20 Invasive alien species: a growing but neglected threat?

Sarah Brunel, Eladio Fernández-Galiano, Piero Genovesi, Vernon H. Heywood, Christoph Kueffer and David M. Richardson

Biological invasions are one of the five major causes of biodiversity loss as global human travel and trade have moved, and continue to move, thousands of species between and across continents. Some species of alien origin have a high probability of unrestrained growth which can ultimately lead to environmental damage.

An alien species — animal, plant or microorganism — is one that has been introduced, as a result of human activity, either accidentally or deliberately, to an area it could not have reached on its own. A common definition of the term 'invasive' focuses on its (negative) impact, while other definitions consider only rate of spread and exclude considerations of impact.

Despite the growing amount of legislation being adopted at the global scale, biological invasions continue to grow at a rapid rate, with no indication yet of any saturation effect. Decision-making in this area is very challenging. The overall complexity of the problem, its interdisciplinarity, the scientific uncertainties and the large number of stakeholders that need to be informed and involved, together demand governance actions that are difficult to see emerging at the regional scale (as in the EU), let alone globally.

It is widely agreed that preventing biological invasions or tackling them at a very early stage is the most efficient and cost-effective approach. Harmless species can be confused with harmful invasive species, however, leading to a waste of resources. Even more seriously, harmful invaders can be mistaken for innocuous species — so-called 'invaders in disguise' — and no appropriate action may be taken to counter the threats they pose.

Even with a very good risk assessment system, new outbreaks of invasive alien species could still occur, necessitating a system of rapid early warning and effective eradication response. The decision on where to draw the line on the acceptable environmental risks versus the introduction of new species or new communities that may carry invasive alien species then becomes a value judgement.

There is lively debate within the scientific community regarding the most appropriate strategies for managing invasive alien species. Governments and institutions charged with making decisions have access to considerable knowledge on the topic, but the lack of rules of interactions between multiple parties regularly thwarts effective decision-making.

20.1 Introduction

Biological invasions are one of the five major causes of biodiversity loss, alongside habitat destruction, over-exploitation, climate change and pollution (Millennium Ecosystem Assessment, 2005). Global human travel and trade have moved, and continue to move, thousands of species between and across continents (McNeely, 2001). Only a small proportion of alien species become established, some of these spread, and a small subset produce major ecological, economic or social effects (generally termed 'impacts'). Ecological impacts include local extinction or a reduction in the diversity of native species, and various types of ecosystem-level changes such as modifications of nutrient cycling or water quality. As an example, in an analysis of 680 recent animal extinctions worldwide, causes were compiled for about 25 % of these. Ninety-one (54 %) included invasive species among the causes of extinction, and in 34 cases they were the only known cause (Clavero and Garcia-Barthou, 2005). For example, feral cats on islands are responsible for at least 14 % of global bird, mammal, and reptile extinctions in recent times (Medina et al., 2011). All types of organism, from micro-organisms, including microbes and diseases, to mega-herbivores, can become invasive, and all can cause impacts on biodiversity and ecosystem functioning. All types of ecosystem are affected: terrestrial, freshwater and marine.

Biological invasions are receiving increased attention in many countries, some of which have already set in place comprehensive legislation or national strategies to deal with various aspects of invasions, in particular concerning their management (e.g. Australia, Great Britain, Mexico, New Zealand, South Africa and USA) (Pyšek and Richardson, 2010). As regards the management of invasive alien species (IAS), it is widely agreed that preventing biological invasions or tackling them at a very early stage is the most efficient and cost-effective approach. For example, the cost of eradicating weeds can increase at least 40 times if action is not taken promptly (Harris and Timmins, 2009), and in most cases eradication quickly becomes unfeasible (Genovesi, 2007). Preventive management calls for a precautionary approach, because prompt response often does not permit full assessment of the risks connected to a newly detected invasion (Genovesi et al., 2010). Despite widespread agreement on these principles, the full range of problems associated with IAS still lacks political recognition and too few government-coordinated actions are in place, or are effective, in most parts of the world, including in the European Union.

There is nevertheless a lively debate within the scientific community regarding the most appropriate strategies to adopt for managing invasive alien species. Aspects of this debate offer important pointers to dimensions that need to be better studied and the measures needed to make the phenomenon of biological invasion better understood by all stakeholders. Invasive alien species represent a growing threat, in particular in a globalised world, as they are introduced and spread by people (McNeely, 2001). This is more a human-driven environmental problem than a strictly biological one. Inherent uncertainties remain about what species will be introduced and which will become invasive. Consequently, making decisions is very challenging. The overall complexity of the problem, its interdisciplinarity, the scientific uncertainties, and the large number of stakeholders that need to be informed and involved, together demand governance actions that are difficult to see emerging at the regional scale (as in the EU), let alone at the global scale. Lessons already learnt in different parts of the world need to be considered when seeking to improve management regimes for IAS in different environments and at different scales.

20.2 The difficulty of defining invasive alien species

The terminology applied to organisms involved in biological invasions is complex, often confusing, and there is no universally accepted definition of IAS (Riley, 2005; Falk-Petersen et al., 2006; Richardson et al., 2011a); all this has serious practical consequences. The term 'alien' (exotic, foreign, non-indigenous, non-native) requires a geographical, biogeographical or ecological context to have a useful meaning — an alien species is one which has been introduced as a result of human assistance, either accidentally or deliberately, to an area it could not have reached on its own. The area in question has to be specified since a species 'may be alien to any definable area, e.g. continents, islands, bio- or eco-regions, or any political entity (e.g. countries, states, provinces)' (Lambdon et al., 2008). The terms alien and invasive both have political overtones. The Convention on Biological Diversity (CBD) requires its Parties, through Article 8(h) to 'prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats and species' and uses the term 'invasive alien species' to refer to such species and defines these as 'alien species whose introduction and/or spread threaten biological diversity'. The term 'invasive' is therefore defined by the CBD in terms of (negative) impact, while other definitions

employ ecological and biogeographical criteria, i.e. invasive species are defined as alien species that sustain self-replacing populations, often in very large numbers at considerable distances from the site of introduction such as in natural areas, and explicitly exclude considerations of impact (see Richardson et al., 2011a; Blackburn et al., 2011 and references therein). Other definitions also include economic impacts, for example on agriculture or the use of amenities, and social impacts such as on human health.

In general, the biogeographical concept is more widely used in the academic world, whereas the impact concept is widely used by decision makers (Ricciardi and Cohen, 2006). Such terminological and conceptual problems have contributed to difficulties in developing a coherent and effective political response to biological invasions.

The amount of information on IAS has grown steadily (Gurevitch et al., 2011) in the last 20 years. Since 2000, when the International Union for the Conservation of Nature (IUCN) Invasive Species Specialist Group (ISSG) established the Global Invasive Species Database (http://www.issg.org/database/welcome/, the first web-based, freely accessible database on invasive species), many tools have been created ([1]). However, partly for the reasons discussed above, accurate and comprehensive information on global or regional numbers of invasive alien species is still difficult to obtain and statistics that are available are often ambiguous and difficult to interpret (e.g. see discussion in Richardson and Rejmánek, 2011). Even taxonomic reference works such as *Floras and Faunas* are notoriously bad at distinguishing between native and alien species (Lambdon et al., 2008). The need for accurate identification is an essential prerequisite for detection of IAS, and many cases of misidentification are coming to light. For example, harmless species can be confused with harmful invasive species, leading to a waste of resources and, even more serious, harmful invaders can be mistaken for innocuous species, so-called 'invaders in disguise' (Verloove, 2010), and no appropriate action taken to counter the threats they pose.

Europe is fortunate in having generally good information about invasive alien species, with many countries having prepared lists, although much more critical evaluation is needed in many cases and under-recording remains a problem. An overview is provided by the DAISIE database (http://www.europe-aliens.org/) and its List of Species Alien in Europe although there are still significant gaps in coverage and distribution and many problems of accurate identification remain to be resolved. For example, even well-known plant invaders such as *Heracleum mantegazzianum* and *Fallopia japonica* are frequently confused with related species, and the invasive hybrids often referred to as *Rhododendron ponticum* have now been named *R.× superponticum* (Cullen, 2011). In other taxa such as the genus *Opuntia* it is often unclear which species are involved in particular invasions, with experts disagreeing, for example, about whether *O. maxima* and *O. ficus-indica* are separate species.

However outside Europe, very few countries have comprehensive, regularly updated lists of alien or invasive alien species. For example, the McGeoch et al. (2010) review of available data on invasive alien species for a set of 57 countries found that the number of invasive alien species varied from 9 to 222, reflecting as much a lack of information as real differences of incidence. Furthermore, because of the dynamic nature of biological invasions, the lists that do exist need regular revision. An example of the difficulties of interpretation is the much-cited paper by Pimentel et al. (2005) which estimates that 50 000 alien species have entered the US. This figure is, however, misleading unless broken down. In the case of plants, the figure of 25 000 alien species (compared with a native flora of about 17 500 species) includes agricultural and horticultural crops, timber and ornamental trees, garden plants, and weeds! In addition, although several countries had compiled lists of alien or invasive alien species by the late 1990s, there is general lack of coordination and harmonisation between these lists. Aggregation of lists developed using different criteria and definitions is a complex task which makes the interpretation of data and the planning of common action difficult and laborious.

20.3 Emergence of awareness of an old problem

The effects of IAS have been known for a very long time. As early as 77AD, Pliny the Elder wrote in his *Naturalis Historia* (The Natural History) that the invasion of rabbits in the Balearic Islands, Spain, was a very severe problem requiring effective control (see Scalera and Zaghi, 2004). In the 19th century,

([1]) See http://www.cbd.int/doc/meetings/sbstta/sbstta-15/information/sbstta-15-inf-14-en.pdf for a very partial overview of main global data providers.

Charles Darwin noted the invasive behaviour of some alien species during his explorations on the *Beagle*. Indeed, Darwin's musing on invasive alien species contributed to the development of his theory of the 'survival of the fittest' (Darwin, 1859). In most cases, however, alien species at that time were regarded as curiosities, rather than a significant threat to global or even regional biodiversity. Concerns regarding the impacts of alien species on native vegetation, particularly on islands (Kiehn, 2011; Kueffer et al., 2010), started to be voiced in the 19th century (Inderjit et al., 2005; Cadotte, 2006). For example, J D Hooker wrote in 1864: 'Among the most interesting phenomena connected with the distribution of plants, are those that concern the rapidity with which some species of one country will, when introduced into another, rapidly displace the aborigines and replace them' (Hooker, 1864). It was not, however, until the 20th century, especially in the second half, that they began to be recognised as a rapidly growing threat to global biodiversity.

A key figure in the history of invasion biology was the British zoologist and ecologist Charles S. Elton (1900–1991) who not only made seminal contributions to modern population biology and community ecology but also set the scene for the emergence of invasion ecology as a separate discipline. His influential monograph *The Ecology of Invasions by Animals and Plants*, published in 1958, set out his concerns about the escalating impacts of IAS on natural ecosystems and the need to conserve species diversity from their adverse impacts. Elton's landmark publication is seen by many as a starting point for the understanding of invasion biology as a distinct field of study, and has been very widely cited (Richardson and Pyšek, 2008), although Kueffer and Hirsch Hadorn (2008) note that the European tradition of research on biological invasions is actually older and is rooted in floristic studies of adventive species in the 19th and early 20th centuries which already considered the role of humans as agents in biotic invasions.

