize the challenges of interdisciplinarity in practice. The importance of fire in earth systems processes and the impacts of our decisions (or indecisions) on sustainable fire management, human health, livelihoods, property, ecosystems and Earth's climate mean that we cannot afford to allow disciplinary and conceptual boundaries to impede our understanding of the complexities of human–fire relationships (Scott *et al.*, 2014).

Christopher I. Roos[1]*,
David M. J. S. Bowman[2],
Jennifer K. Balch[3],
Paulo Artaxo[4],
William J. Bond[5],
Mark Cochrane[6],
Carla M. D'Antonio[7],
Ruth DeFries[8],
Michelle Mack[9],
Fay H. Johnston[10],
Meg A. Krawchuk[11],
Christian A. Kull[12],
Max A. Moritz[13],
Stephen Pyne[14],
Andrew C. Scott[15] and
Thomas W. Swetnam[16]

[1]Department of Anthropology, Southern Methodist University, Campus Box 0336, Dallas, TX 75275, USA, [2]School of Plant Science, University of Tasmania, Hobart, TAS 7001, Australia, [3]Department of Geography, Penn State University, University Park, PA 16802, USA, [4]Instituto de Fisica, Universidade de Sao Paulo 1516, Rua do Matao Travessa R, 187 05508-900, Sao Paulo, SP Brazil, [5]Botany Department, University of Cape Town, Cape Town, Rondebosch 7701, South Africa, [6]Geographic Information Science Center of Excellence, South Dakota State University, Brookings, SD 57007, USA, [7]Environmental Studies Program and Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA 93105, USA, [8]Ecology, Evolution & Environmental Biology, Columbia University, New York, NY 10027, USA, [9]Department of Biology, University of Florida, Gainesville, FL 32611, USA, [10]Menzies Research Institute Tasmania and the Rural Clinical School University of Tasmania, Hobart, TAS 7000 , Australia, [11]Department of Geography, Simon Fraser University, Burnaby, BC V5A 1S6, Canada, [12]School of Geography and Environmental Science, Monash University, Melbourne, Vic. 3800, Australia, [13]Environmental Science, Policy, and Management Department, University of California, Berkeley, CA 94720, USA, [14]School of Life Sciences, Arizona State University, Tempe, AZ 85287, USA, [15]Department of Earth Sciences, Royal Holloway University of London, Egham, Surrey TW20 0EX, UK, [16]Laboratory of Tree-Ring Research, The University of Arizona, Tucson, AZ 85721, USA
**E-mail: croos@smu.edu*

ACKNOWLEDGEMENTS

This response reflects the work of the Pyrogeography Working Group supported by the National Center for Ecological Analysis and Synthesis (NCEAS), funded by National Science Foundation (NSF) grant DEB-0553768, with additional support for J. Balch, a postdoctoral associate at NCEAS. We thank three anonymous referees for their constructive feedback on the manuscript.

REFERENCES

Aragão, L.E.O.C. & Shimabukuro, Y.E. (2010) The incidence of fire in Amazonian forests with implications for REDD. *Science*, **328**, 1275–1278.

Archibald, S., Staver, A.C. & Levin, S.A. (2012) Evolution of human-driven fire regimes in Africa. *Proceedings of the National Academy of Sciences USA*, **109**, 847–852.

Balée, W. (1998) Historical ecology: premises and postulates. *Advances in historical ecology* (ed. by W. Balée), pp. 13–29. Columbia University Press, New York.

Balée, W. (2006) The research program of historical ecology. *Annual Review of Anthropology*, **35**, 79–98.

Beisner, B.E., Haydon, D.T. & Kuddington, K. (2003) Alternative stable states in ecology. *Frontiers in Ecology and the Environment*, **1**, 376–382.

Berna, F., Goldberg, P., Horwitz, L.K., Brink, J., Holt, S., Bamford, M. & Chazan, M. (2012) Microstratigraphic evidence of in situ fire in the Acheulean strata of Wonderwerk Cave, Northern Cape province, South Africa. *Proceedings of the National Academy of Sciences USA*, **109**, E1215–E1220.

Bird, R.B., Codding, B.F., Kauhanen, P.G. & Bird, D.W. (2012) Aboriginal hunting buffers climate-driven fire-size variability in Australia's spinifex grasslands. *Proceedings of the National Academy of Sciences USA*, **109**, 10287–10292.

Bowman, D.M.J.S., Balch, J.K., Artaxo, P. *et al.* (2009) Fire in the Earth system. *Science*, **324**, 481–484.

Bowman, D.M.J.S., Balch, J.K., Artaxo, P., Bond, W.J., Cochrane, M.A., D'Antonio, C.M., DeFries, R.S., Johnston, F.H., Keeley, J.E., Krawchuk, M.A., Kull, C.A., Mack, M., Moritz, M.A., Pyne, S.J., Roos, C.I., Scott, A.C., Sodhi, N.S. & Swetnam, T.W. (2011) The human dimension of fire regimes on Earth. *Journal of Biogeography*, **38**, 2223–2236.

