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Invasion Science: A Horizon Scan of Emerging Challenges and Opportunities

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Letter

Invasion Science: Looking Forward Rather Than Revisiting Old Ground – A Reply to Zenni *et al*.

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Using horizon scanning techniques, we identified 14 emerging issues, not yet widely recognized or understood, that are likely to affect 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 a 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 (https://en.wikipedia.org/wiki/Developing_country), and 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, and South Africa) are arguably more similar to developed countries, in terms of HDI, than to many of the poorest countries of the world [4].

Zenni *et al*. [2] take exception to our observation that developing countries can act as hubs to spread alien species. Nevertheless, 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 govern the susceptibility of a country to invasion 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 the varroa mite, small Indian mongoose, Hottentot fig, Himalayan balsam, Emerald ash borer, water hyacinth, Africanized honey bee, and myrtle rust. Such countries may act as dispersal hubs for particular 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] (Box 1). The economic expansion of developing countries, in combination with their currently limited biosecurity measures, will increase 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.

Regarding the lament by Zenni *et al*. about the composition of our authorship,

Box 1. Trends Expected to Elevate Biological Invasion Risks in Developing Countries

Invasion risks are driven by a myriad of factors beyond increasing trade volume and climate-related range shifts. During our horizon scan deliberations [1] the following trends were judged to be important drivers of invasion risk in some developing countries.

(i) Increasing modification of coastal shorelines with artificial structures (bulkheads and seawalls) to mitigate sea level rise, particularly for low-lying island nations, will create favorable habitats for marine invasive species.

(ii) 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.

(iii) Economic reliance and promotion of in-country international tourism, especially to remote biodiverse areas, will provide pathways for new invasive pests and diseases.

(iv) 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.

(v) Climate-related disasters and geopolitical instability may induce human migrations and require foreign assistance (e.g., international peacekeeping), which will generate opportunities for inadvertent species introductions.

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. Instead, 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 is needed. 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 some 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 crucial 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 barely been exploited. We hope that our study will encourage broader application of horizon scanning techniques in invasion science across all countries.

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