The circumstances in the mid-20th century when Elton formulated his ideas were very different from those of today. The book *Fifty years of Invasion Ecology. The legacy of Charles Elton* documents the radical changes in the extent and nature of invasions since the 1950s and in the ways in which humans perceive and consider managing alien species (Richardson, 2011a). In Europe, in particular, these concepts were slow to manifest themselves widely; for many biologists and conservationists, biological invasions were still perceived as happening 'somewhere else' (rabbits in Australia, water hyacinth in African lakes and waterways, etc). It was not until the last two decades of the 20th century that the significance of biological invasions and the threats they pose to native biological diversity became widely acknowledged at both global and national levels.

An international research programme on the Ecology of Biological Invasions ran in the 1980s under the auspices of the Scientific Committee on Problems of the Environment (SCOPE) (see Drake et al., 1989). This initiative ('SCOPE I') had a strong conservation focus ([2]), and was important in shaping the research agenda on IAS in its framing of the problem and in the core questions that the programme set out to examine. SCOPE I was a global research programme, and collated case studies and syntheses from around the world, thereby providing clear evidence of the global scale of the problem.

Another landmark was the Convention on Biological Diversity (CBD) which entered into force at the end of 1993. IAS was established as a cross-cutting issue and the CBD adopted a set of Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species (COP decision VI/23).

A second SCOPE research programme ('SCOPE II') on IAS was launched in 1997. This was more inter/transdisciplinary than SCOPE I, and considered economic valuation, stakeholder participation, pathway analysis and management (Mooney et al., 2005). SCOPE II was run under the auspices of a consortium of scientific organisations including SCOPE, IUCN, and CABI which developed the Global Invasive Species Programme (GISP), with the explicit objective of providing new tools for understanding and coping with IAS. The report *Invasive Alien Species: a Toolkit of Best Prevention and Management Practices* (Wittenberg and Cock, 2001) gives a good synthesis of the concepts current in the 2000s on biological invasions. In 2011 GISP was closed down, for financial reasons.

In Europe, research on IAS was limited and uncoordinated until the late 1980s. Ambitious research programmes, focussing on risk analysis, inventories and the management of IAS, were launched in the early 2000s, including the EU

([2]) The outcomes of SCOPE 1 were published in a special issue of the journal Biological Conservation, volume 44, parts 1 and 2, published in 1988.

programme 'Delivering Invasive Alien Species Inventories for Europe' (DAISIE; http://www.europe-aliens.org) and 'Assessing Large Scale Risks for Biodiversity with Tested Methods' (ALARM; http://www.alarmproject.net/alarm) to cite only two important European initiatives.

The amount of information on IAS that was accumulating and the need to make it widely available to an audience of managers and scientists led to the development of national, regional and international databases and information systems, web portals and clearing house mechanisms such as the Global Invasive Species Information Network (GISIN) ([3]), the Global Invasive Species Database ([4]), the Invasive Species Compendium (ISC), the Inter-American IABIN Invasives Information Network (I3N) ([5]) for the Americas and NOBANIS ([6]) for North Europe and the Baltic.

20.4 A new discipline with its own approaches and research agenda

The global approach of the SCOPE I project in the 1980s consolidated the recognition of the study of biological invasions as a new scientific discipline. Kueffer and Hirsch Hadorn (2008) reviewed and analysed the state of research on biological invasions, and distinguished different approaches. The research topics have been further divided to make the distinctions clearer, but all these elements have coexisted over time.

The **classical model** of biological invasions that emerged from the SCOPE 1 programme in the 1980s examined case studies of invasions to attempt to answer three main questions: the traits that determine whether or not a species is an invader, why some habitats are more vulnerable to invasion than others, and how management systems using this knowledge can be developed (Drake et al., 1989; Williamson, 1996). During this phase, research on invasions was restricted mainly to population and community ecology, and was based mostly on biogeographic comparisons of invasions, the underlying assumption being that the alien origin of species was important for explaining their behaviour. Despite many studies, and advances on many fronts, no single/common list of traits emerged that distinguish invasive from non-invasive species. The most informative criterion that emerged is that a species becoming invasive elsewhere (assuming that it has had the opportunity to do so), is a powerful predictor of whether that species will become invasive, although this criterion must be used with great caution in a world of rapid global change (Kueffer, 2010).

Invasions were then considered according to the different phases characterising their successive ecological and evolutionary processes. '**Phase transition models**' break biological invasions down into at least the following steps: entry of a species into a new area, establishment after a possible lag phase during which the population size of the species remains small, and spread. Although the idea is older (Usher, 1986), considering invasions as a sequence of distinct phases has become a central piece of biological invasion theory since around 2000 (Richardson et al., 2000; Kolar and Lodge, 2001) and has since guided much synthetic thinking in the field (e.g. Dietz and Edwards, 2006; Blackburn et al., 2011). The development of risk-assessment systems also emerged (e.g. Pheloung et al., 1999). Risk-assessment schemes seek to identify alien species (including those not yet introduced into a territory) that are likely to become invasive, as a basis for preventive measures or prioritised management action. The phase transition model also represents a conceptual basis for a multi-stage management approach involving prevention of entry at borders as a priority, plus early detection and eradication as key responses when prevention fails, or sustained containment and mitigation of impacts as the last option if the former steps fail (Wittenberg and Cock, 2001). Such a model also facilitates taking into account climate and global change.

As a result of SCOPE II and GISP, the **study of pathways of introduction** became an active research area, integrating natural and human sciences, since human activities are the central cause of movement of species (e.g. global trade and travel by rail, road, sea and air, wars, shipping movements and ballast waters, trade in animals and plants, intentional introductions for economic reasons or by tourists, accidental introductions) (McNeely, 2001; Ruiz and Carlton, 2003). A landscape-scale perspective on biological invasions was largely neglected, focusing initially on spatial models of spread, and

([3]) GISIN website: http://www.gisin.org.
([4]) GISD website: http://www.issg.org/database/welcome.
([5]) IABIN website: http://i3n.iabin.net.
([6]) NOBANIS website: www.nobanis.org.

did not became prominent until around 2000 (With, 2002). Such types of study also included the role of land-use change in invasions (Vilà and Ibañez, 2011).

There is now increasing acceptance that biological and social factors interact in complex ways to initiate and sustain different facets of biological invasions (Kueffer and Hirsch Hadorn, 2008), and several studies have in particular highlighted the role of economic factors in the introduction and spread of invasive species (e.g. Kueffer et al., 2010; Pyšek et al., 2010; Essl et al., 2011; Jeschke and Genovesi, 2011). Lately, research on the impact of invasive alien species on ecosystem resilience and ecosystem services has been gaining importance (EFSA, 2011).

Indeed the advances in understanding the mechanisms and the correlates of invasions have had a significant influence on awareness of the issues, and on the development of innovative and more effective response strategies. For example, the recent engagement of European institutions ([7]) to adopt more stringent measures to deal with IAS may also have been helped by an assessment showing that, in addition to the ecological impact, the economic costs of invasive alien species in the region exceed EUR 12.5 billion/year (Kettunen et al., 2009). Furthermore, several assessments have shown the efficacy of eradication of invasives for the recovery of native species affected by IAS at a global scale, with eleven birds, five mammals and one amphibian species having improved their conservation status as a result of the successful removal of IAS (McGeoch et al., 2010). These results contributed to the increased implementation of this management option, with more than 1 100 campaigns being carried out in the world (Genovesi, 2011). However, although some eradications are being undertaken in Europe (e.g. *Carpobrotus* spp. in Menorca or Ruddy Duck *Oxyura jamaicensis* in the United Kingdom, France and Spain), they are uncommon.

20.5 A wealth of initiatives worldwide

Many initiatives focussing on IAS, dealing with legislation, management and communication, have emerged from international organisations, non-governmental organisations, governments and universities across the world. The case of the EU is detailed in Box 20.1. Some are listed below to illustrate their diversity (the listing is in no way exhaustive):

International treaties and agreements

As Riley (2005) notes, at least 42 treaties dealing with environmental issues, the marine environment and international quarantine refer to the regulation of IAS in the world. As regards terrestrial IAS, one of the major treaties is the International Plant Protection Convention (IPPC), setting international standards for phytosanitary measures (although it only covers non-marine invertebrates and plants). The IPPC initially focused mainly on the protection of cultivated plants, but extended its scope in 1999 to include issues relating to wild plants and the environment. The CBD also recognises the need to address invasive alien species in Article 8(h). In 2004, the two Conventions signed a Memorandum of Understanding to avoid duplication of efforts on IAS (Tanaka and Larson, 2006). This required a revision of the glossaries and procedures of the two Conventions for dealing with the analysis of environmental impacts associated with IAS. These organisations have counterparts at the regional scale, and countries are obliged to implement legislation on IAS.

Governments

Governments and parliaments play a major role in preventing the entry and controlling the spread of IAS, in particular through the adoption and enforcement of legislation (both national and international), conducting or financing the eradication of some IAS through appropriate agencies, and promoting research and public awareness of the issue. Within countries, responsibility for the topic is usually divided between ministries of the environment and of agriculture (including farming, forestry, hunting and fisheries, although some aspects may fall within the ministries of health, energy, infrastructure and transport, etc.), with the ministries of agriculture also being responsible for plant and animal health and the associated legislation. Although the environmental and agricultural sectors cooperate at the international level, the mandates are not always clear at the national level. This reflects the fact that pest management (under the plant and animal health regimes) has a longer history than control of invasions, as well as the multiple impacts that IAS may have and the difficulty of categorising these.

Many countries have implemented dedicated legal instruments that relate to the entry and control of IAS (e.g. Australia, New Zealand, USA, South Africa, the United Kingdom), and as a result the number of legal tools has increased steadily in recent decades (McGeoch et al., 2010). For

([7]) See European Commission Environment website: http://ec.europa.eu/environment/nature/invasivealien/index_en.htm).

Box 20.1 Varying European approaches for dealing with IAS

The current situation in Europe is that despite many studies to assess the impacts of IAS, and possible solutions (e.g. Miller et al., 2006), no comprehensive regulation or legislative framework for the EU is yet in place. Partly as a result of the lack of coordinated action, Europe houses a very large number of alien species (around 11 000 according to DAISIE http://www.europe-aliens.org), of which about 10 % (1 094) have ecological impacts and 12 % (1 347) have economic impacts (Vilà et al., 2010). Moreover, many of the invasive alien species of plants and animals that countries spend millions of Euros in managing and controlling can still be freely purchased in some outlets. For instance, the water hyacinth (*Eichhornia crassipes*), which caused spectacular invasions in Portugal, Italy and along 75 km of a Spanish river — which took a few months and 18 million Euros to control (Cifuentes *et al*., 2007) — can still be bought and traded freely in the EU. Another example is the American grey squirrel (*Sciurus carolinensis*) which is known to have replaced the native European red squirrel (*Sciurus vulgaris*) in most of Britain and yet was released in the wild in Italy at three sites, in 1948, 1966 and 1994. Even though the Bern Convention (see below) requested the government of Italy to eradicate the introduced population 'without further delay' and prohibit the trade in the species in 1999, and appropriate plans were made, twelve years later it is still legally offered for sale in pet shops, while the invasive population continues to grow in the absence of any efforts to control or eradicate it (Standing Committee to the Bern Convention, 2011).

