What is an Invasive Species?

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1. Summary

Escalating transport of organisms around the world and the rapid increase in problems with invasive alien organisms worldwide, demands improved precision and objectivity in categorizing non-native species. This is essential for the effective implementation of various policies aimed at reducing impacts of currently problematic non-native species and those aimed at preventing introductions of other species with a high risk of causing problems. Problems that exist in this regard relate to, among other things: (1) poorly resolved systematics for many groups of organisms, especially microscopic organisms for which the geographic origin of many taxa is unknown; (2) the fact that scientific study of the determinants of invasiveness is in its infancy; (3) criteria for defining organisms as feral/naturalized, invasive, etc. have evolved differently in different parts of the world, and for
different taxa; (4) criteria for objective categorization are, in many cases, complicated by complex human-value systems. This article discusses concepts relating to biological invasions, and in particular the processes leading to naturalization or invasion of alien organisms and the progress towards unifying ecological concepts related to the invasions.

2. Background

In colonizing the world, humans have moved other species around with them, intentionally or by accident (di Castri, 1989; Mooney and Hobbs, 2000; Ruiz and Carlton, 2003). Until recently, human-aided movement of species involved relatively few species, and those that were moved were generally moved slowly, over short distances, and in fairly small numbers. Such movement certainly resulted in changes to the distributions of many species, due to both human-aided dispersal and human-driven modifications to ecosystems. But such changes were mostly localized, sometimes involving extensions at the edge of the natural range of species.

Technological innovations that enabled humans to move not only themselves, but almost any other species around the world much quicker and in bigger numbers caused not only a quantitative change, but also a qualitative change in the way that humans impact on the world’s biota (di Castri, 1989). Major biogeographical barriers that had separated biotas of different parts of the world for millennia were easily breached. The stage was set for the rapid homogenization of the planet. Cultural ties and emerging regional and global economies have forged a myriad of complex pathways along which species are moved around the globe (Ruiz and Carlton, 2003).

What started as a trickle, has now become a roaring torrent, with many parts of the world now boasting more species that evolved in distant regions than native ones in certain taxonomic groups [e.g. vascular plants on many islands, Rejmánek (1996)]. It is not only the number of species moved around the world that has increased dramatically, but also the number of individuals of different species, and the number and character of interactions between species (native and foreign, e.g. Keane and Crawley, 2002). Also, an increase in the time since introduction for large numbers of alien species has meant that many of them have been able to move around within their adventive ranges, on their own, or aided by humans or other resident species (Kowarik, 1995; Wu et al., 2003; Pyšek et al., 2004b). Many alien species have had time to prospect many habitats, and to take advantage of sporadic events that may give them a foothold or enable them to increase in numbers and range.

Centuries ago, alien species were usually welcome residents. Humans colonizing new lands needed such species to survive and to make their new homes more convivial. Alien species provided humans with food, fibre, shelter and cultural ties with their homelands. Much effort went into introducing, cultivating, or otherwise nurturing a wide range of alien species (Mack, 2000). The shift from viewing alien species as welcome components of the biota to the current situation where, in most parts of the world, many of the most worrying diseases, pests and weeds are aliens, has followed different trajectories in different regions [developed world vs. developing world; Old World vs. New World; northern vs. southern hemisphere, e.g. Lonsdale (1999)]. For
example, in most parts of Europe, many alien species were incorporated slowly into the biota so that human culture and land management slowly integrated such species into environments with a long history of human modification. In contrast, regions that were colonized by Europeans starting in the 1600s received a deluge of alien species at the same time as the start of major human-driven transformations in these systems (Rolls, 1985; di Castri, 1989).

