Pragmatism required to assess impacts of invasive plants

Alien plants can substantially alter native species' fitness, richness, and abundance as well as modify ecosystem functioning (Vilà *et al.* 2011). However, the diversity of impact assessment techniques available has hindered a more thorough understanding of alien plants' ecological effects. Barney *et al.* (*Front Ecol Environ* 2013; **11[6]**: 322–29) propose a quantitative framework that integrates any number of impact measures as a function of groundcover and geographic extent of the invading species. While their concept certainly challenges current methodologies, we use information from the most comprehensive quantitative assessment of the consequences of alien plant invasions to date (Pyšek *et al.* 2012; Hulme *et al.* 2013) to argue that combining multiple cover–impact response curves into a single metric suffers from several flaws that limit its applicability to distinguish species with major effects.

First, given that the most appropriate impact measures will be a function of both the alien species and the invaded ecosystem, it is unlikely that a universally agreed upon set of measurable outcomes will be forthcoming. Researchers generally examine distinct, and often small, sets of impact measures depending on their interest in the population, community, or ecosystem consequences of invasions (Figure 1). Not surprisingly, ecologists investigating potential impacts on pollination often focus on pollinator richness, visitation rate, and effectiveness, whereas those examining effects on ecosystem processes target a different suite of variables (eg soil chemistry, microbial activity, decomposition rates, etc). Such choices often seem sensible in relation to the problem being examined, regardless of whether studies address plant or animal communities, soil properties, or fire regimes. Thus a single integrative metric based on different inputs cannot be used to objectively compare different species where the focal questions regarding outcomes are different. Second, researchers are unlikely to have the resources or opportunity to assess between 10 and 20 impact measures. Up to now, 75% of studies quantifying the effects of alien plants have examined fewer than three impact measures and less than 1% have assessed more than five (Hulme *et al.* 2013). Of course, researchers could estimate more measures, but these would have to not only be uncorrelated (rarely the case for the most common soil or community-based measures) but also be pertinent to the question being examined (eg a study assessing the effects on pollinator effectiveness would not be informed by token measures of soil pH). Ecologists too often target a small, unrepresentative subset of alien plants; there are benefits to broadening studies to other species and ecosystems rather than focusing on a few species in ever-increasing detail (Hulme *et al.* 2014). Third, even if comparisons are restricted to species affecting the same components of ecosystems, the framework proposed by Barney *et al.* appears to disregard the direction of any difference between the reference and invaded system. Yet doing so would hinder interpretation of the consequences of plant invasions. For example, where an alien plant increases both the rates of litter decomposition and soil mineralization, it may have little net effect on soil organic matter (SOM); however, if these rates differ in direction, then major changes in SOM will occur (Castro-Diez *et al.* 2013). In addition, directionality will be crucial to inform management responses. The value of soil carbon (C) addition in mitigating invasions, for instance, is dependent on both the magnitude and direction of alien plant effects on soil nitrogen pools (Eschen *et al.* 2006). Fourth, individual impact measures can exhibit different non-

