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E-commerce trade in invasive plants

Franziska Humair,* Luc Humair,† Fabian Kuhn,‡ and Christoph Kueffer§**

*Institute for Environmental Decisions—Consumer Behavior, ETH Zurich, Universitätstrasse 22, CH-8092 Zurich, Switzerland
†Department of Computer Science, ETH Zurich, Universitätstrasse 6, CH-8092 Zurich, Switzerland
‡Department of Computer Science, Albert-Ludwigs-Universität, Georges-Köhler-Allee 106, D-79110 Freiburg im Breisgau, Germany
§Institute of Integrative Biology, ETH Zurich, Universitätstrasse 16, CH-8092 Zurich, Switzerland
**Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Matieland 7602, South Africa

Abstract: *Biological invasions are a major concern in conservation, especially because global transport of species is still increasing rapidly. Conservationists hope to anticipate and thus prevent future invasions by identifying and regulating potentially invasive species through species risk assessments and international trade regulations. Among many introduction pathways of non-native species, horticulture is a particularly important driver of plant invasions. In recent decades, the horticultural industry expanded globally and changed structurally through the emergence of new distribution channels, including internet trade (e-commerce). Using an automated search algorithm, we surveyed, on a daily basis, e-commerce trade on 10 major online auction sites (including eBay) of approximately three-fifths of the world's spermatophyte flora. Many recognized invasive plant species (>500 species) (i.e., species associated with ecological or socio-economic problems) were traded daily worldwide on the internet. A markedly higher proportion of invasive than non-invasive species were available online. Typically, for a particular plant family, 30–80% of recognized invasive species were detected on an auction site, but only a few percentages of all species in the plant family were detected on a site. Families that were more traded had a higher proportion of invasive species than families that were less traded. For woody species, there was a significant positive relationship between the number of regions where a species was sold and the number of regions where it was invasive. Our results indicate that biosecurity is not effectively regulating online plant trade. In the future, automated monitoring of e-commerce may help prevent the spread of invasive species, provide information on emerging trade connectivity across national borders, and be used in horizon scanning exercises for early detection of new species and their geographic source areas in international trade.*

Keywords: alien, horizon scanning, internet, invasive, non-native, prevention, trade

El Mercado del Comercio Electrónico de Plantas Invasoras

Resumen: *Las invasiones biológicas son un gran problema para la conservación, especialmente porque el transporte mundial de especies incrementa rápidamente. Los conservacionistas esperan anticiparse y así poder prevenir invasiones futuras al identificar y regular especies potencialmente invasoras por medio de las evaluaciones de riesgo de especies y las regulaciones del mercado internacional. Entre las muchas vías de introducción de especies no-nativas, la horticultura es un conductor particularmente importante de invasiones de plantas. En las décadas recientes, la industria de la horticultura se ha expandido mundialmente y ha cambiado su estructura por causa del surgimiento de nuevos medios de distribución, incluido el internet (comercio electrónico). Con el uso de un algoritmo de búsqueda automatizada, realizamos un censo diario del mercado de comercio electrónico en diez sitios importantes de sitios de venta online (incluido eBay) de aproximadamente tres quintas partes de la flora espermatofita mundial. Muchas especies reconocidas de plantas invasoras (>500 especies asociadas con problemas ecológicos o socio-económicos) fueron comercializadas diariamente a nivel mundial en el internet. Una proporción notablemente mayor de plantas invasoras que de plantas no-invasoras estaba disponible en línea. Para una familia particular de plantas, comúnmente se detectaba en un sitio de subastas entre el 30-80% de especies invasoras reconocidas, pero sólo un pequeño porcentaje de todas las especies de la familia se detectaron en un sitio. Las familias que fueron más comercializadas tuvieron una proporción más alta de especies invasoras que las familias menos*

††*Address correspondence to Christoph Kueffer, email: christoph.kueffer@env.ethz.ch*
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comercializadas. Para las especies leñosas hubo una relación positiva significativa entre el número de regiones en donde se vende una especie y el número de regiones en donde es invasora. Nuestros resultados indican que la bioseguridad no está regulando efectivamente el comercio de plantas en línea. En el futuro, el monitoreo automatizado del comercio electrónico puede ayudar a prevenir la expansión de las especies invasoras, proporcionar información sobre la conectividad emergente del mercado a través de las fronteras nacionales, y puede usarse en los ejercicios de escaneo de horizonte para la detección temprana de especies nuevas y sus áreas de origen geográfico en el mercado internacional.