Many alien species are undisputedly essential for human survival and wellbeing. For example, it is estimated that 95% of food production in the USA depends on non-indigenous species of plants and animals (Pimentel, 2002). On the other hand, in many parts of the world, the harmful effects of invasive alien species are widely recognized, and multi-scale (local-regional-national-international) programmes are underway to reduce the current and potential future impacts of the relatively small number of alien species that cause problems (Daehler and Carino, 2001; McNeeley et al., 2001). Most people agree that some alien species are harmful and that far-reaching and expensive interventions need to be implemented to deal with current populations of such species, and to reduce the likelihood of other alien species from becoming a nuisance (Ewel et al., 1999). Such precautions, it is generally accepted, should relate to alien species already introduced, and perhaps widespread (possibly with some beneficial properties), as well as the many potentially troublesome species not yet introduced. Conflicts of interest exist in almost every case where alien species are deemed problematical and are the focus of management action. One man’s weed is another man’s miracle plant, horticultural subject, or link with his cultural heritage.

In any case, management of invasive alien species needs to compete for resources with many other priorities at different levels of government, and within the fields of environmental conservation, agriculture, forestry, fisheries, etc. For this reason, objective categorization and prioritization of alien species for management action is an essential component of building policies and sustainable strategies. At the core of any objective system of prioritization in this area should be a clear understanding of key biological/ecological/biogeographical concepts relating to naturalization and invasion of alien species.

"What is an invasive species?" is a seemingly simple question, but reference to the burgeoning scientific literature on invasions, and to many policy documents and web sites focusing on alien species shows that much confusion exists (Davis and Thompson, 2000; Richardson et al., 2000b; Daehler, 2001; Rejmánek et al., 2002; Pyšek et al., 2004a). This article explores the multi-faceted nature of the question, differences between taxonomic groups, and the wide range of inherent and policy-driven problems that confront anyone trying to categorize alien species with regard to their status.

3. Native and alien 'pest' species

When organisms show increase in abundance, density or geographic extent, this may be deemed inappropriate or problematic, and such organisms are sometimes termed 'pests', 'problem species', 'weeds', etc. In many cases, such species are native to the areas where their presence, abundance, density, or 'impacts' (variously defined, usually invoking human value systems) are deemed inappropriate. In such cases,
rapid increases in range, abundance or density and subsequent impacts on ecosystems are attributable to human-induced perturbations to such ecosystems. Factors that regularly lead to such changes include altered disturbance or nutrient regimes (Hobbs and Huenneke, 1992; Davis et al., 2000; Shea and Chesson, 2002), or additions and removals of biota, leading to altered ecosystem dynamics (Vitousek and Walker, 1989). Natural fluctuation in climate and other factors drive range changes, but these usually lead to slower range shifts, measurable at the scale of centuries, rather than years or decades (Williamson, 1996).

‘Weedy’ native species sometimes have major impacts and are the subject of intensive and expensive management efforts (Williamson, 1998). Examples include the widespread expansion of native pinyon pines (notably Pinus edulis and Pinus monophylla) in the American Southwest and the similar expansion and densification of native acacias (e.g. Acacia karroo) in parts of southern Africa, both largely attributable to increased grazing and thus reduced competition for tree seedlings from grasses; extensive spread of the native grass Calamagrostis villosa in areas deforested due to air pollution in Central Europe (Pyšek, 1992); spread of the asteraceous herb, Dittrichia viscosa on disturbed habitats in the Mediterranean (Wacquant, 1990); or many native weeds on arable land (Williamson, 1998). Many native animal species have undergone major range expansions, at least partly, in response to human-driven changes to ecosystems.

‘Invasions’ of native species ['expansion’ has been suggested as a more appropriate term for designating spreading native species, see Pyšek et al. (2004a)], although often indisputably problematic and warranting substantial management effort, usually do not rank as major threats to biodiversity and ecosystem functioning. The rampant spread of some alien aliens, has however, wreaked havoc in ecosystems worldwide. Are invasions involving alien species fundamentally different to those involving native species? Do alien invasions demand different management strategies?

