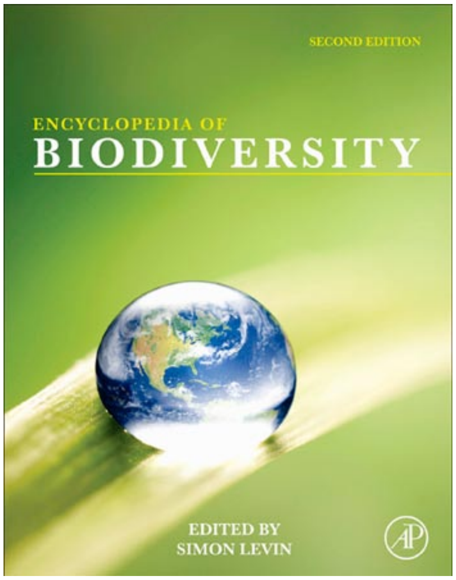

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Globalization Effects on Common Plant Species

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Glossary

Alien species A species introduced from another region or ecosystem.
Globalization The process engaging financial markets to operate internationally, largely as a result of increased trade, transportation, and communications.
Homogenization A blending of species throughout the globe largely as a result of trade and transportation.
Invasive species A species from another country or ecosystem that causes economic or environmental harm, or harms human health.
Native species A species that evolved and is naturally distributed in the region.

Introduction

The trade of goods by humans has bridged the continents, in effect restoring the old supercontinent of Pangaea. In the past century, humans have been responsible for an exponential increase in plant migrations, moving plant species around the globe for food, fuel, forage, horticulture, landscaping, and medicines. Trade within and among continents is breaking geographic barriers and providing long-range dispersal for seeds and propagules at unprecedented rates (Richardson *et al.*, 2000; Wilson *et al.*, 2009). Here, the authors provide a brief review of the globalization effects on common plant species and "homogenization" of the world's plant communities.

It's All About Trade

Globalization is a process that occurs when the trade in goods and service is no longer limited by the physical and administrative barriers that separate countries. Local trading has been a common feature within many cultures. Through human expansion around the globe, increasingly reliable and quick forms of transport, and fewer restrictions on human movement, trade now operates at a global scale. The dawn of long-distance merchant ships in the Minoan, Greek, and Roman civilizations connected Europe, Africa, and Asia. As long ago as 67 BC, the Roman Empire had cargo ships carrying 70,000 kg of grain and other supplies from far and wide (Kessler and Temin, 2007). Indeed, many current invasive plant species in Italy can be traced to early trade. Trade in crops accelerated in the Old World in the mid-eighth to mid-thirteenth centuries AD, with Arab people bringing a range of food items to the Mediterranean. In the New World, Native Americans were trading obsidian, shells, tobacco, maize, squash, and dozens of other plant products.

In the fifteenth to seventeenth centuries AD, the Age of Discovery accelerated the global exchange of agricultural products. Foods such as potatoes, tomatoes, maize, and other agricultural crops, for instance, moved from the New World to the Old World (Crosby, 1972). In the late eighteenth century, the isolated southern-hemisphere continent of Australia was brought into somewhat permanent connection with the rest of the world, when it was established by the British as a penal colony. Since then, over 26,000 alien plant species have been introduced to Australia with periods of high influx over this time (Phillips *et al.*, 2010).

International trade skyrocketed between 1870 and 1913 and after 1950, the volume of world trade merchandise increased seventeen-fold (Flemming, 2004). In the modern day, most of the goods consumed by humans stem from imports (**Figure 1**). As the global economy expanded, so did trade in live plant materials, with ornamental horticulture an important source of introduced invasive plants (Reichard and White, 2001). For example, Maki and Galatowitsch (2004) found that prohibited alien species in Minnesota were acquired in 92% of orders they placed with 34 aquatic plant vendors across the United States. Additionally, 93% of orders contained a plant or animal species not specifically requested, including several additional prohibited taxa. The advent of e-commerce has turned every home and office computer into a virtual port of entry. Live plants and seeds can be mailed to most addresses in many countries.