Palabras Clave: escaneo de horizonte, foráneo, internet, invasor, mercado, no-nativo, prevención

Introduction

Biological invasions are a major concern in conservation; especially because global transport of non-native species is still increasing rapidly (Hulme 2009; McGeoch et al. 2010). Conservationists hope to prevent future invasions by anticipating and preventing the introduction of potentially invasive species through species risk assessments and international trade regulations. It appears that in geographically isolated countries such as Australia and New Zealand strict biosecurity measures have reduced the rate of non-native species introductions (Simberloff et al. 2013). But in most countries, including those of the European Union, introduction rates of new non-native species are still increasing (DAISIE 2009; Simberloff et al. 2013).

Early anticipation of future invaders is crucial for the success of preventive measures. For this purpose, risk assessment systems help predict invasion risks of particular species based on knowledge gained from experiences with their invasive behavior in the past (Hulme 2012; Kumschick & Richardson 2013). However, in a time of rapid environmental and economic change, new species are integrated into global trade on a daily basis, and for such species no experiences regarding possible invasive behavior in non-native places exist (Kueffer 2010). Further, invasion opportunities change rapidly due to global change (e.g., climate change), which may favor different functional groups of non-native species in the near future (Walther et al. 2009; Bradley et al. 2010). In mountains, it is, for instance, expected that invasion risks will greatly increase in the near future with the introduction of new non-native species that pose higher risks than those currently present at high elevations (Kueffer et al. 2013*a*). Woody plant species are also considered of increasing importance as invasive species (Richardson & Rejmánek 2011). Thus, insights gained from past invasions might not necessarily be applicable to prevent future invasions (Kueffer 2010; Kueffer 2013). This problem is amplified by time lags between introduction and invasion (invasion debt; Essl et al. 2011). To anticipate future invaders and human activities that might increase invasion risks, it is therefore essential to monitor current introductions and examine them for emerging risk species (horizon scanning) (Sutherland et al. 2014).

Plant species of recent economic importance might turn out to be the invaders of tomorrow (e.g., biofuels) (Richardson & Rejmánek 2011). More generally, socioeconomic changes, such as changes in consumer behavior, economic growth of a country, or structural changes in relevant industries may lead to novel non-native floras and different invasion risks (e.g., McNeely 2001; Dehnen-Schmutz et al. 2010; Essl et al. 2011).

Among many introduction pathways of non-native species, horticulture is increasingly recognized as a particularly important driver of plant invasions (e.g., Reichard & White 2001; Dehnen-Schmutz et al. 2010; Wersal & Madsen 2012). In recent decades, the horticultural industry has expanded globally and changed structurally through growing demand for horticultural products, falling trade barriers, and improved production methods (Dehnen-Schmutz et al. 2010). Among others, there is a trend toward fewer but larger growers, and new distribution channels are emerging, in particular internet trade (e-commerce) (Dehnen-Schmutz et al. 2010). E-commerce has considerable advantages for sellers and customers, but it is a concern for biosecurity (e.g., Derraik & Phillips 2010; Martin & Coetzee 2011; Kikillus et al. 2012). Internet sellers can directly approach a global clientele at low costs. Thereby, e-commerce not only further accelerates the global interchange of live plants or propagules but also bears the risk of bypassing border controls and plant trade regulations, including those aimed at reducing the risk of spreading plant diseases and pests (e.g., Maki & Galatowitsch 2004; Giltrap et al. 2009; IPPC Secretariat 2012).

We monitored global e-commerce of plants to determine how important e-commerce is as a pathway of invasion; whether there is an empirical relationship between the intensity of e-commerce of a particular plant species and whether it is recognized as invasive; and the potential of automated monitoring of e-commerce as a biosecurity tool. We were particularly interested in whether it is possible to identify emerging potentially invasive species before they are widely distributed.