Europe has a complex, fragmented and continually developing network of legislative instruments and regulations aimed at prohibiting the introduction and spread of alien species that pose a threat to native biodiversity (Miller et al., 2006). The European and Mediterranean Plant Protection Organization (EPPO) establishes regional standards on phytosanitary measures, and the Convention on the Conservation of European Wildlife and Natural Habitats, generally known as the Bern Convention (1979), commits its contracting parties to a strict control of the introduction of alien species (article 11) and since 1993 has established a working group aimed at supporting states in the implementation of their obligations concerning IAS (see Brunel et al., 2009 for further details). These plant health and environment organisations work closely together, and have, for example, jointly published the *European Code of Conduct on Horticulture and Invasive Alien Plants* (Heywood and Brunel, 2009).

European states have developed national legislation on IAS but often in an un-coordinated manner. For example, Norway has adopted comprehensive and coordinated legislation on invasive species, Germany and Austria are developing a list of regulated species (Essl et al., 2011), the United Kingdom is working on a similar list, Spain adopted legislation in November 2011 which includes a list of regulated species, and Switzerland adopted similar legislation in September 2008. However, given that the regulation of trade in the EU lies within the European Commission, all these efforts will only have limited effectiveness until there is a legal tool that can be applied across the EU. No coordinated legal instrument is yet in place despite the many studies undertaken on the topic, but the European Commission is preparing a dedicated legislative instrument to be ready by the end of 2012 (see European Commission, COM, 2011). However, there will always remain matters that are more appropriately regulated on a national basis because of climatic or other country-specific contexts.

One of the reasons for the lack of a coordinated European approach is that neither of the European legal instruments on nature conservation that deal with IAS — the Bern Convention, covering 45 European States, and the Habitats Directive, applied in all the EU-27 Member States — are very specific on the topic of IAS. They were formulated in 1979 and 1992 respectively, before IAS became a major concern of governments. The Bern Convention simply asks governments to '**strictly control the introduction of non-native species**' and the Habitats Directive requires Member States to '**ensure that the deliberate introduction into the wild of any species which is not native to their territory is regulated … and, if they consider it necessary, prohibit such introduction**', without giving much information on how to deal with the IAS issue as a whole i.e. dealing with the prevention of new entries, pathways, unintentional introductions, containment or eradication of introduced species, early detection and rapid response systems, etc. Although the Bern Convention's 'European Strategy on Invasive Alien Species' (2003) and the European Commission's technical documents produced during the preparation of the EU Strategy on Invasive Alien Species (2011) do contain sufficient guidance for precise government action, they are not legally-binding documents and their application has been patchy. Within the framework of a revision of the Plant Health regime, European national plant protection organisations have identified the inclusion of invasive alien plants having detrimental effects on biodiversity as one of their first concerns (Agra CEAS Consulting et al., 2010).

Europe, no coordinated legal instruments are yet in place, despite the many studies undertaken on the topic, but the EU has committed to presenting a draft dedicated legal tool by the end of 2012, and an assessment of the different legal options was published in December 2011 ([8]).

Countries with national strategies on IAS include Canada (Gouvernement du Canada, Environnement Canada, 2004), South Africa, for the Cape Floristic region (CAPE Partnership Program, 2009), Mexico (Comité Asesor Nacional sobre Especies Invasoras, 2010), the Bahamas, (see Pyšek and Richardson, 2010), and a number of European countries (see Box 20.1).

A few governments have also established large interdisciplinary programmes for dealing with invasive species 2011).

Non-governmental organisations

Non-governmental organisations cooperate in the management of IAS through the preparation of strategic documents and gathering of information, or directly by managing sites to conserve native species and restore ecosystems. The Invasive Species Specialist Group (ISSG) of the International Union for the Conservation of Nature (IUCN) is one of the oldest organisations active in this field ([9]). ISSG has long worked with all the main global initiatives, including SCOPE and the Convention of Biological Diversity, providing technical support for improving the ability to prevent and mitigate the impacts of invasive species on biological diversity.

Other major institutions active in the field include CABI, Birdlife, The Nature Conservancy, Wildlife Conservation Society, and Island Conservation (whose mission is specifically to prevent extinctions by removing invasive species from islands). Across the world, at the national and local scale, thousands of associations or foundations are also involved in controlling IAS, for example in nature reserves.

Universities

Many universities and research institutes across the world are engaged in research on IAS, within the disciplines of biological science, weed science, agronomy, and more recently social science. Dedicated research centres and networks have been created in several parts of the world. Networks of scientists are also very active and organise conferences (e.g. NEOBIOTA, see http://cis.danbif.dk/neobiota2010 or EMAPI, Ecology and Management of Alien Plant Invasions).

Thus, despite the growing amount of legislation being adopted at the global scale, invasions continue to grow at a rapid rate, with no indication yet of any saturation effect (Butchart et al., 2010). In addition to the more than 42 international treaties dealing with environmental issues referring to the regulation of IAS (Riley, 2005), there is much reliance on voluntary codes of conduct which by definition lack sanctions for non-compliance, the latest in Europe being the European Code on Pets and Invasive Alien Species (Davenport and Collins, 2011). None of this is helped by the inherent difficulties of defining and tackling IAS and the consequent continuing confusion and debate over terminology and the lack of an agreed core definition of IAS. It is therefore not surprising that the scientific community recurrently undergoes soul-searching over these issues.

20.6 Obstacles to a common understanding

The issue of the extent to which IAS adversely affect the natural environment has long been a subject of controversy, not just between stakeholders with different interests (e.g. conservationists versus horticulturists/foresters) but also within the scientific community. Dissenting voices periodically challenge the extent to which IAS represent a major threat to biodiversity, and the measures that should be taken (see for example the exchange between Sagoff, 2005 and Simberloff, 2005).

The obstacles to reaching a common agreement about the threats posed and measures needed are reflected in the scientific debates on the topic. Although debates and discussion are inherent to the development of any discipline, too much focus on these controversies can have a deleterious effect. A more extensive discussion of the valuation of invasive alien plants can be found in Larson (2007), Kueffer and Hirsch Hadorn (2008), Hattingh (2011) and Rotherham et al. (2011). Some of the key issues that are a cause of conflicting expert views are reviewed in the next section.

([8]) Document available at http://ec.europa.eu/environment/nature/invasivealien/index_en.htm.
([9]) Founded in 1993, it was the first thematic (as opposed to taxonomic) specialist group of the IUCN SSC to be created. ISSG is a voluntary global network of about 1 000 scientists and practitioners working to mitigate the impacts of biological invasions.

Dissenting voices about the 'pros' and 'cons' of managing IAS

As already noted, IAS are broadly defined according to the negative impacts they cause (cf. the CBD definition and definitions extending to economic impacts). The very definition of IAS along these lines is therefore somewhat of a hybrid, mixing biological elements (a species), the effects on the environment that we are able to detect, and human perceptions of its economic, environmental or social impacts. Assessment of these impacts, specially when considering those on the environment (which in some cases are not easy to quantify or qualify, not to mention the dynamic nature of the environment), are subject to multiple interpretations. The assessments are particularly difficult in the context of a precautionary management approach that builds on an ability to predict potential future impacts. It is widely acknowledged that some IAS can have major impacts and that in these cases it would, in principle, be ideal to prevent these invasions before they happen. However, there are divergences in our perception of how common problematic alien invaders are and whether the alien origin of a species is a reliable heuristic for predicting problematic spread. Davis et al. (2011) question whether conservation money is efficiently spent on preventing the introduction of any new alien species until such species are proved innocuous, as a strict interpretation of the precautionary principle would require. In effect, they highlight the opportunity costs of a strict prevention of introduction of alien species, including the opportunity costs of losing the benefits that some alien species might provide.

The IUCN Invasive Species Specialist Group (ISSG) (2011) responded to these points by explaining that the escalating loss of biological diversity is the motivation for invasive management action on alien species. They also recalled that alien species may not manifest invasiveness till decades after their introduction, and draw attention to species that may only have a subtle immediate impact but which eventually affect entire ecosystems, for example through their effect on soil properties. In addition, invasions and impacts appear to be context-dependent. This is particularly true for plants: for example, while an alien species of cinnamon (*Cinnamomum verum*) has been considered as potentially beneficial for restoring novel mid-elevation forests in the Seychelles, it is a major invader in nearby montane cloud forests (Kueffer et al., 2010). The ISSG (2011) argues that, irrespective of how common problematic invasions of alien species are, prevention is needed because of the huge impacts of the invasions that do happen.

Based on such a perspective, the cost of inaction has been estimated at up to USD 1.4 trillion per year, representing about 5 % of global GDP (Pimentel et al., 2005). Examples are also available for countries: USD 138 billion per year for the US, USD 14.45 billion for China (figure for 2000, representing 1.36 % of Chinese GDP) and over EUR 12 billion per year in Europe. While the cost of inaction in Europe is EUR 12 billion per year, the cost of action is estimated at EUR 40–190 million per year, depending on the possible policy options (Kettunen et al., 2009). The management of IAS is therefore, according to this perspective, considered a very cost-effective investment.

It is not, however, obvious how to decide on priorities and what actions should be taken to address the benefits or harm to native biodiversity, human health, ecological services and economies that species might pose when such benefits and harm cannot be predicted. The solution may come from a pragmatic approach that involves prevention or mitigation of the worst impacts of invasives through a combination of preventive measures, early detection and rapid response to new incursions, with permanent management as only the last option.

The lack of acceptance by society of some management actions

Measures to manage IAS may also be subject to criticism, in particular when they involve the killing of animals, or the use of biological control agents or phytosanitary products (i.e. herbicides or pesticides) (see Boxes 20.2 and 20.3). Opponents of the management of invasive alien plants may also oppose the use of herbicides or pesticides, which they perceive as a bigger threat than the actual impacts of the invasives.

Native vs. alien: a polemical topic to explain to the public

A misunderstanding that is pervasive when talking about IAS lies in not differentiating between invasive species and alien species, as already mentioned above, and using this to justify interventions against alien species in general. While conservation biologists and ecologists refer to the threats from alien species because of evidence that indicates that some of them entail particular ecological and economic risks, some social scientists such as Larson (2007) and Warren (2007) have pointed out the problematic social and cultural connotations of such 'prejudice' against

Box 20.2 The grey squirrel and the ruddy duck: too cute to be killed

A good example of protest by animal welfare groups is the case of the grey squirrel (*Sciurus carolinensis*) in Italy. The two officers in charge of the eradication of grey squirrel were brought to court and charged with cruelty toward animals and illegal methods of capture, despite consultations with animal welfare groups and exercising caution in killing the animals. The legal case delayed the enforcement of any action, ruining the whole eradication campaign, and the grey squirrel is now expected to spread across Europe, with huge impacts on biodiversity as well as the economy of the entire region (Bertolino and Genovesi, 2003; Bertolino et al., 2008).

