Invasion Science: Looking forward rather than revisiting old ground

Anthony Ricciardi[1], Tim M. Blackburn[2,3], James T. Carlton[4], Jaimie T.A. Dick[5], Philip E. Hulme[6], Josephine C. Iacarella[7], Jonathan M. Jeschke[8,9,10], Andrew M. Liebhold[11], Julie L. Lockwood[12], Hugh J. MacIsaac[13], Petr Pyšek[14,15], David M. Richardson[16], Gregory M. Ruiz[17], Daniel Simberloff[18], William J. Sutherland[19], David A. Wardle[20,21], and David C. Aldridge[19].

[1]Redpath Museum, McGill University, Montreal, QC, H3A 0C4, Canada
[2]Centre for Biodiversity and Environment Research, Department of Genetics, Evolution and Environment, University College London, Gower Street, London, WC1E 6BT, UK
[3]Institute of Zoology, Zoological Society of London, Regent's Park, London, NW1 4RY, UK
[4]Maritime Studies Program, Williams College-Mystic Seaport, 75 Greenmanville, Mystic, CT 06355, USA
[5]Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, MBC, 97 Lisburn Road, Belfast, BT9 7BL, UK
[6]Bio-Protection Research Centre, Lincoln University, PO Box 85840, Lincoln 7647, Canterbury, New Zealand
[7]University of Victoria, Biology Department, 3800 Finnerty Road, Victoria, BC, V8P 5C2, Canada
[8]Leibniz-Institute of Freshwater Ecology and Inland Fisheries, 12587 Berlin, Germany
[9]Institute of Biology, Freie Universität Berlin, Königin-Luise-Str. 1-3, 14195 Berlin, Germany
[10]Berlin-Brandenburg Institute of Advanced Biodiversity Research, 14195 Berlin, Germany
[11]US Forest Service Northern Research Station, 180 Canfield St., Morgantown, WV, USA
[12]Rutgers University, Department of Ecology, Evolution and Natural Resources, 14 College Farm, New Brunswick, NJ 08901, USA
[13]Great Lakes Institute for Environmental Research, University of Windsor, Windsor, Ontario, N9B 3P4, Canada
[14]Institute of Botany, The Czech Academy of Sciences, CZ-252 43, Průhonice, Czech Republic
[15]Department of Ecology, Faculty of Science, Charles University, Viničná 7, CZ-12844 Prague 2, Czech Republic
[16]Centre for Invasion Biology, Department of Botany and Zoology Stellenbosch University, Matieland 7602, South Africa
[17]Smithsonian Environmental Research Center, Edgewater, MD 21037, USA
[18]University of Tennessee, Department of Ecology and Evolutionary Biology, Knoxville, TN 37996, USA
[19]Cambridge University, Department of Zoology, Pembroke Street, Cambridge, CB2 3QZ, UK
[20]Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, SE901-83 Umeå, Sweden
[21]Asian School of the Environment, Nanyang Technological University, 50 Nanyang Avenue, Singapore

Using horizon scanning techniques, we identified 14 emerging issues, not yet widely recognized or understood, that are likely affect to how biological invasions are studied and managed on a global scale [1]. Zenni *et al.* [2] do not comment on the major issues identified in our study. Instead, they draw attention to the nationalities of our authorship and the lack of representation from developing countries, and they imply that as a consequence our paper promotes misconceptions and ignores key issues affecting such countries. In particular, they criticize our "opinionated statement" that most developing countries have limited capacity to respond to invasions. This is not merely our opinion; we cited Early *et al.* [3], whose analysis concluded that proactive capacities, although far from sufficient globally, are more advanced in countries with a high Human Development Index (HDI) than in those with a low HDI. The term *developing country* is open to misinterpretation, but is often defined as a sovereign state with a low HDI and a less developed industrial base relative to other countries[1]; such countries occur mostly in sub-Saharan Africa and Asia. The ten 'developing countries' listed by Zenni *et al.* as having national invasive species strategies or databases (i.e., Mexico, Jamaica, Guyana, Cuba, Brazil, Colombia, Uruguay, Argentina, Chile, South Africa) are arguably more similar to developed countries economically, in terms of HDI, than to many of the world's poorest countries [4]. Thus, Zenni *et al.* primarily highlight invasive species management in Neotropical countries rather than in developing countries *per se*.

Zenni *et al.* [2] take exception to our observation that developing countries can act as hubs to spread alien species. Yet, we did not attribute the spread of invasive species uniquely or even predominantly to developing countries. Higher numbers of invasive alien species are reported from more affluent nations [5], but these same nations have a greater capacity to detect and track such species. Socioeconomic conditions mediate a country's susceptibility to invasion

[1]https://en.wikipedia.org/wiki/Developing_country (Accessed 31 July 2017).

and its potential role as a source region within a global dispersal network [6–8]. Developing and newly industrialized countries (including some in South America) have been the source of many high-profile global invaders, including varroa mites, small Indian mongoose, Hottentot fig, Himalayan balsam, Emerald ash borer, water hyacinth, Africanised honey bees, and myrtle rust. Such countries may act as dispersal hubs for certain groups of species (e.g., travelers from these regions are more likely to carry arthropods such as scale insects and fruit flies in their baggage [6]), and we expect that they will play an even greater role in the future. Regions with rapidly growing economies – and attendant changes in land use, urbanization, coastal development, infrastructure, tourism, and trade volume – are increasingly susceptible to invasion [9,10] (see Box 1). The economic expansion of developing nations, in combination with their currently limited biosecurity measures, will raise invasion risks internationally. For these reasons, it would be strategically wise for affluent nations to invest in invasive species management strategies on a global scale.