Methods

Data Sources

We developed a software tool that systematically downloaded the information on all internet offers of a pre-defined list of plant species or their propagules in

the category "Flowers, Trees & Plants" on eBay.com. We used eBay.com because it is one of the world's largest online marketplaces. The U.S. site eBay.com was chosen because U.S. eBay sellers are frequently engaged in international trade (Lendle et al. 2013). We examined taxa extracted from the species lists Global Flora and the Invasive Species List. Global Flora is a complete global species list of 23 flowering plant families that together represent approximately three-fifths of the world's spermatophyte flora (assuming a total of 250,000 species [Kadereit & Bresinsky 2013]). We used data from the Kew World Checklist of Selected Plant Families (WCSP 2013) for 21 families and completed it with data for Asteraceae (Global Compositae Checklist [Flann 2009]) and Leguminosae (ILDIS World Database of Legumes [Roskov et al. 2005]) (Supporting Information). We restricted the analysis to 23 families for reasons of data quality (we included only data from families for which review of the data was completed) and global comparability (all selected families had a global distribution). All families except 2 (Begoniaceae, Orchidaceae) included species listed on the Invasive Species List, and they mostly contained a high number of invasive species (Daehler 1998).

The Invasive Species List is a global list of invasive spermatophytes based on data (species names including synonyms, invasive ranges, life forms, human uses) from Weber (2003) and Rejmánek and Richardson (2013). Because these data sets over-represent woody species, we performed some analyses separately for non-woody and woody species.

In total, we searched for scientific species names, including synonyms for genus and species (Aeschimann & Heitz 2005), of 153,394 different plant species. After initial testing, we decided not to use vernacular names so as to avoid false-positive search results.

Data Collection and Analyses

We searched for species offered on eBay.com at 1900 CET on 50 days between February and April 2014 (2 February–19 February, 26 February–21 March 21, 31 March–6 April, and 8 April), and for validation we searched again from 29 December 2014 to 11 January 2015 (Supporting Information). To test the generality of the patterns we found on eBay.com, we monitored 9 additional sellers based in Europe and the United States (Supporting Information). Search hits were treated as valid if the species name was found in the header of an auction site. Although the offers were placed on a U.S. website, species were offered from numerous countries. We collected data on sale offers but could not collect data on actual sales, which would be necessary to reveal the actual flow of traded species.

We determined the location or locations of a species based on the information given in the "item location" field of each offer. Item locations were assigned to 13 geographic regions following Richardson and Rejmánek (2011), except that we treated the Russian Federation as a single region (Supporting Information). Although the region "southern Africa" included all African countries south of 20° S (Richardson & Rejmánek 2011), our data for this region came exclusively from South Africa. To test the validity of our data, we inspected two random offers per search day. Out of 100 random offers, only one was a false positive; it was caused by erroneous product labeling. Statistical analyses were performed using SPSS Version 20 (SPSS, Chicago, IL).

Results

Number of Species Offered on eBay.com

In total 2625 species were offered on eBay.com during the 50 days of our search (2115 from Global Flora, 1.4% of species listed; 510 from Invasive Species List, 39.7% of species listed). A major proportion of the 100 most frequently offered species were ornamentals (64%), sometimes in combination with other uses (e.g., medicine, stimulant) (Supporting Information). Forty-one of the most offered species were invasive; most invasive species were woody species (73%) and ornamentals (75%). Out of the 35 plant species on the list of 100 of the World's Worst Invasive Alien Species (IUCN 2014), 13 were offered on eBay.com and 8 were woody species (Supporting Information).

The average number of offers per day differed considerably among species from Global Flora and the Invasive Species List (global: mean = 317.5 [SD 3456.1]; invasive: mean = 508.4 [SD 664.0]). Cumulative curves (Supporting Information) indicated that a longer search period would likely have yielded substantially more species offered on eBay.com.