The answer to both the above questions is yes. Although the basic processes whereby native and alien species increase in abundance and geographical extent in certain instances are the same, alien species have certain attributes that mean that they demand special attention. For example, native species (even weedy ones) usually have their full complement of co-evolved mutualists and natural enemies, whereas aliens are often introduced without many/most of these (Richardson et al., 2000a), for example when plants are introduced as seeds, or mussels are introduced as spat. The ‘enemy release hypothesis’ (Keane and Crawley, 2002) proposes that aliens are often successful when they leave their enemies behind when they are transported to a new area because they have an advantage over native species whose performance is, to some extent, inhibited by suites of co-evolved enemies. Recent studies indicated that alien species differ from natives in their relationships with organisms of other trophic levels (Chittka and Schürkens, 2001; Klironomos, 2002); this can provide them with competitive advantages during invasion. This article focuses largely on alien species, but it is not always easy to say whether a species is native or alien.

4. When is an organism native or alien?
Species from all taxonomic groups of organisms have been moved around the world through human activities. The extent to which species in a given biota can accurately be labelled as ‘native’ or ‘alien’ varies considerably for different major taxonomic groups and for different parts of the world. Certain taxonomic groups, notably vascular plants and vertebrate animals, are relatively well described, and reasonable lists of species exist for many regions of the world (e.g. Randall, 2002). Such taxonomic resolution is essential for determining which species in a given area are native (i.e. evolved in that area, or at least migrated into the area before the age of human domination of the world’s ecosystems), or alien (i.e. moved there directly by humans or indirectly by transport means associated with human activities) (Pyšek et al., 2004a). For taxonomic groups with less well resolved taxonomies and for which detailed species lists are often lacking, determining whether a species is native to a given area or has arrived via human transport is much more difficult. This applies to many groups of smaller organisms, especially microorganisms such as viruses, prions, viroids, bacteria, fungi, algae and protozoa, but also most groups of arthropods and plankton [but see e.g. Frank and McCoy (1992, 1995) for insects]. In the absence of basic taxonomic monographs and biogeographical information, many species must be labelled ‘cryptogenic’, i.e. of unknown origin - not demonstrably native or alien (Carlton, 1996).

Biological invasions are generally considered at the level of species, i.e. species are either native or alien, invasive or not, etc. There is, however, growing realization that invasions at the level of genes is also a major issue (Petit, 2004). The spread of non-native genotypes within the range of members of their own species has been termed ‘cryptic invasions’ (Saltonstall, 2002). Interspecific hybridization between native and alien species is thought to act as a stimulus for invasiveness in many cases (Abbott, 1992; Ernst, 1998; Ellstrand and Schierenbeck, 2000; Huey et al., 2000; Willis et al., 2000; Daehler and Carino, 2001; Lee, 2002). Examples of increased vigour of hybrids relative to parents include taxa in the plant genera *Spartina* (Daehler and Strong, 1994, 1996), *Carpobrotus* (Vila and D’Antonio, 1998), *Reynoutria* (Pyšek et al., 2003), and for animals, crayfish taxa in the genus *Orconectes* (Perry et al., 2001). Hybridization also complicates the quest for definitive criteria for classifying species as native or alien. There is currently no clear agreement on how to treat products of hybridization involving alien species but it is more appropriate to consider the products of hybridization with alien species involved, as alien (Crawley et al., 1996; Pyšek et al., 2004a).