The comparison between regions with similar climates but with different history of trade may help to elucidate the causes

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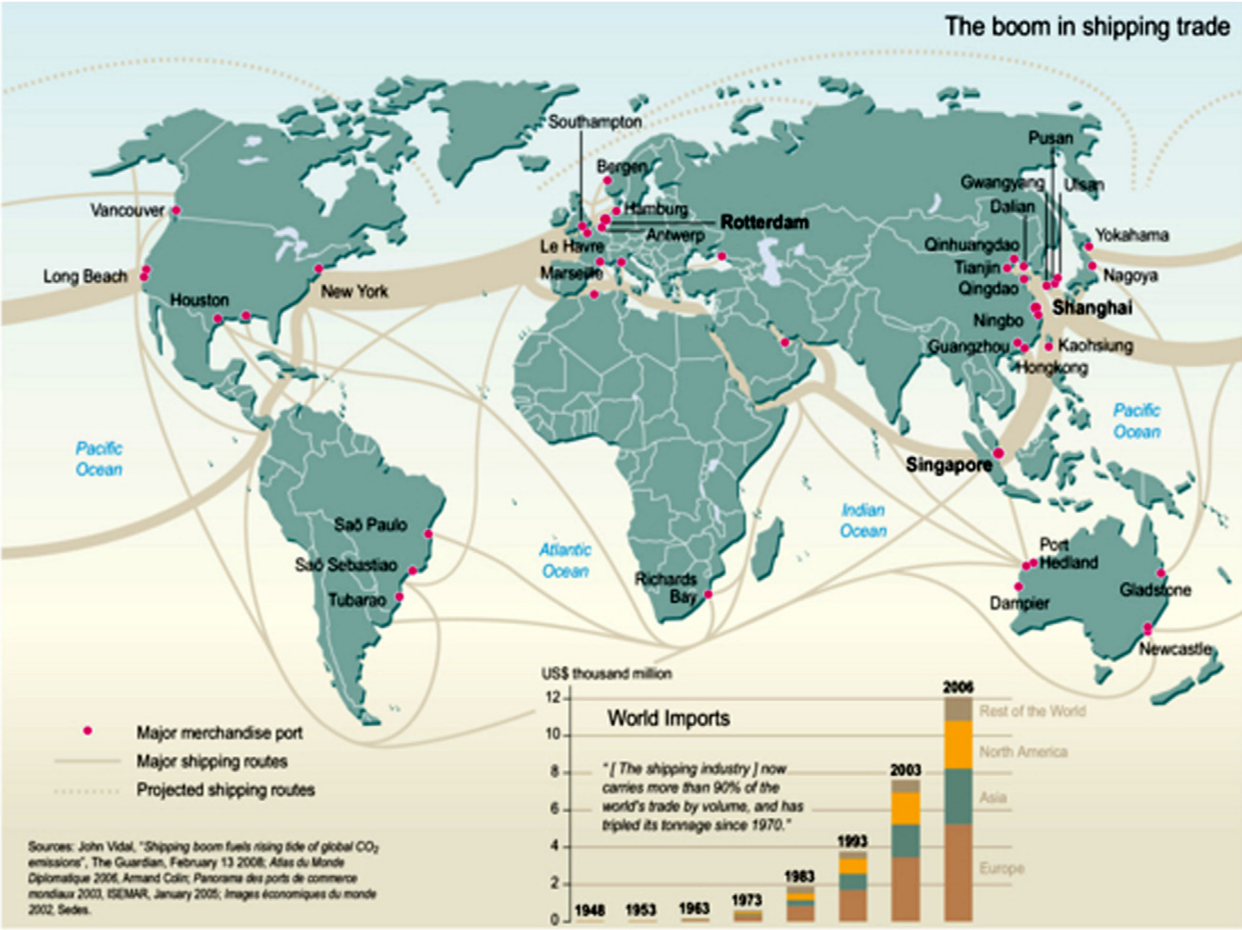

Figure 1 The boom in the shipping trade, reproduced from the website (http://maps.grida.no/go/graphic/the-boom-in-shipping-trade1), and based on John Vidal, ''Shipping boom fuels rising tide of global CO_2 emissions,'' The Guardian, February 13, 2008; Atlas du Monde Diplomatique 2006, Armand Colin; Panorama des ports de commerce mondiaux 2003, ISEMAR, January 2005; Images économiques du monde 2002, Sedes.

of current patterns of homogenization. For example, although central Chile and California share a similar Mediterranean climate, the history of massive introductions in the last two centuries have favored a much more diverse alien flora in California (*ca*. 1200 species) (Jiménez *et al*., 2008). Interestingly, the Chilean alien flora (*ca*. 600 species) is almost completely a subset of its counterpart, including 25 species native to California. Central Chile has a much stronger influence of European species, and because of its higher commercial trade and diverse immigration history, California has a more cosmopolitan flora with a higher proportion of species from Asia, Africa, Australia, and other regions of the Americas.