Overrepresentation of Invasive Species

Relative to Global Flora, invasive species were significantly overrepresented in plant auctions on eBay.com across all families and for particular families (Fig. 1). The same pattern was found for December 2014 and January 2015 on eBay.com and nine other sellers (Supporting Information). There was a weak positive correlation between the percentage of invasive species per family and the number of offers for all species per family ($r_s = 0.41$, $p > 0.05$, Spearman's rank correlation coefficient). A small fraction of species were offered from some families with many invasive species (i.e., Poaceae, 0.6%; Asteraceae, 0.7%) relative to other families (e.g., Iridaceae, 12.7%).

Geographic Distribution of Plant Offers

Offers for non-invasive species were from 65 countries or overseas territories (Supporting Information), mostly from the United States ($n = 1822$), Australia ($n = 919$),

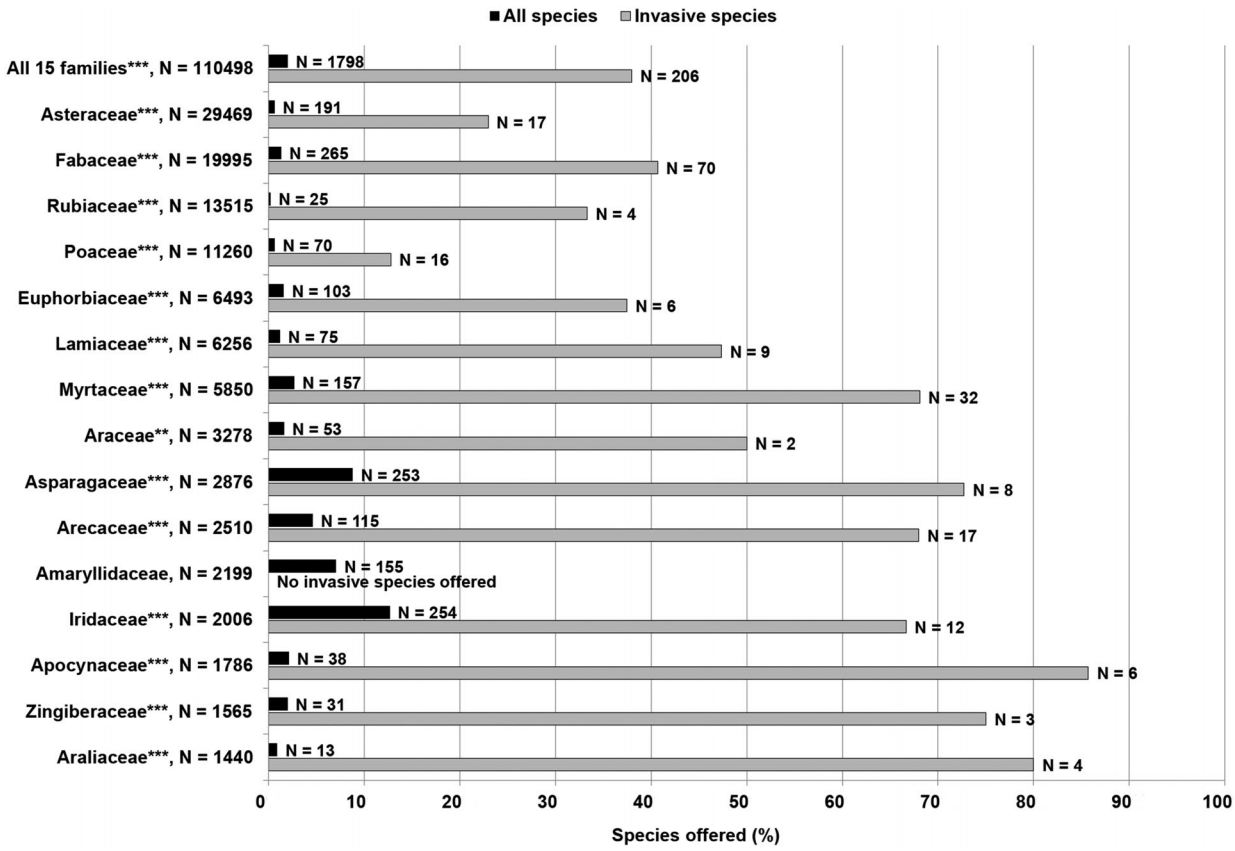

Figure 1. Percentage of species offered on eBay.com in the 15 plant families with the most species in trade (families ordered by total number of species; one-tailed Fisher's exact test, $^{**}p<0.01$, $^{***}p<0.001$; N, number of species).