Besides the problems of taxonomic resolution and invasions at the gene level when attempting to classify species as native or alien, there is the problem of geographic scale. Organisms encroaching in habitats in which they were not present before the first available records can be assessed from an ecological point of view (and termed colonizers), or from biogeographical (invaders, or aliens in a more general sense), or anthropocentric perspectives (pests, weeds) (Williamson, 1993, 1996; Rejmánek, 1995, 2000). In biological invasions, the biogeographical perspective is preferable (Rejmánek, 1995, 2000; Pyšek et al., 2004a). However, is it appropriate to consider a species alien to a continent, to a country, to a state or province, to a biogeographic zone? There is no definitive answer to this question. Clearly, resolution in this regard calls for arbitrary limits and a measure of pragmatism, especially when the categorization is driven by requirements for policy formulation. The best resolution depends on the aim of the assessment. Since most policies are formulated for implementation at the level of political entities (mainly countries), the native vs. alien dichotomy is usually debated for such geographical units. In many cases political boundaries are not an ideal framework because they do not correspond to
biogeographic zones that set biological and ecological barriers which are crucial in biological invasions (Richardson et al., 2000b). This problem is more pronounced in big countries, such as Australia and the USA, where many species from east/west coasts are as foreign on the other coast as species from another continent. For plants, alien and native occurrence in demarcated localities within a region should be ideally distinguished. However, to our knowledge, there is only one source with information categorized in such a way: in the New Atlas of the British and Irish Flora (Preston et al., 2002) which give precise information on the number of alien and native occurrences recorded for each plant species. Such information greatly improves the potential for analyses of alien floras because, in association with environmental characteristics, the data can be examined on a finer scale (Pyšek et al., 2004a).

5. The history of problems with alien species

Significant problems with invasive alien species are a relatively recent phenomenon. In most parts of the world, by far the biggest impacts have been felt only in the last 50 years. There are some prominent examples of widespread invasions, presumably with impacts (although in most cases we have little or no information on this), that date back much further. For instance, Charles Darwin wrote of invasive populations of the alien plant species *Silybum marianum* and *Cynara cardunculus* covering square kilometres in Argentina in 1833.

Means for dealing with invasive alien species, beyond uncoordinated efforts at local scales, had to be developed in many parts of the world rapidly to avert looming species extinctions and various ecosystem-level impacts. Such methods were simultaneously needed at spatial scales ranging from landscapes to continents, and at temporal scales of days or weeks (for small-scale containment or eradication efforts) to years, decades or more (to prevent further introductions across national borders and to limit dissemination within political boundaries). The rush to develop cost-effective management strategies arose at about the same time as ecologists and biogeographers were starting to appreciate both the momentous potential of non-native species to disrupt ecosystem functioning, and also the opportunities that biological invasions provided for studying fundamental issues in biogeography and ecology. As a consequence, ecologists were poorly equipped to provide well-formulated theories and conceptual frameworks to underpin emerging management strategies.

This led to some disasters, e.g. the use of generalist predators for biological control of some vertebrate invaders, and also led to much confusion due to the adoption of a bewildering array of terms used to describe different categories of alien species.

A milestone in the coordinated fight against invasive pests was the establishment of the International Plant Protection Convention (IPPC) in 1951 (revised in 1979 and in 1997) [http://www.ippc.int/IPP/En/model_letters.jsp]. The IPPC is an international treaty whose purpose is to secure a common and effective action to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control. The Convention extends to the protection of natural flora and plant products. Contracting parties meet IPPC
obligations through the actions and policies of national and regional plant protection organizations.

The emergence of prominent national and international initiatives for the management of invasive alien species, especially in natural and semi-natural ecosystems, has brought into focus the need for clear concepts and terminology to distinguish pest species of foreign origin from other non-native, but beneficial or benign, species, and from native species. Prominent examples of international programmes focusing on invasive species include the Global Invasive Species Programme [http://www.gisp.org/] and the World Conservation Union’s (IUCN) Invasive Species Specialist Group [http://www.issq.org/]. The IPPC was initially largely directed at agriculture and food security, but is now applying its guidelines to the protection of uncultivated plants and habitats, e.g. ISPM No. 11, Pest Risk Analysis for Quarantine Pests, revised in 2003 to include a new supplementary section which provides more detail on the 'analysis of environmental risks'. Regional programmes include the South Pacific Regional Environment Programme [http://www.sprep.org.ws/bird_inva/], and national and regional initiatives include the National Weeds Strategy in Australia [http://www.weeds.org.au/], the 'Protect New Zealand' initiative in New Zealand [http://www.protecnz.org.nz/], the 'Working for Water’ programme and associated initiatives in South Africa [http://www.dwaf.gov.za/wfw/], and the National Invasive Species Council in the USA [http://www.invasivespecies.gov/]. Many non-governmental organizations with an interest in conservation issues worldwide are addressing issues relating to invasive species. Important examples include The Nature Conservancy’s Invasive Species Initiative in the USA [http://nature.org/initiatives/invasivespecies/]. Note that the geographic distribution of these initiatives reflects the extent of problems with alien species in different regions of the world.