Homogenization of Biota

Today, plant species from the modern nursery trade often do not stay in their port of entry or primary destination (Reichard and White, 2001). Wind, water, birds, and other animals (including humans), carry propagules to many destinations, where they grow and reproduce. The naturalization of alien species is further facilitated by urbanization, agriculture, and grazing by domestic livestock. The combination of trade, human-caused land use change, and extinction of native species result in biotic homogenization across the globe (Sax *et al*., 2002). Homogenization is defined as the increasing similarity of species composition due to the concurrent extirpation of rare or even unique native species, and the increase of common, widespread alien species primarily due to the effects of modern humans on the rate of change (McKinney and Lockwood, 1999). Generally, local species assemblages lose their uniqueness, affecting also their conservation value (Pino *et al*., 2009; Winter *et al*., 2009). Researchers are just beginning to explore patterns of homogenization at intercontinental and global scales using species frequencies and abundances to provide a more complete view of biotic homogenization (Winter *et al*., 2010). However, in most regions of the world alien invasions exceed regional extirpations, and hence species richness increases (Stohlgren *et al*., 2008).

Uneven Results of Globalization

So to what extent have floras become globalized? The degree to which a flora is composed of alien species has most often been measured by the relative numbers of native and alien species. However, how widespread alien species are in invaded regions is an equally important measure of their success. Recently, a team of scientists from around the world collated the best available data from several countries and regions to see if alien plant species were as widely distributed as native plant species (Stohlgren *et al.*, 2011).

There are, of course, profound differences in how native and alien floras have developed. Native species have had evolutionary time to disperse into the available ecological niches in their respective regions. If alien plant species became equally as widely distributed as native species in a much shorter time, this would indicate that alien plant species and the introduction processes are functioning, in terms of distributional range, in a similar way to native plant species. However, even if this was true, there would still be a principle difference in that these processes would have been operating much faster than in native species, possibly reflecting extraordinary dispersal abilities of aliens and their high competitiveness in colonizing new habitats, for reasons believed to determine the success of alien invasive species (Pyšek and Richardson, 2007). If aliens are more widely spread than natives, this would indicate that part of the invasion process is operating differently to background distributional range expansion and occupancy (i.e., the alien species are different, the environment has changed to favor aliens, or human-assisted dispersal enables aliens to gain wider distributions). If aliens have narrower distributions than natives, this suggests that either aliens tend to not succeed widely across a new range of environments, or that these species have not reached their distributional limits, and that we may only be on the cusp of a homogenization tsunami.

The team of scientists gathered information on the distributions of the 120 most widely distributed plant species in various region of the world, based on their frequency in defined subregions (ecological zones or administrative units) or grid cells (typically 10 km × 10 km). Species were characterized as "native" or "alien," the latter being plant species not native to the biogeographical region or country, having arrived by means of human activities. The initial cutoff point of 120 species was arbitrary, but based on general knowledge of plant frequency distributions (Stohlgren, 2007). The sample sites differed greatly in area and species richness, so they also evaluated the top 120 species in three US states (California, Texas, and Florida), and three European regions (Great Britain and Ireland, the Czech Republic, and Catalonia in Spain) to see if patterns held at smaller spatial extents. What they found surprised them.

First, there were large differences between areas in the percentage of the widespread floral species that was alien (**Figure 2**; Stohlgren *et al.*, 2011). In North America, over half of the most widely distributed species were from other continents, primarily Eurasia. Alien plant species were also well represented in regions of Australia, South America, and South Africa, where they contributed between 22% and 43% to the total number of most widely distributed species, but European regions contained few widespread aliens, <2%, despite thousands of years of long-distance trade in plants. Second, individual subregions in Europe and North America varied considerably in the percentage of aliens on the 120 most widely distributed species lists (**Figure 2**). In subregions, the percentage of aliens can be greater or less than that of the surrounding region. For example, California with 5688 total native plant species had 20% aliens on the list, while Florida, with 3284 total native plant species had only <1% (Stohlgren *et al.*, 2011). Third, the most surprising and consistent finding, was that aliens on the lists were as widely distributed as their native species counterparts, regardless of scale and extent of the study areas. Aliens were significantly more widely