United Kingdom ($n = 863$), Germany ($n = 472$), Italy ($n = 430$), and South Africa ($n = 412$) (Fig. 2). Regionally, numbers of species were 1837 from North America, 1711 from Europe, 920 from Australasia, 698 from Asia, and 412 from southern Africa (de facto South Africa). Invasive species were offered from 55 of the 65 countries or territories (Fig. 2). Many offers of invasive species were from the United States (413, 81% of all globally offered invasive species), United Kingdom (231, 45%), and Australia (196, 38%). Remarkably few invasive species were offered from South Africa (20, 4%). Most species from Global Flora were sold from one (680, 32%) or 2 regions (892, 42%), whereas most invasive species were offered from 2 (221, 43%) or 3 regions (116, 23%). Only a few species were sold from a higher number of regions, and most of them were invasive species (Supporting Information).

Europe and North America had the most traded species in common (43%) (Supporting Information). These 2 regions also offered many of the same species as Australasia (20%) and Asia (18%). Southern Africa shared many species with Europe (59%), but at most 21% with other regions. The remaining pairs of regions had only 2% or less of their plants in common. Some species were sold from only one region. The fraction of such species was particularly high in Australasia (20%) and southern Africa (34%) (Supporting Information).

In total, we found 387 invasive woody species offered on eBay.com and a significant positive relationship between the number of regions where a particular species was sold and the number of regions where it was an invasive woody species ($r = 0.2$, $p < 0.001$, Fig. 3). This relationship was not evident for non-woody species (Supporting Information).

Discussion

Unabated E-commerce of Invasive Species

We found that international horticultural e-commerce of recognized invasive species is apparently not yet effectively regulated. About 40% of the studied invasive species—including 13 of the world's most invasive plants (Supporting Information)—were offered on eBay.com (Fig. 1), many on a daily basis (Supporting Information) and from numerous countries and different world regions (Fig. 2). Most sellers offered to ship plants to most countries worldwide. Although plant trade through new channels such as eBay.com