Another relevant case is the control of the American ruddy duck (*Oxyura jamaicensis*) which escaped from captivity in the United Kingdom and, after reaching a population of several thousand, spread throughout Europe and started to hybridise with the endangered native white-headed duck (*Oxyura leucocephala*). In Spain it threatened the very intense efforts of the conservation authorities to prevent the extinction of the native species. Selective shooting of ruddy ducks and hybrids soon started in Spain, but this was only a temporary measure. Realising that the long-term solution for the Spanish populations of white-headed duck could only come from the eradication of the ruddy duck in the United Kingdom, a European eradication plan was proposed by the Bern Convention and its eradication financed by the UK government and the European Union from 1997. The problem was that shooting attractive ruddy-ducks caused a public and vociferous outcry in that bird-loving country, until the support of the Royal Society of the Protection of Birds for the controls was decisive in getting the project started. That courageous decision cost the society the loss of probably a few thousand members, but by December 2011 the number of birds in the United Kingdom had been reduced to a few hundred and there are good chances of eradicating the species from the wild in Europe by 2015 (Standing Committee to the Bern Convention, 2011; Consulting et al., 2010).

species of non-native origin. Some consider that environmentalists, conservationists and gardeners are 'xenophobic' when dealing with IAS.

Invasive species may indeed be flagged in the press with pejorative names such as 'the yellow peril' for water primroses (*Ludwigia grandiflora* and *L. peploides*) in the south of France. But from a scientific point of view, the focus on alien species is not xenophobic but has a scientific basis (Simberloff and 141 scientists, 2001). The focus lies on alien species not because they are considered unwanted *per se*, but because they show that some species of alien origin have a higher probability of unrestrained growth which can ultimately lead to environmental damage. One reason why some alien species differ ecologically from native species is that they are not subject to the control of natural enemies (diseases, pests, herbivores) that are not present in the newly colonised area.

An even greater difficulty in defining what is 'natural'

The debate on native versus alien goes beyond the species level and touches on the definition of ecosystems and on what conservationists or society decide to protect. The definition of an 'alien' species in an era of accelerated global change is also a challenge. Davis et al. (2011) call for management approaches that recognise that the 'natural' ecosystems of the past have changed forever due to drivers such as climate change, nitrogen eutrophication, increased urbanisation and other land-use changes. They argue that most human and natural communities now contain both long-term residents and new arrivals, and that ecosystems with combinations of species that never existed before are emerging as a consequence of climatic and other global change ('novel ecosystems' *sensu* Hobbs et al., 2006; 'no-analogue ecosystems' *sensu* Williams and Jackson 2007).

These arguments only represent a part of the emerging challenges in the struggle against invasions (Kueffer, 2010). For example, the increasing use of novel alien crops such as those used for biofuel and biomass present a risk of favouring new invasions (Genovesi, 2010; Sheppard et al., 2011); and synthetic biology may in the near future produce still more fundamentally novel species. To overcome the effects of climate change, some authors have proposed translocating native species to areas outside their natural ranges (so called assisted migration (McLachlan et al., 2007) or assisted colonisation (Hunter, 2007; Hoegh-Guldberg et al., 2008): see Seddon et al., 2009; Stanley-Price, 2010), with the possible risk of causing further impact on native species, as in the case of the proposed translocation of the Iberian lynx into the British Isles (Thomas, 2011; Vilà and Hulme, 2011).

Box 20.3 Fear of biological control agents

Biological control is a management method that triggers reluctance in decision makers and the public, though generally supported by scientists if proper and conclusive research has first been carried out. Such caution prevents this efficient technique from being used when IAS are widespread. The mistrust of biological control agents springs from the fear that the agent may not prove specific enough and end up attacking non-target native species, thus aggravating the problem instead of solving it. The public also finds it odd and risky to introduce a new non-native species into a complex ecosystem, particularly in a psychological context of negative feelings towards alien species. Often scientists are not fully trusted either. The use of the lepidopteran *Cactoblastis cactorum* (Pyralidae) to manage the invasive *Opuntia* species that threatens endemic plants in rocky habitats is a typical example that is used to oppose biological control. While the introduction of the Lepidopteran had proved successful in managing millions of hectares of invasive *Opuntia* species in Australia, South Africa and then in Hawaii and the Caribbean Islands, *Cactoblastis cactorum* was then accidentally introduced in Florida where it threatened a native *Opuntia* species (Sforza, 2006). In this case, the potential for accidental spread of the species in areas where it could be detrimental had not been assessed accurately.

Another well-known example of the introduction of a biological control agent that itself became invasive is that of the cane toad (*Rhinella marina*) which was introduced in Queensland (Australia) to control insects that feed on sugarcane and other crops. Cane toads became naturalised and spread, and have detrimental impacts as they feed on many terrestrial animals and compete with native amphibians for food and shelter (Global Invasive Species Database http://www.issg.org/database/species/ecology.asp?fr=1&si=113). In this case, the potential adverse impacts of the species on native fauna had not been assessed accurately.

Even if successful, the method may be susceptible to criticism. The recent release of *Cibdela janthina* in Reunion Island in 2009 to combat the highly invasive plant *Rubus alceifolius* (Le Bourgeois and Della Mussia, 2009) triggered intense debate in the media. Apiculturists and fruit producers feared that the biological control agent would outcompete bees, jeopardising fruit production on the island. The issue even reached the French Senate (JO Sénat, 21/05/2009). After undertaking additional studies and dialogue with stakeholders, it finally appeared that *Cibdela janthina* had no impact on bees, and was efficient at controlling the targeted plant. Many other biological control programmes have proved successful, and the selection of an agent is nowadays carefully studied through formal risk assessment protocols (the same as those used for IAS) that greatly reduce the chance of unexpected behaviour of released species.

At a European level, legislation on the introduction of biological agents is quite stringent, while legislation against the introduction of any other species, including acknowledged invasive ones is non-existent.

In the case of the control of the water hyacinth (*Eichhornia crassipes*) in Spain, mentioned above, the authorities ruled out the introduction of a biological control agent, used successfully in Africa, because of the complex European legislative framework impeding the release of agents.

It should be noted, however, that after extensive research and discussion, the biological control agent *Aphalara itadori* was released in the United Kingdom to control the highly invasive Japanese knotweed (*Fallopia japonica*) whose management and control costs more than GBP 150 million a year. This represents the first classical biological control release against an invasive alien plant in Europe. CABI had carried extensive testing on this insect over the past five years to verify that it can be safely released into the environment. A public consultation was launched: 20 respondents were against the release, 42 in favour (CABI, 2010).

20.7 The limits of governance on the complex issue of IAS

The interdisciplinary nature of the skills required for dealing with IAS is a challenge and can slow action and cooperation. An IAS may, for example, have both environmental and agricultural impacts as well as providing other agricultural benefits. This raises the question of which legislative framework should be in charge. At a macro scale such as the EU, various principles, terminologies and legislative frameworks need to be aligned before any decision can be taken, complicating and slowing the effective application of legislation and management measures. This has been of particular concern in the case of ragweed (*Ambrosia artemisiifolia*). The pollen of this plant is very allergenic, and the species is also a weed in crops,

particularly of sunflower. Discussions on which department — health or agriculture — should deal with the problem has much delayed measures to control the species.

Managing an invasive alien species is difficult not only because of its intrinsic biological characteristics and technical difficulties, but also because of the very many stakeholders that need to be involved for coordinated action. Classical environmental management tools (i.e. habitat protection, liability for environmental damage or mediation in environmental conflicts) prove of little use for IAS. Indeed, before becoming invasive, a species may remain unnoticed in an area for several decades, the so-called 'lag phase'. This can makes the application of a liability approach very difficult, as the traceability of who introduced a species may be lost with time. Environmental mediation that would permit a consensus between conflicting interests about the introduction of a particular species is handicapped by uncertainty in the potential invasive behaviour of an introduced species, as the decision on whether or not to introduce a species needs to be taken far in advance of the species becoming effectively invasive. For example, the potential impacts had not been assessed accurately before introducing the signal crayfish (*Pacifastacus leniusculus*) into Europe. When the Scandinavian fisheries of European crayfish (*Astacus astacus*) were damaged by a crayfish plague, signal crayfish, originating from North America, were introduced to Norway and Finland for recreational and commercial crayfish capture. It turned out that signal crayfish was not only the carrier of the crayfish disease, but it also became invasive, threatening the European crayfish as well as macro-invertebrates, benthic fish and aquatic plants. The species has spread widely and is now out of control (Global Invasive Species Database, *Pacifastacus leniusculus*, http://www.issg.org/database/species/ecology.asp?fr=1&si=725). The species nevertheless has beneficial effects for crayfish production, resulting in a conflict of interest between those who want to control the species and those who want to breed it. Clearly a decision should have been taken long before allowing the introduction of this species in Europe.

These complex and difficult decisions are taken on the basis of risk assessment, which is a time-consuming exercise. Furthermore, even with a very good risk assessment system, new outbreaks of IAS could still occur, making the need for a system of rapid early warning and effective eradication response necessary. The decision on where to draw the line on the acceptable environmental risks versus the introduction of new species or new communities that may carry invasive alien species then becomes a value judgement to be taken by governments. The question of the proportionality of the measures to be taken (allowing the entry of any species versus prohibiting the entry of all non-native species) is very delicate and should involve, in addition to the strategic position of governments, a societal debate. This would imply, in the first place, a good knowledge by the public of the phenomenon and of the impacts of invasive alien species. The stakeholders involved in introducing IAS, and the public who are often responsible for the entry or further spread of these species, both need to be engaged in the debate. Another element of 'proportionality' that makes legislative measures complex lies in the geographical range over which measures should be taken. A species might be a problem only in a given bioclimatic area, but free movement and trade might occur between this area and others, particularly in the free-trade space of the EU. Should this species therefore be prohibited in the whole free movement and trade area, even if it only has detrimental effects in part of it? Such concern is being raised for the development of a European legislative framework on IAS. In other words, should the attractive water hyacinth (*Eichhornia crassipes*), which in Europe may only become naturalised and be invasive in Mediterranean countries, be prohibited from trade in the United Kingdom where it is harmless? The UK nursery industry might like to make use of a plant that does not threaten UK biodiversity, but its introduction, given the free movement of persons and goods within the EU, might compromise management efforts in areas at risk. The question of balance between legislative and voluntary approaches in dealing with IAS is crucial. As many stakeholders are involved, both approaches are needed, the one reinforcing the other.

20.8 Applying the precautionary principle to invasive alien species

Because of the lack of robust criteria for predicting invasiveness, and because most research on biological invasions assumes that alien species are 'guilty until proven innocent', rigid application of the precautionary principle in managing biological invasions is problematic in the context of free-trade agreements. New Zealand, for example, requires that every species imported to the country is assessed for risks, and only if found to pose a low risk can an authorisation be issued. Some countries, however, regulate the introduction only of species

on a list of 'unwanted' invasive or potentially invasive species ([10]). This approach is also proposed by the International Plant Protection Convention (IPPC).