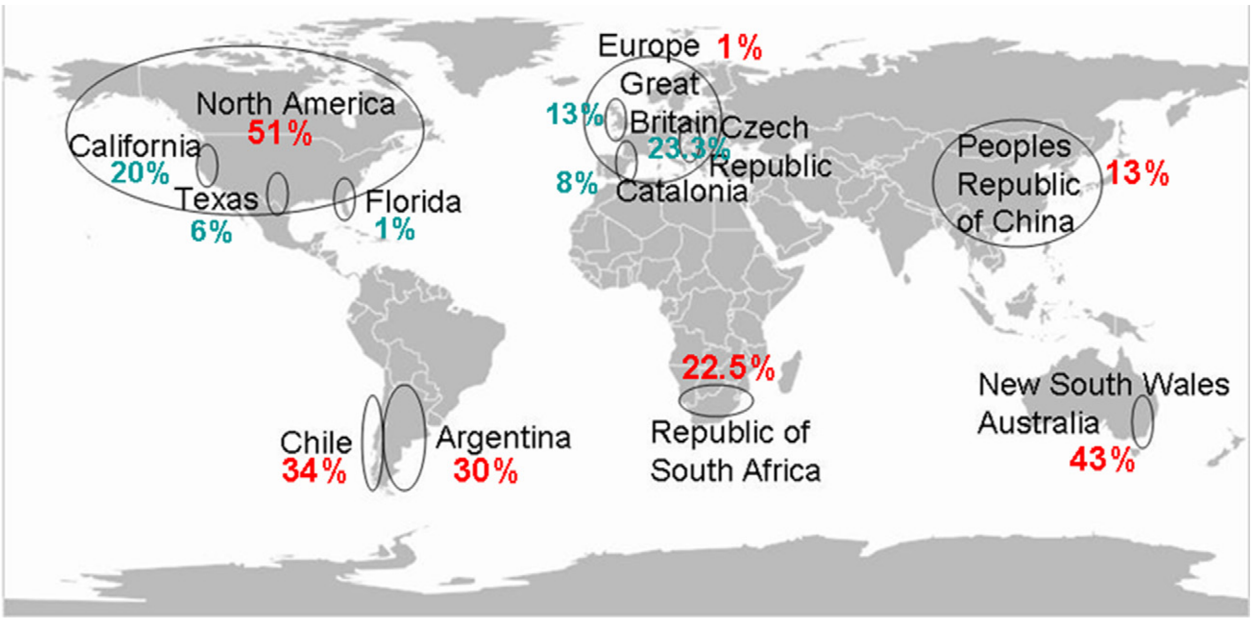

Figure 2 Relationship of percent alien species in the 120 most widely distributed species in a region. Reproduced from Table 1 in Stohlgren TJ, Pyšek P, Kartesz J, *et al.* (2011) Widespread plant species: Natives vs. aliens in our changing world. *Biological Invasions*. doi: 10.1007/s10530-011-0024-9, with permission from Springer.

distributed than native plant species in North America, Argentina, Chile, and the Republic of South Africa, and equally widely distributed as native species in California, Texas, Florida, and throughout Europe.

Donor and Receptor Regions

To evaluate donor and receptor regions for common plants around the world, it is helpful to assess how common plant families overlap across continents. Broadly spread plant families include Asteraceae, Brassicaceae, Poaceae, and Fabaceae. Likewise, many families often overlap between native and alien species within countries or regions. In the aforementioned study by Stohlgren *et al*. (2011), the Poaceae and Asteraceae were more broadly spread in North America, South Africa, and New South Wales (across origin status). The Rosaceae family included widely spread native and alien species in Great Britain and Ireland.

In terms of particular regions, Europe and Asia contributed many species to lists of widely distributed species in the New World (Stohlgren *et al*., 2011). As such, Europe appears to be a better donor than receptor of plant species (Pyšek, 1998; Winter *et al*., 2009; **Figure 2**), while North America proves to be a melting pot of its flora. However, every region on the globe must be considered a potential donor of alien species.