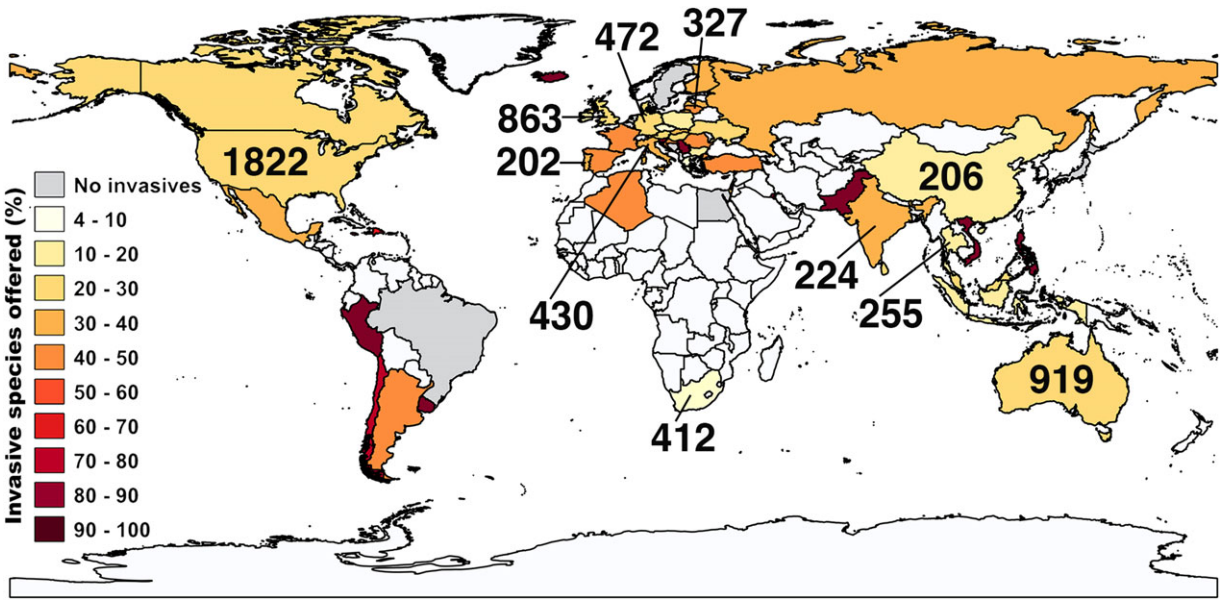

Figure 2. The 65 countries (or overseas territories) where plant species were offered on eBay.com and the percentage of invasive species among those offered (grey, no invasive species; yellow to red, increasing percentage of invasive species). The total number of species sold from a country is indicated when this number is >200.

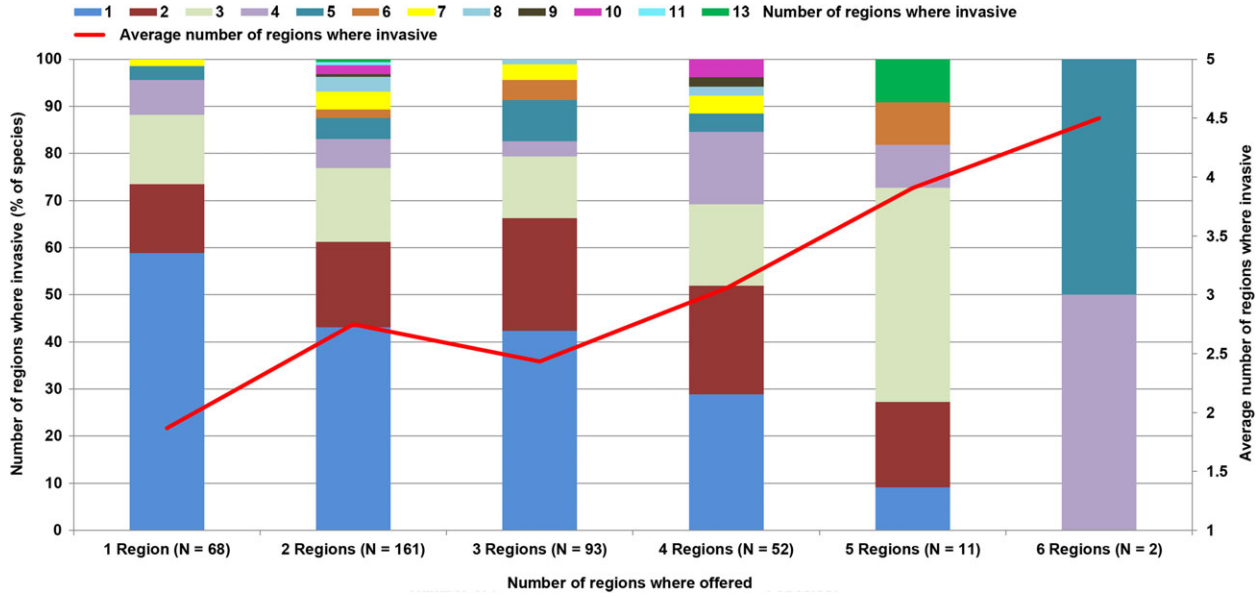

Figure 3. Relationship between the number of regions (total 13) where an invasive woody species is offered on eBay.com (x-axis) (total number of species 387) and the number of regions where species are known to be invasive according to Richardson and Rejmánek (2011) and Weber (2003) (y-axis) (N, number of species offered in the given number of regions). The right axis shows mean across species and the left axis shows frequency distribution (i.e., percentage of species offered in a particular number of regions known to be invasive in 1, 2, 3, etc. regions [color-coded]).

may make up a small proportion of the total plant trade volume, such trade can be particularly difficult to monitor and control due to its heterogeneity, the many small and informal sellers involved, and its dynamism.

