



Naturalization and invasion of alien plants: concepts and definitions

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Abstract. Much confusion exists in the English-language literature on plant invasions concerning the terms ‘naturalized’ and ‘invasive’ and their associated concepts. Several authors have used these terms in proposing schemes for conceptualizing the sequence of events from introduction to invasion, but often imprecisely, erroneously or in contradictory ways. This greatly complicates the formulation of robust generalizations in invasion ecology.

Based on an extensive and critical survey of the literature we defined a minimum set of key terms related to a graphic scheme which conceptualizes the naturalization/invasion process. **Introduction** means that the plant (or its propagule) has been transported by humans across a major geographical barrier. **Naturalization** starts when abiotic and biotic barriers to survival are surmounted and when various barriers to regular reproduction are overcome. **Invasion** further requires that introduced plants produce reproductive offspring in areas distant from sites of introduction

(approximate scales: > 100 m over < 50 years for taxa spreading by seeds and other propagules; > 6 m/3 years for taxa spreading by roots, rhizomes, stolons or creeping stems). Taxa that can cope with the abiotic environment and biota in the general area may invade disturbed, seminatural communities. Invasion of successional mature, undisturbed communities usually requires that the alien taxon overcomes a different category of barriers.

We propose that the term ‘invasive’ should be used without any inference to environmental or economic impact. Terms like ‘pests’ and ‘weeds’ are suitable labels for the 50–80% of invaders that have harmful effects. About 10% of invasive plants that change the character, condition, form, or nature of ecosystems over substantial areas may be termed ‘transformers’.

Key words. aliens, barriers, biological invasions, casual alien plants, invaders, naturalized species, pests, plant introduction, transformers, weeds.

INTRODUCTION

The expanding field of invasion ecology has seen a proliferation of terms to describe various concepts. There has also been considerable confusion and misuse of existing terminology.

Invasion ecology has perhaps suffered more than most scientific disciplines since the notion of ‘invasion’ frequently evokes anthropocentric concepts (aggression, assault, attack, encroachment, incursion, infringement, intrusion, onslaught, raid, etc.). Several recent contributions

have debated the relative merits of various terms in invasion ecology with special reference to plants (e.g. Jarvis, 1979; Mack, 1985; Di Castri, 1990; Carr, 1993; Binggeli, 1994; Pyšek, 1995; Weber, 1997). Much of the debate on terminology is essentially semantic, and poses little threat to the development of an increasingly robust understanding of invasions (other than bedevilling computerized searches for references). An area of confusion with more profound ramifications for invasion ecology exists around the lack of clarity and consistency in the use of the term 'naturalized'. One problem involves the widespread use of this term as a synonym for 'invasive', thus lumping two overlapping, but not identical, phases in the naturalization/invasion process.

This confusion has clear practical implications. The shift from 'naturalized, noninvasive' to 'invasive' (as we understand these concepts; see later) represents the point at which the presence of an alien species may start to have detectable ecological or economic consequences. The absence of clearly defined, and widely accepted, terminology to describe the status of alien plants confounds the objective formulation of priorities for management (e.g. Westman, 1990).

Many recent studies have described various processes and/or phases that may be identified in the invasion of a new region by an introduced taxon. In conceptualizing these phases it is useful to consider the limiting factors that restrict the spread of introduced taxa in a region as a series of 'barriers' [the concept of barriers was probably first used in connection with biological migrations by De Candolle (1820; p. 45) and later by Cain (1944; p. 149)]. This approach has proved useful in deriving generalizations on various aspects of invasion ecology (e.g. Kruger *et al.*, 1986; Carr, 1993; Reader & Bricker, 1994; Mack, 1996; Richardson & Higgins, 1998). However, the approach loses much of its value if the different stages in invasion are imprecisely defined. The lack of clarity in this regard has unfortunately been exacerbated by the uncritical use of terminology and concepts in several prominent reviews. To cite but one example, Cousens & Mortimer (1995; p. 21), in a chapter on 'The dynamics of geographical range expansion', follow Groves (1986) in advocating that

the process of invasion of an unoccupied region by new taxa may be divided into the following three phases:

1. INTRODUCTION. As a result of dispersal, propagules ... arrive at a site beyond their previous geographical range and establish populations of adult plants.
2. COLONIZATION. The plants in the founding population reproduce and increase in number to form a colony that is self-perpetuating.
3. NATURALIZATION. The species establishes new self-perpetuating populations, undergoes widespread dispersal and becomes incorporated within the resident flora.

In our view, this scheme confuses stages in the naturalization/invasion process. Introduction and establishment (understood as survival, not as reproduction) are clearly fundamental requirements for invasion, and we have no serious problem with lumping these under the broad heading INTRODUCTION. However, we believe that the phases COLONIZATION and NATURALIZATION in the above scheme are incorrectly defined. What is described as COLONIZATION above corresponds with what we believe is an integral part of 'naturalization' (see later) whereas NATURALIZATION in the above scheme conforms to our understanding of 'invasive'.

Does it matter that different authors perceive the naturalization/invasion process differently? We suggest that it is fundamentally important to resolve this issue. Only a small fraction of all introduced taxa reproduce and spread over large areas; most taxa fail at some stage before reaching such levels of success. One of the main tasks of invasion ecology is to explain why some taxa are better invaders than others. This is greatly complicated if the criteria for judging success are poorly demarcated. Similarly, attempts to define correlates of invasibility of different regions are misleading in the absence of objective criteria for the inclusion of taxa on lists of 'invasive' organisms.