Stohlgren *et al*. (2011) also found many examples of widely distributed species, which help us to understand donor and receptor regions for plants. For example, *Chenopodium album*, contains varieties from Europe (*Chenopodium album* var. *album*) that are now widely dispersed in North America. Likewise, *Cirsium vulgare*, a native species in Europe, is a widely dispersed alien species in other parts of the world. In these cases, widely distributed native species became widely distributed alien species. The scientists also found that some species were more widely spread in their invaded habitat compared to their native homelands. *Senecio vulgaris* ranges broadly in Catalonia, and less so in Great Britain and Ireland, but was widespread throughout North America. Likewise, *Agrostis stolonifera*, a species native to the United States and temperate Europe, was found to be narrowly ranged in Great Britain and Ireland, but less so in Catalonia, and a widespread weed in Chile. However, *Bromus tectorum*, a well known Eurasian invader in North America, did not appear on any other New World lists. Likewise, *Opuntia ficus-indica*, is the most widely distributed alien invader in South Africa, and is now common in Argentina, but is not as relatively widespread in its native Mexico.

Selected Examples

There are many examples of common plant species now spreading around the world. Knowledge of the distributions of native and alien species around the globe provides the opportunity to understand the traits of highly invasive species, and thereby develop effective monitoring and prevention programs against the harmful spread of invasive species. The following examples serve to illustrate the global and continental scales of invasions (**Figure 3**).

Water Hyacinth (*Eichhornia crassipes*)

Water hyacinth is a perennial, free-floating aquatic plant native to tropical regions of South America, and now present on all continents except Antarctica. Plants rapidly increase biomass and form dense mats, reproducing from stolons (i.e., vegetative runners). Water hyacinth can completely cover lakes and wetlands, outcompeting native aquatic species, reducing oxygen levels for fish, and creating ideal habitat for disease-carrying mosquitoes. Large infestations of water hyacinth can prevent river transport, fishing, damage bridges, and clog dams. Lake Victoria, Africa, and the water-ways of Papua New Guinea are prime examples where massive populations have limited transportation and fishing, and increased the incidence of diseases (Masifwa *et al*., 2001).

Within the US, water hyacinth is thought to have been introduced to Louisiana in the 1880s, and released later in the St. John's River in Florida. Enthusiasts distributed it around the world and water hyacinth was naturalized in Egypt, India, Australia, and Java well before the end of the nineteenth century. It is now found across the tropics and in some subtropical countries, for example, New Zealand and Portugal. Despite regional bans on its transport, and various control efforts, it has invaded many new areas particularly in Africa. Water hyacinth is a popular aquarium plant, and can be purchased at many aquatic plant nurseries and online distributers around the world.

Castor Oil Plant (*Ricinus communis*)

Native to Africa and the Middle East, Castor oil plant is a member of the spurge family, Euphorbiaceae. It produces seeds containing between 40% and 60% oil rich triglycerides. The plant is a fast growing shrub or tree that can reach a height of 12 m or more in tropical areas. Today, the plant is widespread in tropical regions of the world, largely as a crop. Castor seed production is around one million tons per year, with major growers in India, China, Brazil, and Ethiopia (www.faostat.fao.org). Horticulturists have created and sold several cultivars as landscaping trees and shrubs, adding to its spread. The seeds of this species, which are commercially widely available, are dispersed by both wind and ants over long distances. Once established, castor oil plant can invade natural areas such as those found in Hawaii, Florida, and elsewhere, creating problems for land managers trying to contain this fast-growing plant.

Alligator Weed (*Alternanthera philoxeroides*)

Alligator weed, native to South America, is an amphibious plant species in the Amaranthaceae family. It has become highly invasive in China, Australia, New Zealand, Thailand, and the United States. Like water hyacinth, it grows quickly to reduce water flow, canopy light, and oxygen levels in the water column, thus reducing habitat quality for various wetland species. However, alligator weed can also invade dry lands and agricultural fields. In the US, it has become a species of great concern in south Texas, and throughout most of Florida. In the US, it has now spread to 337 counties and 15 states, with recent records extending as far north as Virginia and Illinois. It

