cropping and grazing systems, but also causes human health problems (allergic contact dermatitis, rhinitis, and bronchitis) and has been associated with reductions in grassland biodiversity in many parts of the world (Navie *et al.* 1998).

Various schemes have been developed to rectify this. For example, a framework proposed by Blackburn *et al.* (2014) builds on a general scheme that considers 12 impact classes for biological invasions in terms of biodiversity (of which *competition*; *hybridisation*; *transmission of diseases to native species*; *parasitism*; *poisoning/toxicity*; *bio-fouling*; *chemical, physical, or structural impact on ecosystem*; and *interaction with other alien species* are relevant for plant invasions). Notably, several of these impacts do not require an introduced species to naturalise, let alone become invasive. This impact classification scheme is similar in format to the IUCN conservation Red List, and is in the process of being implemented as the IUCN Environmental Impact Classification for Alien Taxa (EICAT) Scheme (Fig. 2.3; Hawkins *et al.* 2015). The next step is to develop similar metrics for socio-economic impacts. However, much work still needs to be done to resolve the issues of comparing different populations, ensuring that assessments are mathematically sound, developing predictions, and ensuring that the context-specific nature of impacts is appreciated.

Box 2.1 *Plant Traits Associated with Impact on Native Plant Species Richness (Montserrat Vilà, Rudolf P. Rohr, José L. Espinar, Philip E. Hulme, Jan Pergl, J. Jacobus Le Roux, Urs Schaffner, & Petr Pyšek)*

There has been a considerable amount of research on the particular species traits that might determine why an introduced plant species can establish and become invasive. This information is of great value as it can be used as an important component of risk assessment to screen lists of species for introduction (e.g. for gardening, reforestation, biofuel) to identify those that have the potential to become invasive. The general pattern is that invasive plant species are larger and have higher relative growth and physiological rates than non-invasive plants (van Kleunen, Weber, & Fischer 2010). Are these also plant traits that confer greater ecological impacts on the invaded ecosystem? Not necessarily. It is already well accepted that plant success at different invasion stages from introduction to spread are driven by different factors. Different plant species traits play a significant role in each stage, together

with characteristics of the ecosystem and the history of introduction. As the success of a non-native species to invade and the extent of invasion are not linked to the damage the invader can cause, traits associated with the success of invasion do not need to be associated with traits conferring impact. Moreover, the impact of many well-known successful invaders has yet to be investigated in depth (Vilà *et al.* 2011).

Research on plant impacts has mostly focused on assessing the type and magnitude of impacts of non-native species on native plant populations, on plant community structure, or on a handful of ecosystem processes, such as nutrient cycling (Hulme *et al.* 2013). However, in recent years the first attempts have been made to compile and analyse these studies to provide more generic insights into which plant attributes lead to particular impacts (e.g. Pyšek *et al.* 2012). More recently, we have conducted a meta-analysis based on 155 studies that looked at the effect of non-native plants on plant species richness in invaded communities (Vilà *et al.* 2015). We compared the number of native plant species in plots dominated by a single non-native plant species with paired uninvaded control plots to assess whether the magnitude of impact was dependent on some of the major characteristics of the non-native species and/or the broad characteristics of the invaded site. As the data set accounted for 81 different species from 31 families, we also considered the influence of shared evolutionary history among species. Specifically, we used six categorical variables and the phylogeny of the non-native species as predictor variables. Three of these variables were non-native species descriptors: life form (tree, shrub, perennial forb, annual forb, perennial grass, and annual grass); presence of either clonality or vegetative reproduction (yes or no); and ability to fix nitrogen (yes or no). The three other variables were related to the type of invaded ecosystem (forest, shrubland, grassland, old field, ruderal, desert, riparian, coastal, wetland); biogeographic region (temperate, Mediterranean, tropical, sub-tropical, arid, and semiarid); and insularity (whether the study was conducted on an island or not).