To avoid false positive search results, we used scientific names. Further, we limited our search to a single internet marketplace, where data requests were not restricted and where data were presented in a well-structured and consistent way. Therefore, most likely our data represents a substantial underestimation of true e-commerce trade of invasive plants. According to cumulative curves, the number of species found in this study has not reached

saturation. Thus, a longer search period would probably yield many more invasive species offered on eBay.com (Supporting Information). Possibly, different species are offered in other seasons of the year, or some sellers might use vernacular names or synonyms not covered by our search. Further, although eBay.com is one of the largest online markets, it represents only a fraction of global horticultural internet trade and overrepresents sellers located in the United States. More invasive species are likely offered through other eBay domains, other online marketplaces (e.g., Amazon), or directly on the websites of individual horticultural companies. This might also explain why we found so few plant offers from some countries that are major players in global plant trade (e.g., the Netherlands, Columbia, Ecuador, and Kenya) (AIPH, Union Fleurs 2012). Monitoring additional e-commerce auction sites and conducting longitudinal studies would reveal more traded species and help document structural changes in plant trade as a means for early warning and horizon scanning. In any case, the large number of traded invasive species we found clearly demonstrates the importance of e-commerce as a dispersal pathway of invasive plant species.

As global e-commerce increases, the complexity of international plant trade also increases. Online trade offers new market opportunities to sellers and facilitates shopping for consumers. Therefore, e-commerce is expected to contribute considerably to the dispersal of invasive species (e.g., Walters et al. 2006; Papavlasopoulou et al. 2014) and is a major biosecurity concern (e.g., Australian Government 2014). Particularly, import channels or suppliers that are not in the jurisdiction of a regulatory body might circumvent national biosecurity regulations (Giltrap et al. 2009), and ever-new species are available more easily and included more quickly in trade. Further, direct shipment from international sellers to private buyers via ordinary mail may hamper invasive species border control. As a consequence of the growing economic importance of e-commerce, there may be an increase in non-experts in the plant trade who may be ignorant of biosecurity regulations or incorrectly identify their products (Walters et al. 2006; Giltrap et al. 2009). Preventive measures depend on collaborations with professional sellers, but such liaisons may become more difficult due to the diversification and globalization of e-commerce.

Overrepresentation of Invasive Species in International Trade

Invasive species were highly overrepresented in plant auctions on eBay.com. Depending on the plant family, up to 85% of the invasive species in a family were on sale, whereas only a few percent of all species of each family were on sale (Fig. 1). This high fraction is even more remarkable considering that plant trade—and particularly e-commerce—is only one introduction pathway of non-native species. Indeed, families with many weedy species (i.e., ruderal or early successional species that are often introduced involuntarily to new regions, such as Asteraceae or Poaceae) had a low proportion of offered invasive species, and families with a high proportion of horticultural species had a particularly high fraction of offered invasive species (e.g., Myrtaceae or Verbenaceae). Invasive species also tended to be traded from more regions (2 or 3) than non-invasive species (1 or 2 regions). We found a weak correlation between the fractions of invasive and traded species per family, and the more widely an invasive woody species was traded the wider was its invasive range (Fig. 3).

One reason for the overrepresentation of invasive species in e-commerce may be that inclusion in international trade increases the likelihood of becoming invasive (Dehnen-Schmutz et al. 2007). Alternatively, it may also be that commonness in trade may increase the use of plants and thereby their invasiveness. Increased familiarity with widespread plant species (e.g., invasive species) increases people's positive attitudes toward them and decreases perceptions of associated environmental risks (Humair et al. 2014), possibly driving consumers toward buying those species. We did not find the same distribution pattern for invasive non-woody species, possibly because many non-woody species have only recently been included in global trade and are still in the process of spreading or because many herbaceous invasive species are weedy and do not depend on plant trade as a vector. These differences between woody and non-woody species indicate that combining plant trade data with detailed plant functional trait information may help in the prediction of new invasion risks when new species are integrated into international trade.