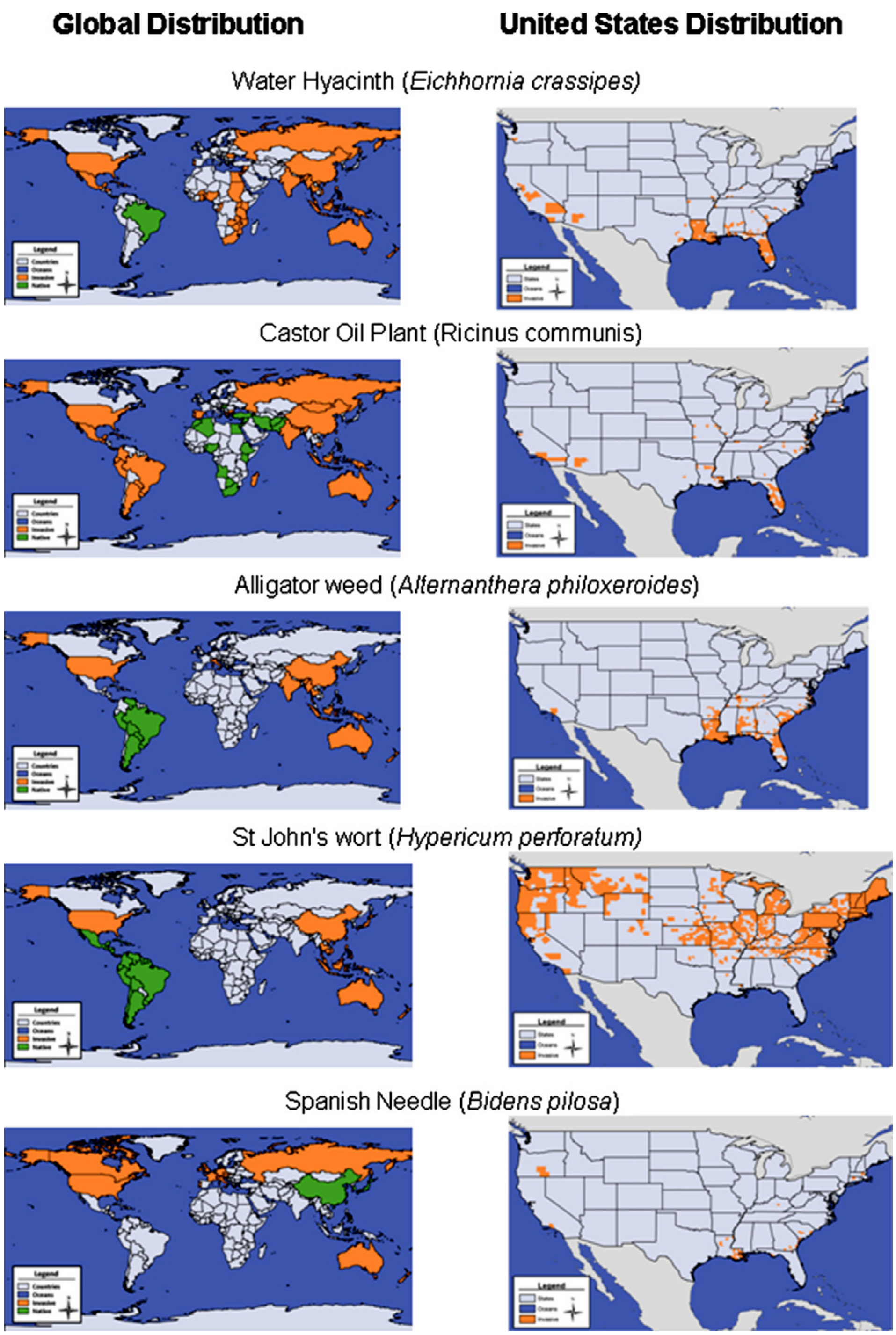

Figure 3 Maps of selected alien species at global scales, and in the United States.

spreads easily as small stem fragments can quickly produce new plants.

St. John's Wort (*Hypericum perforatum*)

St. John's wort is a yellow-flowering perennial herb native to Europe, grows wild in North America, Asia, India, Australia, South Africa, and many islands. It is a member of the Hypericaceae family (formerly placed in the Clusiaceae family), with a long history of human uses including warding off evil, and serving as an antidepressant. St. John's wort is currently treated as a noxious weed in many areas, because high concentrations of hyperforin and hypericin make it toxic to livestock. Throughout the US, populations of St. John's wort can be found in rocky open ground, wooded areas, and meadows. Seeds, which adhere to wildlife and livestock for easy dispersal are commercially available for wildflower plantings.