All the above organizations focus on invasive alien species that have substantial impact on biodiversity, the functioning of ecosystems, and human wellbeing. In the websites and policy documents of these organizations, ‘invasive species’ tend to be loosely equated with ‘alien species that cause damage’. As we will see below there are some problems with the application of this definition in practice.

6. When does an alien species become feral, naturalized, invasive?

A review of the scientific and popular literature on invasions clearly shows that different people mean different things when they write about ‘introduced’, ‘casual’, ‘feral’, ‘naturalized’ or ‘invasive’ species. Several recent contributions have reviewed the confusing array of terms and the fuzzy application of concepts related to them (e.g. Richardson et al., 2000b; Daehler, 2001; Davis and Thompson, 2001; Rejmánek et al., 2002; Colautti and McIsaac, 2004; Pyšek et al., 2004a). It is symptomatic that even these review papers express different views on terminology (see below). Table 1 lists the most widely used terms in the lexicon of invasion ecology and attempts to provide objective, non-ambiguous definitions for each, with notes relating to problems of interpretation and difficulties pertaining to specific types of organisms or in particular localities.
Although imprecise definitions are widely used for most terms, most confusion and debate has centred on the term ‘invasive’. Most widely used definitions of ‘invasive’ include statements relating to two or more of the following: (1) the alien status of the species; (2) its ability or potential to establish and overcome various barriers to reproduction, dispersal and proliferation in the new environment (as in Figure 1); and (3) its ability or potential to cause harm to the environment and/or human health (reviewed in Richardson et al., 2000b).

There are two main groups of definitions of ‘invasive’:

1. Those based on ‘biological/ecological’ principles and more or less objective and measurable criteria - invasive species are a subset of naturalized species that produce reproductive offspring, often in very large numbers, are able to
disperse considerable distances from parent populations, and thus have the potential to spread over a large area (Richardson et al., 2000b; Pyšek et al., 2004a). The advantage of this definition is that ‘invasive’ taxa can be defined, using reasonably objective criteria, according to their position along the ‘naturalization-invasion’ continuum (Richardson et al., 2000b; see Figure 1). Importantly, the definition infers no connotation of impact.

2. The second category of definitions may be lumped under the heading ‘anthropocentric’ - invasive species are those that are alien to the ecosystem under question, and whose introduction causes, or is likely to cause, economic or environmental harm to human health. This definition has been widely adopted in policies, including such influential ones as the Executive Order 13112 of 1999 signed by President Clinton in the USA [http://www.invasivespecies.gov/laws/execorder.shtml]. The rationale for such a definition is usually stated as being the need to focus the attention of policy makers on the biggest problems. A substantial problem with this definition is that many impacts are not readily measurable or, in the absence of objective criteria for comparing impacts of different species in different ecosystems, assigned meaningful currency. At what stage in an invasion can an alien organism be considered to be causing ‘harm’? And, given the problem inherent in predicting which alien species are likely to invade (i.e. spread), how can we decide which species are likely to cause harm? Nonetheless, the definition adopted by GISP reads "Invasive alien species are non-native organisms that cause, or have the potential to cause, harm to the environment, economies, or human health".

A most readable review of the debate in this regard, dealing with issues such as whether it is practical or desirable to include impact as an integral part of the definition of ‘invasive’ or not, and discrepancies between scientific and popular usage of the term is provided by Carlton (2002).