In contrast to invasive species, only a small fraction of the Global Flora species (approximately 1%) was offered on eBay.com (Fig. 1). Even fewer Global Flora species were offered frequently and from different countries (Supporting Information). We thus documented a global plant-related culture that is highly homogenized and favors some species over many others. Such socioeconomic homogenization of floras is well known in agriculture and forestry, where very few species and varieties make up a major fraction of production (FAO 2010).

Need for More Efficient Biosecurity Policies

We found that despite major efforts, many recognized invasive species are still offered daily on the internet to most countries in the world. Many invasive species were offered in political jurisdictions that consider themselves leaders of invasive species prevention: Australia, United States, and Europe (European Parliament and the European Council 2014; Plant Health Australia 2014; U.S.

Department of Agriculture 2014). Given the resources spent on preventive measures at local, national, and international levels, this might indicate a need to strengthen biosecurity policies. Surveillance of online trade can reveal real-time information on which invasive species are traded and from where, and such surveillance might be used as a new tool to survey trade networks as they become more diverse and complex. We documented only plant offers, not whether trade of these plants actually happened. Such data are sufficient to identify risks (i.e., species that are particularly widely available or new species entering the international e-commerce), but additional data on actual trade would be needed for an estimate of propagule pressure (i.e., number of plants introduced to a region).

The classic model of biosecurity is based on the assumption that a species is transported from a country in its native range to a country that is not in its native range and that this transport can effectively be intercepted at the national boundaries of the recipient country. Our data, however, document frequent offers of invasive species from the non-native range of the species and indicate the possibility of trade in invasive species within national and regional boundaries. Automated online surveillance can help deal with emerging trade connectivity that is not bound to national borders.

We demonstrated that automated surveillance of selected auction sites would be relatively easy to implement, but developing a system that captures a broader range of online platforms would be more complex and require the use of more advanced data mining techniques. Ideally, such surveillance efforts would be coordinated among national and regional (e.g., EU) regulatory bodies and between invasive species and plant health authorities. Legal concerns regarding the violation of data privacy would need to be considered, and an institutional framework would have to be in place that enabled early responses in close collaboration with relevant stakeholders once a new and potentially invasive species is detected in trade.

Horizon Scanning for Emerging New Risk Species

Monitoring internet trade can help identify emergent risk of non-native species invasion early in the integration of a species into horticultural trade (Gibson et al. 2011). It can also detect an increase in introduction intensity of a known invasive species that could trigger new invasions through higher propagule pressure or genetic diversity. For instance, we documented intensive trade of woody species that are increasingly known to naturalize and become problematic invaders in new areas (Binggeli 2001; Richardson & Rejmánek 2011). However, recent changes in plant trade might not yet be manifested in invasion patterns (Kueffer 2010). For instance, the horticultural market in Africa and more generally in tropical countries has been expanding rapidly since the 1990s (Dehnen-Schmutz et al. 2010). In our study, southern Africa offered 412 species, but to date few of these species are recognized as invasive. This might be particularly problematic because the region also seems to harbor a distinct traded flora: one-third of species that occur in South Africa were sold exclusively from there; some of these may become invasive in the future (Essl et al. 2011). It has been observed increasingly that species native to tropical countries are introduced in trade (Dehnen-Schmutz et al. 2010). Therefore, it must be expected that plant families and item locations, such as African countries, that are not yet widely integrated into international trade are currently contributing new potentially invasive species to the international plant trade.

Thus, data on emerging new sources of plant trade can help target preventive measures and be the basis of information campaigns, especially in regions such as Africa, where problem awareness and management capacity is low but horticultural trade is rapidly growing.

A straightforward horizon scanning approach might be to focus on new species integrated into trade from plant genera and families that are known to have a high proportion of invasive species. We found, for instance, 28 *Acacia* species in trade that were not on the invasive species list we used (e.g., *Acacia simplex*, native to New Caledonia and the only species sold from there). However, it must also be kept in mind that the traits of future invaders may differ from those of known invaders (Kueffer et al. 2013*b*). Analyzing social media data may provide further information on changing preferences for particular plants or their traits and on early signs of the novel invasive behavior of species.

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