Another way of applying the precautionary principle, while not preventing the entry of IAS, is to eradicate new invaders in a timely manner. The case of *Caulerpa taxifolia* is a good illustration of a missed opportunity to undertake early action in Europe. The alien alga was detected in France in 1984 at a very early stage of invasion, and could have been quickly removed. However, the management of *C. taxifolia* only started when it had already expanded to a large portion of the Mediterranean, when eradication was no longer possible. When the same species was recorded in California in 2000, eradication started only 17 days after its discovery, leading to its successful removal (Genovesi, 2007).

The precautionary principle is the first of the CBD's Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species ('The Guiding Principles' Annex Decision VI/23 ([11])) (see Cooney, 2004). It is applied to some extent by the IPPC, when considering all sources of uncertainty in performing a pest risk analysis. Biosecurity is a very dynamic field of research that seeks to integrate the latest techniques and concepts in its methods to assess risks: the modelling of a species' potential area of establishment, pathway analysis, etc. Such techniques face the challenge of identifying species that may be invasive, and also those that may be invasive under novel conditions created by climate change and/or other facets of global change. Approaches for addressing such situations are being developed, such as consideration of the impacts of IAS on ecosystem services through the elaboration of different scenarios (EFSA, 2011; Chytrý et al., 2012).

20.9 Addressing invasion pathways: a late engagement with the stakeholders

A pathway for engagement: Codes of conduct

Managing IAS now consists of placing more emphasis on pathways of introduction of IAS, as well as identifying the stakeholders involved, although such aspects have been adopted quite recently considering the history of the discipline. This has shifted the focus away from preventing particular species to managing risks associated with introduction pathways, including the human activities that create, shape and sustain such pathways (Wilson et al., 2009; Richardson, 2011b), involving local knowledge. Researchers in the social sciences have become interested in exploring perceptions of alien and invasive species and their impacts (Menozzi, 2007; Andreu et al., 2009; Kueffer and Hirsch Hadorn, 2008; Javelle et al., 2010). Cooperation with stakeholders involved in introducing and disseminating IAS is becoming increasingly common.

For invasive alien plants, the horticultural trade is the primary invasion pathway (Reichard and White, 2001; Dehnen-Schmutz et al., 2007; Drew et al., 2010; Richardson and Rejmánek, 2011). As a response, some countries have prepared voluntary codes of conduct or good practice for the horticultural industry, for example the United States (Fay et al., 2001) and Europe (Heywood and Brunel, 2009). Such approaches have so far had limited effectiveness and buy-in (Drew et al., 2010), although 12 European countries report initiatives related to the implementation of a code of conduct on horticulture and invasive alien plants. The effectiveness of such voluntary codes depends largely on how well they are promoted (Dehnen-Schmutz and Touza, 2008; Brundu et al., 2011); this requires continuing communication and dialogue with the stakeholders (Gibbs, 2011). When developing this code of conduct in Europe, the International Association of Horticulture Producers (AIPH) was involved in the drafting of the document. For the specific case of invasive alien plants, the industry cannot be seen as preventing legislation from happening, and although playing its role in challenging the issue, it has been collaborative in considering that if some species present a problem, then some alternative can be found.

Pathway approaches are also emerging in the field of plant health. It is increasingly considered that a species-by-species regulatory approach relying on inspections is more and more difficult in today's markets context. As a consequence, the forest entomology and pathology science communities recommend a pathway approach for regulating nursery stock, similar to that adopted for wood packaging material. This is based on the principle that best management practices that effectively

([10]) Such lists used to be called 'Black lists', but such a term is now not considered politically correct.
([11]) See http://www.cbd.int/decision/cop/?id=7197.

prevent known IAS will significantly reduce the risk of also introducing unknown pests. In this regard, the IPPC is developing an international standard for plants for planting (see the UK Forestry Commission website: http://www.forestry.gov.uk/fr/INFD-6YUJRD).

Other initiatives to prepare codes of conduct involve botanical gardens (see Heywood, 2011 for Europe; Fay et al., 2001 for the US), the pet industry, hunting, recreational fishing, zoos and aquaria, aquaculture, marine ballast waters, commercial forestry and other sectors.

Stakeholders: what forces lie behind action and inaction?

Scientists and experts have been active in communicating the dangers of IAS for biodiversity — although not necessarily in the most coherent way, as most scientists are not trained in public relations or communication. Dissenting views have probably had little influence on government decisions on IAS, where the consensus is now that this is a serious problem requiring some degree of attention. Other interest groups have been silently watching the growing interest in IAS with much attention and a degree of reluctance. This includes not only animal welfare activists, alarmed at the possible eradication of animals, but also industries and lobbying groups, for whom restrictions on the trade of some species would hinder or complicate business. Horticulture would have to change its current practices substantially if serious measures to avoid new introductions were put in place. But as they feel that their industry is part of the environment business, they do not want to be seen as environmentally unfriendly. A number of other stakeholders who deal with animals and plants may not welcome restrictions, i.e. foresters, the pet trade, aquaculture, recreational fishing and, to a lesser extent, hunters, zoological gardens, aquaria and botanical gardens. Many of these groups are generally aware of the problem and display in general a cooperative attitude with governments and scientists, but prefer a voluntary approach with agreed codes of conduct to hard laws. The industry may also be divided in some cases. While few businesses are in favour of more bureaucracy, some think they might be at a disadvantage compared with those who decide not to apply codes and therefore that legislation would be fairer. The pet industry is more favourable to a voluntary approach and has been actively engaged in the drafting of a European Code of Conduct on Pets and Invasive Alien Species. It would certainly not welcome some mandatory regulations, for instance any relating to the shipping of all pets, as these would increase costs and imply new complex procedures and operations. Yet it is clear that responsibility for the introduction of many invasive species lies partly with the industry and its activities, although it is also a consequence of the slowness of governments to take action or introduce legislation.

20.10 Lessons learnt on invasive alien species: towards more transdisciplinarity in a rapidly changing world?

During the past few decades, we have acquired greatly increased awareness of the extent of biological invasions, the impacts they have on biodiversity and the economy, and a much better understanding of how to prevent and manage them. Faced with the uncertainties posed by a rapidly changing world, we need to learn lessons from this large body of experience so as to avoid further losses.

Biological invasions currently interest a large and growing body of people, including researchers and students in academic institutions, conservation agencies and NGOs, civil servants, park managers, activists, volunteers and a growing number of concerned citizens in many parts of the world. This network of people, interests and perspectives has assembled over the past 30 years worldwide. The 'game rules' for interactions between different parties are still being defined, tested, and debated. Governments and institutions charged with making decisions have access to considerable knowledge on the topic, but the lack of rules of interactions between multiple parties regularly thwarts effective decision-making. Governance of IAS needs to be achieved before the introduction of species, which means dealing with uncertainties and setting a level of protection. Lessons can, nonetheless, be learnt that could pave the way to more effective interaction and communication between parties, which should result in more effective and transparent decisions. Some of these lessons are late ones (EEA, 2001).

Align concepts for a better understanding by society and public engagement

Public understanding of the threats posed by IAS is fundamental for effective governance. Occasional divergence of opinion among experts in the field of biological invasions may weaken public confidence in the advice of 'experts'. Rather than talking with one voice to the public and insisting on convergent opinions, it is more important to ensure that different opinions are made clearly understandable and transparent to the public and decision makers.

In the historical framing of the phenomenon of biological invasions (see above), it was assumed that the problem could be solved by identifying the biological traits of potentially invasive species and preventing their introduction to new areas. Fifty years of research have shown that the identity (alien or native) and traits of the species are indeed highly relevant, but it has become increasingly obvious that other factors are also involved (e.g. propagule ([12]) pressure, habitat factors, land use). In particular, several studies have shown that biological invasions are strongly correlated with economic factors (Essl et al., 2011; Jeschke and Genovesi, 2011; Pyšek et al., 2010). A comparison of plant invasions on oceanic islands highlighted the fact that economic development (measured as gross domestic product) is the most important predictor of invasive species richness on islands (Kueffer et al., 2010). Human activities are an essential factor in the understanding and solution of the IAS issue, so that public engagement is vital if we are to adopt effective measures and ensure good governance.

Harmonise concepts for improved coordination of on-the-ground actions

The lack of clear and common concepts and definitions of IAS has led to serious problems in obtaining reliable information on species involved in biological invasions and has undoubtedly hampered the development of detailed databases. This is a key element to be addressed when considering ways of strengthening strategies for the management of IAS. This is indeed one of the reasons why some countries do not have a comprehensive list of alien or invasive alien species and is exacerbated by the fact that some countries do not appear to be aware of the extent or seriousness of biological invasions. Another cogent reason is the dynamic nature of biological invasions, so that existing lists need to be regularly updated, requiring budgets and trained staff. A better connection between science and management would help increase and improve policy and legislative action. Initially, most research questions were disconnected from management concerns, and arose from the issues of population and community ecology (Kueffer and Hirsch Hadorn, 2008). Also, impacts were considered without explicitly clarifying the broader human and economic context, and it was often assumed that any detectable effect of an alien species on an ecosystem would be undesirable (Kueffer and Hirsch Hadorn, 2008). Researching global concepts may have hindered the provision of concrete and simple actions. With time, the study of biological invasions has become much more interdisciplinary, and links to management agencies have strengthened. The valuation of costs and benefits associated with alien species (including IAS) and their management has become an important research focus (Kueffer and Hirsch Hadorn, 2008). Consequently, the problem of IAS, initially recognised and brought forward by scientists, is now being more firmly rooted in civil society (e.g. NGO groups).

A late lesson not yet learnt: take account of wider social interests and values

As mentioned in *Late lessons from early warnings* Vol. 1 (EEA, 2001), 'taking account of wider social interests and values' has been overlooked when dealing with IAS. Further social studies are needed to understand human perceptions of biological invasions, so as to eventually adapt the concepts and reconcile diverging opinions between experts and stakeholders. It has for example been shown that the alien origin of a species is of minor importance for stakeholders, while the role that humans play in the spread of a species, its aesthetic and cultural value, or personal experiences with the impacts and management of a particular invasive species in a specific site, are of high importance in their valuation (Bardsley and Edwards-Jones 2007; Bremner and Park, 2007; Gobster, 2011; Selge et al., 2012). Additional care and thought must also be given to the language used in communicating on the topic (Larson, 2010; Hattingh, 2011). For problems associated with IAS, it is crucial to involve all stakeholders, including those who introduce species and members of the public who have divergent ideas about the species. Identifying the pathways of introduction of the invaders and implementing any regulations that affect these demands ongoing dialogue with stakeholders (e.g. in formulating codes of conduct), which, to be effective, should be undertaken at an early stage. It is important to recognise that sociological aspects are very important in addressing this problem, and some of the research questions still need to be explored and the results acted on, such as personal attitudes to IAS and those of interest groups such as animal rights groups.

Another late lesson: avoid paralysis by analysis

Much progress has been made in enhancing the consistency and transparency of protocols for (pest) risk analysis and cost-benefit studies, such as research undertaken for the PRATIQUE project at the European scale (see EPPO, 2011). Such progress in evaluating the risks that species pose has become

([12]) A propagule is defined as any plant organ or part, as a spore, seed or cutting, used to propagate a new plant.

increasingly sophisticated and multidisciplinary, bringing together zoologists, botanists, managers, policy makers and economists (Hulme, 2011a). However, despite the significant advances in predicting the risks related to species introductions, the complexity of the relationships between the many potential explanatory variables still limits the precision of current risk assessment tools (Hulme, 2011b). In addition, the discipline known as 'biosecurity' ([13]) which encompasses all aspects and measures that deal with the prevention of pests will also need to address the emerging challenges of a changing world.