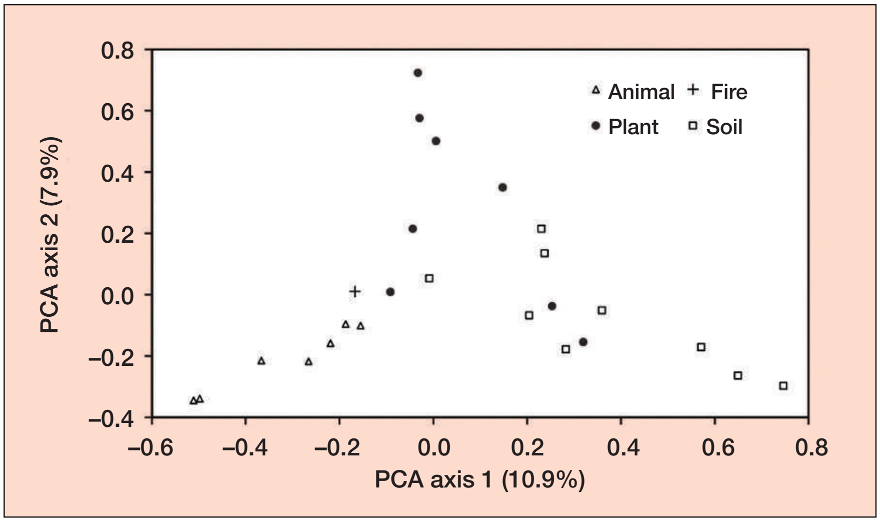

Figure 1. *The association of 25 different impact measures examined within 287 published papers classified according to four broad targets: (•) populations, species, and communities of plants; (△) populations, species, and communities of animals; (□) soil characteristics; and (+) fire regimes. Results are depicted along two axes of an unrotated principal component analysis (PCA) undertaken on a data matrix describing the frequency with which each of the different variables was examined in each of the 287 studies. The separation of soil, animal, and plant measures indicates that a single universal metric being applied across all studies is unlikely. The 25 impact responses included: abundance, diversity, richness, biomass, fitness, and performance of resident plant and animal species; animal and microbial activity; soil parameters, including nutrients, minerals, pH, soil fauna, and microbial richness and diversity; and plant tissue measures, including nutrient and mineral content and flammability. See Pyšek* et al. *(2012) for details on primary data.*

linear relationships with plant abundance, and these separate thresholds would be lost in a single metric. Gooden *et al.* (2009) found distinct thresholds in the level of *Lantana camara* cover associated with declines in the richness of different life-forms that ranged from as low as 30% cover for fern richness to as high as 80% cover for other herbs. There is no simple way to sum these important differences into a single metric. Finally, alien plant impacts are shaped by environmental gradients and cannot be assumed to be similar across the entire species' range (Hulme *et al.* 2013). Thus *Impatiens glandulifera* has negligible effects on riparian plant species richness in the Czech Republic (Hejda and Pyšek 2006) but reduces species richness by as much as 25% in the UK (Hulme and Bremner 2006). As this case illustrates, scaling up a single metric from local to regional scales will be complex and not necessarily valid.

We argue that, rather than focusing on developing a single metric, a hypothesis-led approach to plant invasion impacts is needed – one that not only requires predictions based on the alien species' traits and recipient ecosystems' characteristics but also targets specific ecosystem stocks (eg soil C content) and the flow of materials between them (eg C sequestration rate). Instead of concentrating on many uncorrelated variables, this approach would entail focusing on targeted ecosystem metrics that are causally related (and hence not independent) to identify the consequences for ecosystem services and to better inform management.

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The authors' reply

Although Hulme *et al.* (hereafter HEA) contend that our proposed integrated impact framework has limited applicability to distinguish species with major effects, we do not find their critiques and suggestions incompatible with our advocacy of multi-metric, cover-specific, population-level, ecological impact evaluation.

First, HEA call for a hypothesis-driven approach to identify specific impacts to focus on (eg ecologists investigating plant–pollinator networks would focus on related metrics only), arguing that an integrated metric that subsumes these metrics of interest among a suite of other metrics cannot be used to make interspecific comparisons in these circumstances. On the contrary, we do not find that hypothesis-driven questions (eg those related to pollinator networks) are mutually exclusive to questions on broad ecosystem impacts for several reasons. Our proposal is adaptable to any number of metrics. If a researcher is focused exclusively on the impacts to soil nutrient pools, our framework is capable of integrating these. Additionally, focal questions and hypothesis-driven metric choices can be made in parallel with broad accounting of ecosystem impact as we propose. Would it not be more informative to identify the consequences to pollinator networks, but also know the greater effect to ecosystem pools and processes? This depth and breadth adds valuable information for each studied population, further lending itself to future "big data" projects. Second, HEA argue that researchers are unlikely to have the economic or human capital to assess 10–20 metrics as we suggest. This would of course depend on the metrics that are chosen. Basic plant community, edaphic, and ecosystem properties (eg soil moisture, light) are inexpensive to measure, do not require special expertise, and comprise the vast majority of historically characterized impacts (Hulme *et al.* 2013). Additionally, the limited suite of metrics generally measured in individual studies is considered a weakness of current research (Hulme *et al.* 2013). For instance, Farnsworth and Ellis (2001) found contrasting evidence for the impacts of *Lythrum salicaria* to native wetland vegetation depending on the metrics measured, and thus called for a multi-metric evaluation of impacts. Third, HEA claim that our proposal of ignoring impact directionality would hinder interpretations. On the contrary, some of the same authors (Pyšek *et al.* 2012) state that "the valid measure of impact is the net change compared to