The most intense and challenging debate on defining ‘alien’ and ‘invasive’ species has focused on plants. This is probably because there is generally much more precise geographical data available for plant species than for most other types of organisms. This is partly because most plants stand still and wait to be counted, allowing their populations to be mapped accurately. They do not migrate. Evaluating geographical ranges is generally much more difficult for animals, even for large, conspicuous species.

Although the term ‘invasive’ has lost its precise meaning through convoluted usage, it is likely to remain in widespread use, especially in socio-political circles. Some prominent ecologists are abandoning the term ‘invasive’ as a scientific concept.

7. What terminology should research scientists, policy makers, conservationists and quarantine staff use for practical applications in the future?

This question has yet to be debated with sufficient vigour in the relevant forums and international conventions. Urgent attention is required to harmonize concepts and develop international guidelines for practical application by policy makers, researchers, phytosanitary organizations, conservationists, etc. Whatever
terminology is used, several key points must be considered. Firstly, it is essential that objective criteria be used to separate native from alien taxa wherever possible. Cryptogenic species will remain a problem in this regard, but focused biogeographic and systematic studies currently underway will improve the situation somewhat. Secondly, particulars of space and time are essential: a species may well be invasive at one locality at one time, but not invasive under other situations. Guidelines for the practical use of concepts such as ‘potentially invasive’ and ‘potentially causing harm’ are urgently required. Thirdly, if impact is used as a criterion for labelling species as invasive, objective parameters that define such impact should be used.

8. References


Daehler CC, Strong DR, 1994. Variable reproductive output among clones of Spartina alterniflora (Poaceae) including San Francisco Bay, California: the influence of


Table 1. Suggestions for a standardized terminology for alien species [adapted from Pyšek et al. (2004a) unless stated otherwise].

**Native species** (applies to all taxonomic groups)

*Synonym*: indigenous species.

*Definition*: taxa that have originated/evolved in a given area without human involvement or that have arrived there without intentional or unintentional intervention of humans from an area in which they are native.

*Interpretation*: this definition excludes products of hybridization involving alien taxa since ‘human involvement’ in this case includes the introduction of an alien parent.

**Alien species** (applies to all taxonomic groups)

*Synonyms*: exotic species; introduced species; non-native species; non-indigenous species.

*Definition*: taxa in a given area (see below) whose presence there is due to intentional or unintentional human involvement, or which have arrived there without the help of people from an area in which they are alien.

*Interpretation*: taxa can be alien to any definable geographical area, e.g. continents, islands, bio- or ecoregions, or any political entity (e.g. countries, states, provinces). Reference to human involvement in the definition does not include habitat changes, global warming, atmospheric nitrogen fertilization, acid rain, etc. Native species that change their geographical range due to these processes should not be considered aliens unless there is clear evidence of significant leaps in distribution attributable to human-aided dispersal of propagules. For the purpose of particular studies, a geographic modifier should be included of how far a taxon has to be moved by human activities from the border of its native distribution to be considered alien. It would normally be arbitrary where political boundaries are involved, and natural where biogeographic boundaries exist, e.g. between islands and mainlands, on the
borders of phytogeographical regions or wherever there are natural barriers. The term alien also includes all non-native taxa under cultivation. Many alien taxa that currently are not casual aliens, naturalized species or invasive species, may become such in the future.

**Cryptogenic species** (applies to all taxonomic groups, but most often to microscopic or other taxa with poor taxonomic resolution).

*Synonyms:* none known.

*Definition:* species that are not demonstrably native or alien (Carlton, 1996).

*Interpretation:* the term ‘cryptogenic’ is gaining widespread acceptance in the marine invasions literature, has slowly crept into the freshwater realm, but has made only minor inroads into the terrestrial literature. Cryptogenic has been mistakenly used to mean an introduced species whose original home is not known, i.e. of unknown geographic origin, albeit clearly recognized as non-native.

**Casual alien species** (applies to all taxonomic groups)

*Synonyms:* given the difficulties associated with definition of casual plants, there are no consistently used synonyms in the literature [see Pyšek et al. (2004a) for discussion].