As for Zenni *et al.*'s lament about the composition of our authorship, we acknowledged that our assessment was based on a limited set of views and we explicitly raised the possibility of additional issues being offered by researchers from developing countries. However, none of the issues proposed by Zenni *et al.* are emerging or novel. Rather, they are a series of generalizations and vaguely stated goals that have been discussed frequently over the past few decades and are being addressed by many international organizations (such as the Centre for Agriculture and Biosciences International), although much more work needs to be done. While we certainly agree that these goals are important, they do not "broaden and balance" the results of our horizon scan.

The need for horizon scanning in invasion science

In using our paper to draw attention to longstanding management goals, Zenni *et al.* overlook our main message: invasion risks are rapidly changing under the influence of diverse and dynamic forces, and there is a critical need for advanced information to adapt to them. Globally, rates of invasion show no sign of slowing [11]. As we noted [1], vectors and pathways are diversifying across the world; human transportation systems (e.g., the Panama and Suez Canals) are being modified; international patterns of trade and tourism are shifting; and global environmental changes and biotechnological advancements are accelerating.

Excessive delays in recognizing, preparing for, and responding to emerging environmental problems can result in unnecessary harm [12]. Delayed management and policy responses to invasion threats lead to aggravated ecological and socioeconomic impacts [13,14]. Invasion scientists must improve their capacity to provide timely advice through better identification and prioritization of forthcoming challenges. Horizon scanning is a useful tool for these aims, but it has hardly been exploited. We hope that our study will encourage broader application of horizon scanning techniques in invasion science across all countries.

References

1. Ricciardi, A. *et al.* (2017) Invasion science: a horizon scan of emerging challenges and opportunities. *Trends. Ecol. Evol.* 32, 464–474
2. Zenni, R.D. *et al.* (2017) Invasion science in the developing world. *Trends. Ecol. Evol.* 32, nnn–nnn
3. Early, R. *et al.* (2017) Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature Comm.* 7, 12485

4. United Nations Development Programme (2016) Human Development Report 2016 – Human Development for Everyone. Human Development Report Office, UNDP, New York
5. Lotz, A., and Allen, C.R. (2013) Social-ecological predictors of global invasions and extinctions. *Ecology Soc.* 18(3), 15
6. Liebhold, A.M. *et al.* (2006) Airline baggage as a pathway for alien insect species invading the United States. *Amer. Entomol.* 52, 48–54
7. Brenton-Rule, E.C. *et al.* (2016) Corruption, development and governance indicators predict invasive species risk from trade. *Proc. Roy. Soc.* 283, 20160901
8. Thuiller, W. *et al.* (2005) Niche-based modelling as a tool for predicting the risk of alien plant invasions at a global scale. *Global Change Biol.* 11, 2234–2250
9. Seebens, H. (2015) Global trade will accelerate plant invasions in emerging economies under climate change. *Global Change Biol.* 21, 4128–4140
10. Hulme, P.E. (2015) Invasion pathways at a crossroad: policy and research challenges for managing alien species introductions. *J. Appl. Ecol*. 52, 1418–1424
11. Seebens, H. *et al.* (2017) No saturation in the accumulation of alien species worldwide. *Nature Comm.* 8, 14435
12. Sutherland, W.J. and Woodroof, H.J. (2009) The need for environmental horizon scanning. *Trends Ecol. Evol*. 24, 523–527
13. Harris, S. and Timmins, S.M. (2009) Estimating the benefit of early control of all newly naturalised plants. Science for Conservation 292. New Zealand Department of Conservation, Wellington.

14. Simberloff, D. *et al.* (2013) Impacts of biological invasions: what's what and the way forward. *Trends Ecol. Evol.* 28, 58–66

Box 1. Trends expected to elevate biological invasion risks in developing countries.

Invasion risks are driven by myriad factors in addition to expanding trade volume and climate-related range expansions. During our horizon scan deliberations [1], the following trends were judged to be important drivers of invasion risk in developing countries:

- Increasing coastal development, particularly for mitigating sea level rise in low-lying island nation economies, will provide colonizable habitat for new marine invasive species.
- Growing affluence among middle classes will fuel demand for non-native plants and animals for ornamental gardens and pets, respectively, which may subsequently escape and become invasive.
- Economic reliance and promotion of in-country international tourism, especially to remote areas, will provide pathways for new invasive pests and diseases.
- Massive changes to natural ecosystems driven by land conversion (agricultural expansion, urbanization) and climate change will create conditions for rapid evolution of increased invasiveness in local populations.
- Climate-related disasters and geopolitical instability may induce human migrations and require foreign assistance (e.g., international peacekeeping), which will lead to inadvertent species introductions.