A specific lesson for Europe which concerns the need to act without waiting for coordinated European action is presented in Box 20.4.

Anticipate further challenges and 'blind spots' in a changing world

Kueffer and Hirsch Hadorn (2008) suggest that biological invasions represent a complex societal issue because knowledge is highly uncertain, and because conflicts of interest and values are central to the problem. A wider and more intense debate is expected on options for preventing and managing invasions, and on how to deal with the risks related to novel approaches to conservation and the economy such as biofuel crop planting and managed relocation. Contextual factors are amplified through the global changes that we are currently witnessing: climate change, habitat change, land-use change, etc. Consequently, criteria currently used to consider the invasive behaviour of a species in particular areas are likely to be increasingly challenged (Kueffer, 2010). For example, in montane areas, future invaders may be mountain specialists directly introduced through human activity between high-elevation habitats, rather than the current situation where most invaders of montane regions are climatically plastic species that spread from lowlands (McDougall et al., 2011). As already described, increasing interest in 'novel ecosystems' (Hobbs et al., 2006) as well as novel crops, and in radical conservation measures such as managed relocation, pose new challenges for nature conservation which will demand in-depth discussion.

Box 20.4 A lesson for Europe: do not take the need for European coordination as an excuse for inaction

A particular problem for Europe has been the long time taken by European institutions to propose coordinated stringent measures to control the introduction, trade and spread of IAS and to promote eradication or containment measures. It is likely that a dedicated legislative instrument will be prepared before 2013, to be implemented in the following years, but 2013 is twenty years after scientists alerted governments to the dimension of the problem and the growing risks to European native biological diversity from IAS. During that time the problem has grown worse. Many governments were reluctant to pass legislation on the grounds that the free movement of goods in the EU did not permit them to restrict the import of alien species that might threaten their native biodiversity through national laws. This remains a doubtful claim, as a few European governments did not hesitate to take that step. However many European governments have been slow to act.

As environment is a competence of the EU and resources are scarce, some EU states, when fixing their priorities for conservation action, pay a greater attention to the legal requirement for implementation of EU legal instruments and tend to pay less attention to other issues not specifically covered by European legislation, including much-needed action on IAS. Although the 1992 EU Habitats Directive contains obligations on the introduction of IAS and the European Commission has since the late 1990s invested substantial funds on research, data gathering and eradication operations, government awareness of the need for a more stringent legislative instrument has only come since the growing economic and environmental costs of invasive species have become difficult to ignore. The problem is complex, awareness only relatively recent, government interest limited, and public resources scarce. Hard times for native species!

([13]) The FAO notes that 'Biosecurity is a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risks in the sectors of food safety, animal life and health, and plant life and health, including associated environmental risk. Biosecurity covers the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and management of invasive alien species and genotypes. Biosecurity is a holistic concept of direct relevance to the sustainability of agriculture, food safety, and the protection of the environment, including biodiversity.' http://www.fao.org/biosecurity.

Do not allow philosophical debates to create blockages in tackling the problem

Biological invasions occupy a position between 'nature' and 'culture', as they have both biological and social aspects. While many problems that affect biodiversity directly relate to human activities (destruction of habitats, pollution), issues related to IAS are 'nature threatening nature' through human activities, making the role of humans difficult to unravel. This is particularly true in Europe, where ecosystems have been modified since prehistoric times. Such uneasiness sends us back to the classical argument 'it is natural therefore it is safe'. The emerging questioning of IAS reflects the difficulties inherent in defining what nature is and how to protect it, in particular in a context of climate and global change. Global change will increasingly challenge current assumptions and concepts relating to biological invasions. The risk of invasion should be perceived not only as coming from alien species, but rather as a socio-ecological phenomenon in which our perceptions about how humans move species and manage land are considered as a whole (Kueffer, 2010). The response to invasions therefore needs to take into account the human dimension, combining the need to consider the rapidly changing patterns of our society with the urgent need to respond to the threats posed by invasive species.

Table 20.1 Early warnings and actions

77 AD	Pliny the Elder wrote in his *Naturalis Historia* that the invasion of rabbits in the Balearic Islands, Spain, was a very severe problem requiring effective control
1830s	Charles Darwin noted the invasive behaviour of some alien species during his explorations on the *HMS Beagle*, which contributed to the development of his theory of natural selection
1958	Publication by the British zoologist and ecologist Charles S. Elton of his landmark monograph *The Ecology of Invasions by Animals and Plants* which is seen by many as a starting point for the understanding of invasion biology as a distinct field of study
1980s	International research programme on the Ecology of Biological Invasions by the Scientific Committee on Problems of the Environment (SCOPE I) which was important in shaping the research agenda on IAS and led to an explosive growth in invasion biology
1993	Entry into force of the Convention on Biological Diversity (CBD) and of its Article 8(h) on invasive alien species, requiring parties to: Prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species. Establishment of the IUCN SSC Invasive Species Specialist Group, first interdisciplinary specialist group of IUCN
1997	Launch of a second SCOPE research programme ('SCOPE II') on IAS, which was more inter/transdisciplinary than SCOPE I, and considered economic valuation, stakeholder participation, pathway analysis and management. SCOPE II was run under auspices of a consortium of scientific organizations including SCOPE, IUCN, and CABI which developed the Global Invasive Species Programme (GISP), with the explicit objective of providing new tools for understanding and coping with IAS
2002	Adoption, by the Convention on Biological Diversity (CBD) of Guiding Principles for the Prevention, Introduction and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species (COP decision VI/23)
2000s	Development of national, regional and international databases and information systems, web portals and clearing house mechanisms such as the Global Invasive Species Information Network (GISIN) ([a]), the Global Invasive Species Database ([b]), the Invasive Species Compendium (ISC), the Inter-American IABIN Invasives Information Network (I3N) ([c]) for the Americas, DAISIE ([d]) for Europe and NOBANIS ([e]) for North Europe and the Baltic

Note: ([a]) GISIN: http://www.gisin.org.
([b]) GISD: http://www.issg.org/database/welcome.
([c]) IABIN: http://i3n.iabin.net.
([d]) DAISIE: www.europe-aliens.org.
([e]) NOBANIS: www.nobanis.org.

References

Agra CEAS Consulting, Food Chain Evaluation Consortium (FCEC), Civic Consulting — Agra CEAS Consulting, Van Dijk Management Consultants — Arcadia International, 2010. *Evaluation of the Community Plant Health Regime*, European Commission Directorate General for Health and Consumers.

Alyokhin, A., 2011, 'Non-natives: put biodiversity at risk', *Nature,* (475) 36.

Andreu, J., Vila, M., Hulme. P.E., 2009, 'An assessment of stakeholder perceptions and management of noxious alien plants in Spain', *Environmental Management,* (43) 1 244–1 255.

Bardsley, D.K., and Edwards-Jones, G., 2007, 'Invasive species policy and climate change: social perceptions of environmental change in the Mediterranean', *Environmental Science & Policy,* (10) 230–242.

Bremner, A. and Park, K., 2007, 'Public attitudes to the management of invasive non-native species in Scotland', *Biological Conservation,* (139) 306–314.

Bertolino, S., Genovesi, P., 2003, 'Spread and attempted eradication of the grey squirrel (*Sciurus carolinensis*) in Italy, and consequences for the red squirrel (*Sciurus vulgaris*) in Eurasia', *Biological Conservation,* (109) 351–358.

Bertolino, S., Lurz, P., Sanderson, R. and Rushton, S., 2008, 'Predicting the spread of the American grey squirrel (*Sciurus carolinensis*) in Europe: A call for a co-ordinated European approach', *Biological Conservation,* (141) 2 564–2 575.

Blackburn, T.M., Pyšek, P., Bacher, S., Carlton, J.T., Duncan, R.P., Jarošík, V., Wilson, J.R.U. and Richardson, D.M., 2011, 'A proposed unified framework for biological invasions', *Trends in Ecology and Evolution,* (26) 333–339.

Brundu, G., Brunel, S. and Heywood, V., 2011, 'The European Code of Conduct on Horticulture and Invasive Alien Plants'. In: Rindos, E. (ed.), *Plant Invasions: Policies, Politics, and Practices. Proceedings of the 2010 Weeds Across Borders Conference*, 1–4 June 2010, pp. 32–26. National Conservation Training Center, Shepherdstown, West Virginia. Bozeman, Montana: Montana State University, Center for Invasive Plant Management.

Brunel, S., Petter, F., Fernandez-Galiano, E., Smith, I. M., 2009, 'Approach of the European and Mediterranean Plant Protection Organization to the evaluation and management of risks presented by invasive alien plants', Chapter 16, In Inderjit (ed.) *Management of Invasive Weeds*, Springer. 363 p.

Brunel, S., 2009. 'Pathway analysis: aquatic plants imported in 10 EPPO countries', *Bulletin OEPP/EPPO Bulletin,*(39) 201–213.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A., Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J., Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Morcillo, M.H., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vié, J.-C. and Watson, R., 2010, 'Global Biodiversity: Indicators of Recent Declines', *Science* (New York, N.Y.) 1 164.

CAB International, 2010, Japanese Knotweed Alliance (http://www.cabi.org/japaneseknotweedalliance/?site=139&page=356) accessed 7 March 2012.

Cadotte, M.W., 2006, 'Darwin to Elton: Early ecology and the problem of invasive species'. In: M.W. Cadotte, S. M. McMahon and T Fukami (eds) *Conceptual ecology and invasion biology: reciprocal approaches to nature*, Springer, Dordrecht, The Netherlands, pp. 15–34.

CAPE Partnership Program, 2009, *Invasive Alien Species Strategy Greater Cape Floristic Region*. Western cape Nature conservation Board t/a CapeNature, 30 p.

Chytrý, M., Wild, J., Pyšek, P., Jarošík, V., Dendoncker, N., Reginster, I., Pino, J., Maskell, L.C., Vilà, M., Pergl, J., Kühn, I., Spangenberg, J.H. and Settele, J., 2012, 'Projecting trends in plant invasions in Europe under different scenarios of future land-use change', *Global Ecology and Biogeography,* (21) 75–87.

Cifuentes, N., Hurtado, A. and Ruiz T., 2007, Integrated control of the Water Hyacinth (*Eichhornia crassipes*) in the Guadania river [In Spanish]. Invasiones Biológicas, un facto de cambio global. EEI 2006 actualización de conocimientos. 1, 266–269 GEIB Grupo Especialista en Invasiones Biológicas. Dep Leg. LE2069-2007, León, Spain.

Clavero, M. and Garcia-Berthou, E., 2005, 'Invasive species are a leading cause of animal extinctions', *Trends in Ecology and Evolution*, (20) 110.

Comité Asesor Nacional sobre Especies Invasoras, 2010, *Estrategia nacional sobre especies invasoras en México, prevención, control y erradicación*. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Comisión Nacional de Áreas Protegidas, Secretaría de Medio Ambiente y Recursos Naturales. México. 91 p.