*Definition:* taxa that may flourish and even reproduce occasionally as aliens outside cultivation or captivity in an area, but that eventually die out because they do not form self-replacing populations, and rely entirely on repeated introductions for their persistence.

**Naturalized species** (applies to all taxonomic groups)

*Synonym:* established species; feral species (see below).

*Definition:* alien species that sustain self-regenerating populations for a reasonable period of time (see below), unsupported by and independent of humans.

*Interpretation:* naturalized species do not necessarily invade natural, semi-natural or human-made ecosystems. How long a species must persist to be considered naturalized is inevitably arbitrary, and this affects how the definition should be used in practice [see Pyšek et al. (2004a) for discussion relating to plants].

**Feral species** (usually applied to animals [mostly mammals, birds and fish], but also to invertebrates [mostly insects]).

*Definition:* species that have lapsed into a wild form from a domesticated condition.

*Interpretation:* various analogical terms are used for plants introduced to cultivation and subsequently escaping: cultivation relics, garden/greenhouse escapes (Clement and Foster, 1994).

**Invasive species** (applies to all taxa)
**Definition:** invasive species are a subset of naturalized species that produce reproductive offspring, often in very large numbers, are capable of dispersal/movement over considerable distances from the parent populations, and thus have the potential to spread over a large area.

**Interpretation:** 'over considerable distance' is ideally defined, but different criteria are required for different types of organisms. For plants, Richardson et al. (2000a) suggested the following approximate spatial scales: >100 m in <50 years for taxa spreading by seeds and other propagules for dioecious taxa that rely exclusively on seeds for reproduction, this applies only after the introduction of both sexes; and >6 m in 3 years for taxa spreading by roots, rhizomes, stolons, or creeping stems. To our knowledge, no comparable dimensions have been proposed for animals. Organisms should be labelled 'invasive' with reference to a given geographic locality. Organisms that spread previously, but do not spread currently because the total range of suitable habitats and landscapes has been occupied, should still be termed invasive because local eradication will undoubtedly lead to re-invasion. Many alien taxa that are not classified as 'invasive' by the criteria above may become invasive in the future, given time to reach optimum habitats, to make adaptive genetic changes, or when key mutualist partners (mainly for plants) arrive in their new range; some taxa may also become invasive because of the introduction of new genotypes. The definition infers no connotation of impact, although many invasive species do have impact.

**Transformers** (applies to plants)

**Synonyms:** transformers are essentially equivalent with edificators ('environment forming plants'), a term used in the European, especially Russian, literature.

**Definition:** a subset of invasive plants (not necessarily alien) that change the character, condition, form or nature of ecosystems over a substantial area; substantial meaning relative to the extent of that ecosystem.

**Interpretation:** the term is an ecological one; a plant can be a transformer without receiving human attention by way of economic concern or control efforts. Several categories of transformers may be distinguished: excessive users of resources (water, light, oxygen), donors of limiting resources (nitrogen), fire promoters/suppressors, sand stabilizers, erosion promoters, colonizers of intertidal mudflats/sediment stabilizers, litter accumulators, salt accumulators/redistributors, etc. [see Richardson et al. (2000a), Table 1, for examples of species].

**Pests** (applies to all taxa)

**Synonyms:** harmful species; problem species; noxious species. The last term is often used, particularly in USA, for a subset of taxa whose control/eradication is mandatory.

**Definition:** taxa (not necessarily alien) that grow or live in sites where they are not wanted and which have detectable economic or environmental impact or both.

**Interpretation:** for plants, a special term 'weed' is used besides those given above. This term is anthropocentric and a plant is considered a weed if it interferes with
human objectives. The terms ‘environmental weeds’ or ‘species of environmental concern’ are used for alien plant taxa that invade natural vegetation, usually adversely affecting native biodiversity and/or ecosystem functioning [see Pyšek et al. (2004a) for discussion].

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