On average we found that non-native plants reduced plant species richness by 20.5%. Of the six categorical variables assessed, clonal growth and N-fixing were the only ones influencing the magnitude of the impact. Clonal plants or plants with vegetative reproduction reduced species richness more than non-clonal plants (Box 2.1 Fig. 1).
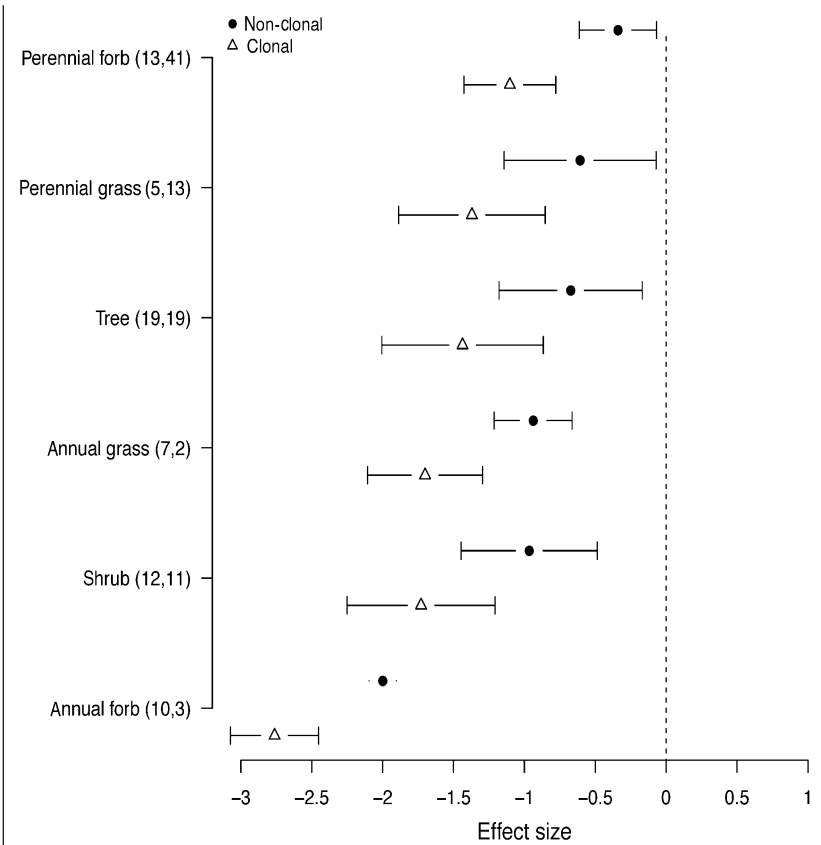
Figure 1. The impact of non-native plant species on native plant species richness. Effect size (±1.96 SE, i.e. 95% confidence interval) is computed as the log-ratio of the number of species in the invaded plot over the control plot. An effect size is significantly different from zero when its 95% confidence interval does not bracket zero. A negative effect size indicates a decrease in plant species richness. Sample sizes for non-clonal and clonal species are indicated respectively in parentheses. Reproduced from Vilà *et al.* (2015) with permission.

In plant invasion biology there has been a lot of emphasis on the impact of N-fixing species on N-cycling (Castro-Díez *et al.* 2014). However, contrary to the general wisdom, N-fixing species reduced plant species richness less than non-N-fixing species. In fact, there have been many cases of N-fixing non-native species (e.g. *Acacia* spp.) not reducing local species richness in all study sites.

The most striking result was the presence of a phylogenetic signal on the magnitude of impact. Closely related species tend to have

impacts of comparable directionality and strength. The cause of this signal is probably due to closely related species sharing traits that might increase competitive ability. Although our study did not precisely identify these traits, our results support the use of information from closely related species to infer potential impacts of an unknown invader in risk assessments.

2.3 Understanding Mechanisms of Invasion and Impact

While such exercises in determining correlates and traits of invasiveness and impact have substantial conceptual interest, and provide a link between ecological and evolutionary theory and invasion science, it is important to keep in mind that the predictive power is still limited. As such, the broad generalisations that have emerged to date have interest for research, but the practical consequence is that either a substantial invasion risk needs to be allowed or unnecessarily restrictive regulations are enacted. If, however, we could understand the mechanisms of invasion and impact, then it might be possible to understand, predict, and effectively manage the risks.

There are several performance-related traits that are directly associated with invasiveness (e.g. physiology, leaf-area allocation, shoot allocation, growth rate, size and fitness (van Kleunen, Weber, & Fischer 2010)), but trait data are not always readily available to risk assessors. However, in some cases a single mechanism can be identified that acts to prevent an invasion (e.g. the presence of herbivores or the lack of a sustaining resource). Once the limitation is lifted, the invasion occurs. For example, certain leguminous species failed to set seed before the introduction of buzz-pollinators to New Zealand (Richardson *et al*. 2000a). The dynamics of a number of plant invasions involve a significant **lag phase** between introduction and invasion, sometimes extending to many decades (Box 2.2; Kowarik 1995; Crooks 2005; Aikio, Duncan, & Hulme 2010b). Any delay presents an opportunity for very effective intervention at a stage when a species is highly restricted in space, but equally there is a risk that resources might be expended to manage a plant that might otherwise never become a significant problem (e.g. the plant population is not in a lag phase, it simply will never expand widely). How to prioritise these species is essentially a risk-management issue (Chapter 4).