Cooney, R., 2004., Precaution and Invasive Alien Species: challenges at the interface of the trade and environment regimes. Proceedings of a Global Synthesis Workshop on Biodiversity Loss and Species Extinctions: managing risk in a changing world (sub theme Invasive Alien Species: coping with aliens). 18–20 November 2004, Bangkok, Thailand.

Cullen, J., 2011, Naturalised rhododendrons widespread in Great Britain and Ireland, *Hanburyana*, (5) 11–29.

Darwin, C., 1859, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life* , John Murray, London, pp. 502.

Davenport, K. and Collins, J. 2011, *European Code of Conduct on Pets and Invasive Alien Species*, Council of Europe. T-PVS/Inf (2011) 01 rev. 41p.

Davis, M. A., Chew, M. K., Hobbs, R. J., Lugo, A. E., Ewel, J.J., Vermeij, G. J., Brown, J. H., Rosenzweig, M. L., Gardener, M. R., Carroll, S. P., Thompson, K., Pickett. S. T. A., Stromberg, J. C., Del Tredici, P., Suding, K. N., Ehrenfeld, J. G., Grime, J. P., Mascaro, J., and Briggs, J.C., 2011, 'Don't judge species on their origins', *Nature,* (474) 153–154.

Dehnen-Schmutz, K, and Touza, J. 2008, 'Plant invasions and ornamental horticulture: pathway, propagule pressure and the legal framework'. In: Teixeira da Silva, J.A. (ed) *Floriculture, ornamental and plant biotechnology: advances and topical issues*. Global Science Books, Isleworth, the United Kingdom, pp. 15–21.

Dehnen-Schmutz, K., Touza, J., Perrings, C., and Williamson, M. 2007, 'A century of the ornamental plant trade and its impact on invasion success', *Diversity and Distributions,* (13) 527–534.

Dietz, H. and Edwards, P. J., 2006, 'Recognition that causal processes change during plant invasion helps explain conflicts in evidence', *Ecology,* (87) 1 359–1 367.

Drake, J.A., Mooney, H.A., di Castri, F., Groves, R.H., Kruger, FJ., Rejmánek, M. and Williamson, M., (eds) 1989, Biological Invasions: A Global Perspective, vol. 37 of SCOPE, Chichester; New York (Wiley).

Drew, J., Anderson, N. and Andow, D., 2010, 'Conundrums of a complex vector for invasive species control: a detailed examination of the horticultural industry', *Biological Invasions,* (12) 2 837–2 851.

EFSA, 2011, *Scientific Opinion. Guidance on the environmental risk assessment of plant pests*. EFSA Panel on Plant Health (PLH), 118 p.

Elton, C.S., 1958, T*he Ecology of Invasions by Animals and Plants, 1958,* Methuen, London. Reprinted 2000 by The University of Chicago Press.

European Commission, COM, 2011, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and Committee of the Regions. Our life insurance, our natural capital: an EU biodiversity strategy to 2020 {SEC(2011) 540 final}, {SEC(2011) 541 final}. 17 p.

EPPO, 2011, Decision support scheme for quarantine pests. Guidelines on Pest Risk Analysis. PM 5/3 (5). 44 p.

Essl, F., Nehring, S., Klingenstein, F., Milasowszky, N., Nowack, C., Rabitsch, W., 2011, 'Review of risk assessment systems of IAS in Europe and introducing the German–Austrian Black List Information System (GABLIS)', *Journal for Nature Conservation*, doi:10.1016/j.jnc.2011.08.00.

EEA, 2001, *Late lessons from early warnings: the precautionary principle 1896–2000,* Environmental issue report No 22, European Environment Agency.

Essl, F., Dullinger, S., Rabitsch, W., Hulme, P.E., Hulber, K., Jarošík, V., Kleinbauer, I., Krausmann, F., Kuhn, I., Nentwig, W., Vila, M., Genovesi, P., Gherardi, F., Desprez-Loustau, M.-L., Roques, A. and Pyšek, P., 2010, Socioeconomic legacy yields an invasion debt. *Proceedings of the National Academy of Sciences,* (108) 2–6.

Falk-Petersen, J., Bøhn, T. and Sandlund, O.T., 2006, On the numerous concepts in invasion biology, *Biological Invasions,* (8) 1 409–1 424, doi:10.1007/s10530-005-0710-6.

Fay K., Fay K.C. et al., 2001, Proceedings of the Workshop at the Missouri Botanical Garden, St. Louis, Missouri, 1–4 December 2001.

Genovesi P., Shine C, 2003, European Strategy on Invasive Alien Species, final version. Convention on the Conservation of European Wildlife and Natural Habitats. Council of Europe, Strasbourg.

Genovesi, P., 2007, Limits and potentialities of eradication as a tool for addressing biological

invasions. In *Biological Invasions*, ed. Wolfgang Nentwig, (193) 385–401, Ecological. Springer — Verlag Berlin Heidelberg.

Genovesi, P., 2010, European biofuel policies may increase biological invasions: the risk of inertia. *Current Opinion in Environmental Sustainability,* (103) 1–5.

Genovesi, P., Scalera, R., Brunel, S., Roy, D.B. and Solarz, W. 2010, *Towards an early warning and information system for invasive alien species (IAS) threatening biodiversity in Europe*, EEA Technical report No 5/2010, European Environmental Agency.

Genovesi, P., 2011, 'Are we turning the tide? Eradications in times of crisis: how the global community is responding to biological invasions'. In: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds), 2011. *Island invasives: eradication and management*, IUCN, Gland, Switzerland.

Gobster, P.H., 2011, 'Factors affecting people's responses to invasive species management'. In: Rotherham, I.D., Lambert, R.A. (eds), *Invasive and Introduced Plants and Animals — Human Perceptions, Attitudes and Approaches to Management*. Earthscan, London, pp. 249–263.

Gouvernement du Canada, Environnement Canada, 2004, *An Invasive Alien Species Strategy for Canada*. 40 p.

Gibbs, A. 2011, 'Working with the United States Horticulture Industry'. In: Rindos, E. (ed.), *Plant Invasions: Policies, Politics, and Practices*. Proceedings of the 2010 Weeds Across Borders Conference, 1–4 June 2010, pp. 29–31. National Conservation Training Center, Shepherdstown, West Virginia. Bozeman, Montana: Montana State University, Center for Invasive Plant Management.

Gurevitch, J., Fox, G.A., Wardle, G.M., Inderjit, Taub, D., 2011, 'Emergent insights from the synthesis of conceptual frameworks for biological invasions', *Ecology Letters,* (14/4) 407–418.

Harris, S., Timmins, S.M., 2009, 'Estimating the benefit of early control of all newly naturalised plants', *Science for Conservation,* (292) 1–25.

Hattingh, J., 2011, *Conceptual clarity, scientific rigour, and 'The stories we are': Engaging with the two challenges to the objectivity of invasion biology*, pp. 359–393 in D.M. Richardson, editor. Fifty Years of Invasion Ecology: The Legacy of Charles Elton. Wiley-Blackwell, Oxford, the United Kingdom.

Heywood, V., and Brunel, S., 2009, 'Code of conduct on Horticulture and Invasive Alien Plants. Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention)', *Nature and environment*, No. 155. Council of Europe Publishing, 74 p.

Heywood, V. H., 2011, 'A code of conduct on invasive alien species for Europe's botanic gardens, *BG journal,* (8/2) 26–28.

Hobbs R.J., Arico S., Aronson J., Baron J.S., Bridgewater P., Cramer V.A., Epstein P.R., Ewel J.J., Klink C.A., Lugo A.E., Norton D., Ojima D., Richardson D.M., Sanderson E.W., Valladares F., Vila M., Zamora R. and Zobel M., 2006, 'Novel ecosystems: theoretical and management aspects of the new ecological world order', *Global Ecology and Biogeography,* (15) 1–7.

Hulme, P., 2011a, *Biosecurity: the changing face of invasion biology.* In Richardson D (ed.) (2011) Fifty Years of Invasion Ecology: The Legacy of Charles Elton, pp. 301–314.

Hulme, P., 2011b, 'Weed risk assessment: a way forward or a waste of time?', *Journal of Applied Ecology,* (49) 1 365–2 664.

Inderjit, Cadotte, M.W, and Colanti, R., 2005, 'The ecology of biological invasions: past, present and future'. In: Inderjit (ed.), *Invasive plants: ecological and agricultural aspects*, pp. 19–43.

ISSG, 2011. We need to strengthen, not weaken, the struggle against harmful invasive species, 15 June 2011, ISSG Website.

Javelle, A., Kalaora, B., Decocq, G., 2010, 'De la validité d'une invasion biologique. *Prunus serotina* en forêt de Compiègne', *Etudes rurales,* (185) 39–50.

Jeschke, J.M. and Genovesi, P., 2011, 'Do biodiversity and human impact influence the introduction or establishment of alien mammals?', *Oikos,* (120) 57–64.

Kettunen, M., Genovesi, P., Gollasch, S., Pagad, S. and Starfinger, U., 2009, Technical support to eu strategy on invasive alien species (IAS) Assessment of the impacts of IAS in Europe and the EU. Brussels, Belgium.

Kueffer, C, and Hirsch Hadorn, G., 2008, 'How to achieve effectiveness in problem-oriented landscape research: the example of research on biotic invasions', *Living Reviews in Landscape Research*, (2/2).

Kiehn, M., 2011, 'Invasive alien species and islands'. In: Bramwell, D. and Caujapé-Castells, J. (eds), *The*

Biology of Island Floras, pp. 365–384, Cambridge University Press, Cambridge.

Kolar, C.S., Lodge, T.S., 2001, Progress in invasion biology: predicting invaders, *Trends in Ecology & Evolution,* (16/4) 199–204.

Kueffer, C., Daehler, C. C., 2008, *A Habitat-Classification Framework and Typology for Understanding, Valuing and Managing Invasive Species Impacts*. Chapter 5 in Inderjit (ed.) Management of Invasive Weeds, pp. 77–101.

Kueffer, C. and Hirsch Hadorn, G., 2008, How to achieve effectiveness in problem-oriented landscape research: the example of research on biotic invasions. Living Reviews in Landscape Research 2:2.

Kueffer, C., 2010, 'Transdisciplinary research is needed to predict plant invasions in an era of global change', *Trends in Ecology and Evolution*, (25) 619–620.

Kueffer, C., Daehler, C.C., Torres-Santana, C.W., Lavergne, C., Meyer. J.Y., Otto, R. and Silva, L., 2010, 'A global comparison of plant invasions on oceanic islands', *Perspectives in Plant Ecology, Evolution and Systematics,* (12) 145–161.

Larson, B.M.H., 2007, 'An alien approach to invasive species: objectivity and society in invasion biology, *Biological Invasions,* (9) 947–956.

Larson, B.M.H., 2010, 'Reweaving narratives about humans and invasive alien species', *Etudes rurales,* (185) 25–38.

Le Bourgeois, T., Della Mussia, S., 2009, 'Un insecte efficace contre la vigne marronne à la Réunion', *Insectes,* (153) 17–19.

Lerdau, M. and Wickham, J.D., 2011, 'Non-natives: four risk factors', *Nature,* (475) 36–37.