Bowman, D.M.J.S., O'Brien, J. & Goldammer, J. (2013) Pyrogeography and the global quest for sustainable fire management. *Annual Review of Environment and Resources*, **38**, 57–80.

Coughlan, M.R. & Petty, A.M. (2012) Linking humans and fire: a proposal for a transdisciplinary fire ecology. *International Journal of Wildland Fire*, **21**, 477–487.

Coughlan, M.R. & Petty, A.M. (2013) Fire as a dimension of historical ecology: a response to Bowman *et al.* (2011). *Journal of Biogeography*, **40**, 1010–1012.

Fulé, P.Z., Ramos-Gómez, M., Cortes-Montaño, C. & Miller, A.M. (2011) Fire regime in a Mexican forest under indigenous resource management. *Ecological Applications*, **21**, 764–775.

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

Holz, A. & Veblen, T.T. (2011) The amplifying effects of humans on fire regimes in temperate rainforests in western Patagonia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **311**, 82–92.

Keane, R.E., Hessberg, P.F., Landres, P.B. & Swanson, F.J. (2009) The use of historical range of variability (HRV) in landscape management. *Forest Ecology and Management*, **258**, 1025–1037.

Krawchuk, M.A., Moritz, M.A., Parisien, M.-A., Van Dorn, J. & Hayhoe, K. (2009) Global pyrogeography: the current and future distribution of wildfire. *PLoS ONE*, **4**, e5102.

Kull, C.A. (2004) *Isle of fire: the political ecology of landscape burning in Madagascar*. University of Chicago Press, Chicago, IL.

Laland, K.N. & Brown, G. (2011) *Sense and nonsense: evolutionary perspectives on human behaviour*. Oxford University Press, Oxford, UK.

Lansing, J.S. (2003) Complex adaptive systems. *Annual Review of Anthropology*, **32**, 183–204.

Lansing, J.S. & Downey, S.S. (2011) Anthropology and complexity. *Philosophy of complex systems* (ed. by C. Hooker), pp. 569–601. North Holland/Elsevier, Oxford, UK.

Lansing, J.S., Kremer, J.N. & Smuts, B.B. (1998) System-dependent selection, ecological feedback, and the emergence of functional structure in ecosystems. *Journal of Theoretical Biology*, **192**, 377–391.

Laris, P. (2011) Humanizing savanna biogeography: linking human practices with ecological patterns in a frequently burned savanna of southern Mali. *Annals of the Association of American Geographers*, **101**, 1067–1088.

McWethy, D.B., Higuera, P.E., Whitlock, C., Veblen, T.T., Bowman, D.M.J.S., Cary, G.J., Haberle, S.G., Keane, R.E., Maxwell, B.D., McGlone, M.S., Perry, G.L.W., Wilmshurst, J.M., Holz, A. & Tepley, A.J. (2013) A conceptual framework for predicting temperate ecosystem sensitivity to human impacts on fire regimes. *Global Ecology and Biogeography*, **22**, 900–912.

Pyne, S.J. (2001) *Fire: a brief history*. University of Washington Press, Seattle, WA.

Pyne, S.J. (2007) Problems, paradoxes, paradigms: triangulating fire research. *International Journal of Wildland Fire*, **16**, 271–276.

Roebroeks, W. & Villa, P. (2011) On the earliest evidence for habitual use of fire in Europe. *Proceedings of the National Academy of Sciences USA*, **108**, 5209–5214.

Scheffer, M. & Carpenter, S.R. (2003) Catastrophic regime shifts in ecosystems: linking theory to observation. *Trends in Ecology and Evolution*, **18**, 648–656.

Scott, A.C., Bowman, D.J.M.S., Bond, W.J., Pyne, S.J. & Alexander, M. (2014) *Fire on Earth: an introduction*. J. Wiley and Sons, Chichester, UK.

Swetnam, T.W., Allen, C.D. & Betancourt, J.L. (1999) Applied historical ecology: using the past to manage for the future. *Ecological Applications*, **9**, 1189–1206.

Whitlock, C., Higuera, P.E., McWethy, D.B. & Briles, C.E. (2010) Palaeoecological perspectives on fire ecology: revisiting the fire-regime concept. *The Open Ecology Journal*, **3**, 6–23.

Winterhalder, B. (1994) Concepts in historical ecology: the view from evolutionary ecology. *Historical ecology: cultural knowledge and changing landscapes* (ed. by C.L. Crumley), pp. 17–41. School of American Research Press, Santa Fe, NM.

Winterhalder, B. & Smith, E.A. (2000) Analyzing adaptive strategies: human behavioral ecology at twenty-five. *Evolutionary Anthropology Issues News and Reviews*, **9**, 51–72.

Editor: Robert Whittaker