Spanish Needle (*Bidens pilosa*)

Spanish Needle (*Bidens pilosa*), an annual member of the Asteraceae family, has long been called Hairy Beggarsticks (in the US). The species is native to South America, but it is now commonly established throughout tropical and subtropical areas of the world. It is also common on many islands in the Indian Ocean. Spanish Needle can dominant plant cover in cultivated fields, plantations, and other cultivated and ruderal areas. Considered one of the most noxious annual weeds in East Africa, it invades fields of over 30 crops and is now well established in more than 40 countries (Holm *et al*., 1991). The plant is thought to produce allelopathic toxins that affect a number of crops. The colorful white and yellow flower produces 1.8 cm long barbed seeds that adhere to the legs of humans and other mammals, representing an effective means of dispersal. In some parts of the world, such as in sub-Saharan Africa, the plant is used for food or medicine (Grubben and Denton, 2004).

Giant Hogweed (*Heracleum mantegazzianum*)

One of the most impressive invader weeds of Europe is the Asian hogweed genus (*Heracleum*) of the family Apiaceae. Several members of the genus were introduced as garden ornamentals or as fodder crops outside their native range. The most distinctive characteristic of these closely related species is their conspicuous appearance; they can attain heights of up to 4–5 m, which ranks them among the tallest and largest herbs in Europe. The most widely distributed member of the genus, giant hogweed (*Heracleum mantegazzianum*) produces phototoxic sap, dangerous to humans. The first known record of this species was reported in Kew Botanic Gardens, London in 1817. In 1828, the first naturalized population was recorded in the wild in Cambridgeshire, England. Soon afterwards, the plant began to spread rapidly across Europe; and is currently recorded from 19 European countries. A likely reason for its widespread distribution in Europe is due to multiple introductions, as suggested *via* genetic analysis of invading and native populations of this species. Giant hogweed has a number of characteristics that contribute to its invasiveness: including its extremely high fecundity, rapid growth rate, capability of selfpollination, extended germination period by means of short-term persistent seed bank, high germination, and negligible impact of natural enemies (Pyšek *et al*., 2007).

Implications

For reasons still unknown to us, some geographic areas are more easily invaded than others (Richardson *et al*., 2005). General observations suggest that areas with high numbers of native species are vulnerable to invasions due to high resource availability and high environmental heterogeneity – a pattern that holds up generally well over large portions of the earth from local and regional scales (Stohlgren *et al*., 1999; 2003) to global scales (Lonsdale, 1999). Increasing trade and transportation diminishes dispersal limitations, and increases the number of introductions and species overlap among regions and nations (Pyšek *et al*., 2010). The number and overlap of alien taxa among countries or regions (Stohlgren *et al*., 2011) is a testament to trade and transportation. However, the paucity of widely distributed alien species in Europe remains an aberration. Very few of the 1600 plant species that were introduced to Europe since AD 1500 have become widespread (Lambdon *et al*., 2008). The approximately 11,000 native plant species seem to be holding their ground.

Climate, level of disturbance, time since introduction, and trade volume are often given as reasons for differences in invasion patterns. However, geographic areas within the Peoples Republic of China, North America, and portions of Europe include temperate zones with very different invasion patterns. All these areas are heavily affected by land use change. The early plant invaders in Europe (pre AD 1500) showed that as a group, they are equally distributed despite widely different times since introduction (Pyšek *et al*., 2002; Stohlgren *et al*., 2011). Increased volume of trade and transportation with Peoples Republic of China, a country very rich in species diversity, may create additional future challenges for other countries and regions. Europe, especially its Mediterranean region, has been traditionally considered a donor of invasive species to other parts of the world due to historical reasons and its long association of plants and animals with humans since the beginning of agriculture some 10,000 years ago. This is reflected by the majority alien species on other continents being of Eurasian origin (Pyšek, 1998).

Regional and national plant inventories and databases are essential to understand patterns of invasions. Many areas of the globe may lose their floristic uniqueness as plant species continue to invade. Trade and transportation and changing patterns of widely distributed species will most likely dominate future patterns of biodiversity. We may be witnessing accelerating effects of the great reshuffling of species on the globe as geographic isolation diminishes over time. Human-assisted migrations, and unintentional species establishment followed by natural dispersal by wind, water, and animals may further spread alien assemblages from local to global scales. While the scientific community is making great strides in tracking global invasive species, it might be prudent to begin thinking about the tracking of widely distributed native species as likely donor populations.

See also: Dispersal Biogeography. Economic Control of Invasive Species. Global Species Richness. Human Impact on Biodiversity, Overview. Introduced Species, Impacts and Distribution of. Loss of Biodiversity, Overview. Mediterranean-Climate Ecosystems. Plant Invasions. Species Coexistence. Species Distribution Modeling

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