McDougall, K., Alexander, J., Haider, S., Pauchard, A., Walsh, N., Kueffer, C., 2011, 'Alien flora of mountains: global comparisons for the development of local preventive measures against plant invasions', *Diversity and Distributions,* (17) 103–111.

McGeoch, M.A., Butchart, S.H.M., Spear, D., Marais, E., Kleynhans, E.J., Symes, A., Chanson, J. and Hoffmann, M., 2010, 'Global indicators of biological invasion: species numbers, biodiversity impact and policy responses', *Diversity and Distributions*, (16) 95–108.

McNeely, J.A. (ed.) 2001, *The Great Reshuffling: Human Dimensions of Invasive Alien Species*. IUCN, Gland, Switzerland and Cambridge, the United Kingdom.

Medina, F.M., Bonneaud, E., Vidal, E., Tershy, B.R., Zavaleta, E.S., Donlan, C.J., Keitt, B.S., Le Corre, M., Horwath, S.V. and Nogales, M., 2011, 'A global review of the impacts of invasive cats on island endangered vertebrates', *Global Change Biology*, doi:10.1111/j.1365-2486.2011.02464.x.

Menozzi, M.J., 2007, "Mauvaises herbes', qualité de l'eau et entretien des espaces', *Natures Sciences Sociétés,* (15) 144–153.

Millennium Ecosystem Assessment, 2005, 'Ecosystems and Human Well-being: Biodiversity Synthesis', Washington, DC (World Resources Institute).

Miller, C., Kettunen, M. and Shine, C., 2006, *Scope options for EU action on invasive alien species (IAS),* Final report for the European Commission, Institute for European Environmental Policy (IEEP), Brussels, Belgium. 109 pp + Annexes.

Mooney, H.A., Mack, R.N., McNeely, J.A., Neville, L.E., Schei, P.J. and Waage, J.K. (eds), 2005, *Invasive Alien Species: A New Synthesis*, vol. 63 of SCOPE, Washington, London (Island Press), 368 p.

Morse, L.E., Kartesz, J.T., Kutner, L.S., 1995, 'Native vascular plants'. In: LaRoe, E.T., Farris, G.S., Puckett, C.E., Doran, P.D., Mac, M.J. (eds), *Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals and Ecosystems*. U.S. Department of the Interior, National Biological Service, Washington, DC, pp. 205–209.

O Sénat, 2009, Conséquences pour les apiculteurs de l'introduction de la tenthrède cibdela janthina à La Réunion, 13 ème législature. Question orale sans débat n° 0559S de Mme Anne-Marie Payet (La Réunion — UC). publiée dans le JO Sénat du 21/05/2009, page 1 250.

Pheloung, P.C., P.A. Williams, and Halloy. S.R., 1999, 'A weed risk assessment model for use as a biosecurity tool evaluating plant introductions, *Journal of Environmental Management,* (57) 239–251.

Pimentel, D., Zuniga, R., Morrison, D., 2005, 'Update on the environmental and economic costs associated with alien-invasive species in the United States', *Ecological Economics,* (52/3) 273–288, doi:10.1016/j.ecolecon.2004.10.002

PRATIQUE Website, 2011, *PRATIQUE: Enhancements of Pest Risk Analysis Techniques*.

Pyšek, P., Jarošík, V., Hulme, P.E., Kühn, I., Wild, J., Arianoutsou, M., Bacher, S., Chiron, F., Didziulis, V., Essl, F., Genovesi, P., Gherardi, F., Hejda, M., Kark, S., Lambdon, P.W., Desprez-Loustau, M.-L., Nentwig, W., Pergl, J., Poboljsaj, K., Rabitsch, W., Roques, A., Roy, D.B., Shirley, S., Solarz, W., Vilà, M., and Winter, M., 2010, 'Disentangling the role of environmental and human pressures on biological invasions across Europe', *Proceedings of the National Academy of Sciences of the United States of America,* (107) 12 157–12 162.

Pyšek, P., Richardson, D.M., 2010, 'Invasive species, environmental change and management, and ecosystem health', *Annual Review of Environment and Resources,* vol. 35, pp. 25–55.

Reichard, S.H., White P. 2001, 'Horticulture as a pathway of invasive plant introductions in the United States', *BioScience,* (51) 103–113.

Ricciardi, A., Cohen, J., 2006, 'The invasiveness of an introduced species does not predict its impact', *Biological Invasions,* (9) 309–315.

Richardson, D.M., Pyšek, P., Rejmánek, M., Barbour, M.G., Panetta, F.D., West, C.J., 2000, 'Naturalization and invasion of alien plants: concepts and definitions', *Diversity and Distributions*, (6) 93–107.

Richardson, D.M., Pyšek, P., 2007, 'Classics in physical geography revisited: Elton, C.S. 1958: The ecology of invasions by animals and plants, Methuen: London'. *Progress in Physical Geography,* (31) 659–666.

Richardson, D.M., Pyšek, P., 2008, 'Fifty years of invasion ecology — the legacy of Charles Elton', *Diversity and Distributions,* (14) 161–168.

Richardson, D.M. (ed.), 2011a, *Fifty years of invasion ecology. The legacy of Charles Elton,* Wiley-Blackwell, Oxford.

Richardson, D.M., 2011b, 'Invasion science: the roads travelled and the roads ahead'. In: Richardson, D.M. (ed.) *Fifty years of invasion ecology. The legacy of Charles Elton*, pp. 397–407, Wiley-Blackwell, Oxford.

Richardson, D.M., Pyšek, P., Carlton, J.T, 2011, 'A compendium of essential concepts and terminology in invasion ecology'. In: Richardson, D.M. (ed.) *Fifty years of invasion ecology. The legacy of Charles Elton*, pp. 409–420, Wiley-Blackwell, Oxford.

Richardson, D.M., Rejmánek, M. 2011, 'Trees and shrubs as invasive alien species — a global review', *Diversity and Distributions,* (17) 788–809.

Riley, S., 2005, 'Invasive Alien Species and the Protection of Biodiversity: The Role of Quarantine Laws in Resolving Inadequacies in the International Legal Regime', *Journal of Environmental Law,* (17/3) 323–359.

Rotherham, I.D., Lambert, R.A., 2011, *Invasive and Introduced Plants and Animals. Human Perceptions, Attitudes and Approaches to Management*. Earthscan London.

Ruiz, G.M., and J.T. Carlton, (eds), 2003, *Invasive Species. Vectors and Management Strategies*, Island Press, Washington, London.

Sagoff, M., 2005, 'Do Non-Native Species Threaten The Natural Environment?' *Journal of Agricultural and Environmental Ethics,* (18) 215–236.

Scalera, R., Zaghi, D., 2004, *Alien species and nature conservation in the EU, The role of the LIFE program*. European Commission — Environment Directorate-General, Office for Official Publications of the European Communities, Luxembourg.

Seddon, P.J., Armstrong, D.P., Soorae, P., Launay, F., Walker, S., Ruiz-Miranda, C.R., Molur, S., Koldewey, H., Kleiman, D.G., 2009, 'The risks of assisted colonization', *Conservation biology : the journal of the Society for Conservation Biology,* (23) 788–789.

Selge, S., Fischer, A., and van der Wal, R., 2012, 'Public and professional views on invasive non-native species — A qualitative social scientific investigation', *Biological Conservation*, in press, doi:10.1016/j.biocon.2011.1009.1014.

Sforza, R., 2006, *La lutte biologique contre les plantes envahissantes méditerranéennes : comment gagner du temps?* In Brundel S (ed.) Proceedings of the 1st Workshop on Invasive Plants in Mediterranean Type Regions of the World, Mèze (France), 25–27 May 2005 (2006) 214–220.

Sheppard, A.W., Raghu, S., Begley, C., Genovesi, P., De Barro, P., Tasker, A., Roberts, B., 2011, 'Biosecurity as an integral part of the new bioeconomy: a path to a more sustainable future', *Current Opinion in Environmental Sustainability,* (3) 1–7.

Simberloff, D., 2005, 'Non-native Species DO Threaten the Natural Environment! *Journal of Agricultural and Environmental Ethics',* (18) 595–607.

Simberloff, D. and 141 scientists, 2011, 'Non-natives: 141 scientists object', *Nature,* (475) 36.

Simberloff, D., Genovesi, P., Pyšek, P. and Campbell, K., 2011, 'Recognizing conservation success', *Science,* (332) 419–421.

Standing Committee to the Bern Convention, 2011, Report of meeting. Council of Europe. T-PVS(2011)26. 110 p.

Stanley-Price, M., 2010, 'IUCN Species Survival Commission: the Reintroduction and Invasive Species Specialist groups' task force for moving species for conservation purposes', *Oryx,* (44) 323.

Tanaka, H. and Larson, B., 2006, 'The role of the International Plant Protection Convention in the prevention and management of invasive alien species'. In: Koike, F., Clout, M.N., Kawamichi, M., De Poorter, M. and Iwatsuki, K. (eds), *Assessment and Control of Biological Invasion Risks*. Shoukadoh Book Sellers, Kyoto, Japan and IUCN, Gland, Switzerland, pp. 56–62.

Thomas, C.D., 2011, 'Translocation of species, climate change, and the end of trying to recreate past ecological communities', *Trends in Ecology & Evolution*, (1 354) 1–6.

Usher, M.B., 1986, *Invasibility and wildlife conservation: invasive species on nature reserves*. Philosophical Transactions of the Royal Society of London, B314, 695–710.

Verloove, F., 2010, 'Invaders in disguise. Conservation risks derived from misidentification of invasive plants', *Management of Biological Invasions,* (1) 1–5.

Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P., Gollasch, S., Nentwig, W., Olenin, S., Roques, A., Roy, D., Hulme, P.E., DAISIE partners, 2010, 'How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment', *Frontiers in Ecology and the Environment*, (8) 135–144.

Vilà, M., Hulme P.E., 2011. 'Jurassic Park? No thanks', *Trends in Ecology & Evolution,* (26) 496–497.

Vilà M., I. Ibáñez. 2011, 'Plant invasions in the landscape', *Landscape Ecology,* (26) 461–472.

Warren, C.R., 2007, 'Perspectives on the 'alien' versus 'native' species debate: a critique of concepts, language and practice', *Progress in Human Geography,* (31) 427–46.

Weidema, I.R., (ed.) 2000, *Introduced Species in the Nordic Countries*. Nordic Council of Ministers, Copenhagen, Nord 2000, 13, 242 pp.

Williams, J.W. and Jackson, S.T., 2007, 'Novel climates, no-analog communities, and ecological surprises', *Front. Ecol. Environ.*, (5) 475–482.

Williamson, M., 1996, *Biological Invasions*, vol. 15 of Population and Community Biology Series, London; New York (Chapman & Hall).

Wilson, J.R.U., Dormontt, E.E., Prentis, P.J., Lowe, A.J. and Richardson, D.M., 2009, 'Something in the way you move: dispersal pathways affect invasion success', *Trends in Ecology & Evolution,* (24) 136–144.

With, K.A. 2002. 'The landscape ecology of invasive spread', *Conservation Biology*, (16) 1 192–1 203.

Wittenberg, R. and Cock, M.J.W., 2001, *Invasive alien species: a toolkit of best prevention and management practices*. Pages xvii-228. CAB International, Wallington, Oxon.