One recent example illustrates the type of problem that confronts invasion ecologists. Haber (2000) presents a very valuable list of vascular plants of the Monteverde cloud forest in Costa Rica. However, only about 60% of alien

species are recognized as such (labelled with an asterisk). An explanation that these are 'species introduced or escaped from cultivation' (p. 518) helps us very little, since asterisked taxa span the continuum from taxa persisting temporarily after cultivation (*Brugmansia candida*) to fully naturalized and invasive species (*Impatiens walleriana*). Many recent reviews on various aspects of biological invasions have used just such lists uncritically, with the result that many generalizations that have been proposed are spurious. Obviously, more attention must be paid to clear categorization and terminology in manuals, floras, and checklists which include alien taxa.

In this paper we: (a) examine how the term 'naturalized' is being used in relation to what we consider to be its precise meaning; (b) explore reasons for the lack of consistency; (c) discuss some problems with the current imprecise usage of terms; and (d) suggest ways to confine the use of 'naturalized' and other terms in plant invasion ecology.

METHODS

We first examined definitions of 'naturalized' in various dictionaries and encyclopedias of ecology and other widely cited books dealing with both animal and plant invasions. Next, we searched the TREECD database (1939–98), a CAB Abstracts Forestry Database, published by CAB International, Wallingford, Oxford, UK, for publications with the words 'naturaliz/ sed' or 'naturaliz/sation' in the title, abstract or 'descriptors' (keywords). As the name implies, this database contains references pertaining to *woody* plants; this is appropriate as invasions of woody taxa serve very well for illustrating the general problem of imprecise terminology in plant invasion ecology. After editing our list to remove various nonbiological or otherwise inappropriate papers, our database comprised 157 papers. We also examined all recent books dealing with plant invasions, and our own large personal collections of invasion-related publications. Various regional and national floras and catalogues of invasive taxa were examined to determine the criteria that are used to distinguish between the various categories of alien plants.

RESULTS

The definitions of 'naturalized' in dictionaries, encyclopedias and widely cited books span a wide range (Appendix 1). The main areas of divergence in this sample of 'authoritative' definitions relate to: (a) the role of human assistance considered necessary to establish the alien (see definitions 1 and 2 in Appendix 1); (b) the assumption that, to be naturalized, a taxon must invade *natural* vegetation (see 3, 4, 5 and 7 in Appendix 1); and (c) imprecise statements on the degree to which the alien is established and/or reproducing and self-sustaining (see 6, 8 and 10 in Appendix 1).

In the 157 original papers we studied we were able to distinguish four main categories of use of the words and concepts 'naturalized' and 'naturalization'. In 15% of papers insufficient details were given to categorize the intended meaning.

1 'Naturalized' [the conventional meaning] (23% of articles analysed)

This usage refers to alien plants that reproduce and sustain populations without direct intervention by humans, often producing plentiful offspring, mainly close to parent plants. Such plants do not necessarily invade natural and seminatural vegetation to any extent (although many do). This understanding corresponds to usage by De Candolle (1855; p. 643); Thellung (1911–1912); Sukopp & Trepl (1987); Stace (1991; p. 1190); Huston (1994); Scott (1996); Sell & Murrell (1996; p. 376); Williamson (1996; e.g. p. 37); Crawley (1997; p. 617); Lincoln *et al.* (1998); Provost (1998), among others. This concept conforms with that of 'established' in Williamson (1996; p. 37) and Vitousek *et al.* (1997).

2 'Naturalized' meaning self-sustaining populations in natural or seminatural vegetation (8%)

This usage is similar to '1' except that it considers taxa to be naturalized **only** if they reproduce (regularly) outside human-dominated systems. For example, '... an alien plant is considered to be naturalized when it grows

and reproduces **in the wild state** unaided by humans' (Esler, 1987). This concept is expanded upon by Heenan *et al.* (1998) who define 'fully naturalized' species as those that 'form a **wild population** self-maintained by seed or vegetative reproduction or occur repeatedly **in the wild**'. Clement & Foster (1994) consider naturalized species to be 'established extensively amongst native vegetation so as to appear native' (see also Ghate & Vartak, 1990). Other examples of this usage include Walker (1989); Allaby (1994) and Cronk & Fuller (1995). This usage coincides with the term 'established' as defined by Kloot (1987).

3 'Naturalized' as a synonym for 'alien' [non-native] (25%)

These papers usually refer to plants that are reproducing in the new environment, but give no indication of how well the taxon is established or whether it is spreading. Typical examples of this usage are given in Holub & Jirásek (1967) and Sachse (1995).

4 'Naturalized' as a synonym for 'invasive' (29%)

More publications were placed in this category than in any other. A typical example of this usage is: 'this paper studies the distribution of ... which has spread and naturalized in ...'.

We conclude that a very large proportion of recent publications describing aspects of plant invasions have used the terminology loosely and their lack of rigour has led to confusion.

How are 'naturalized' and 'invasive' species distinguished in regional lists of alien species? Most such lists include some information on the frequency of occurrence of the given taxon. Such information is usually qualitative, using terms such as 'adventive', 'acquired', 'established', 'casual', 'persistent' (Ahti & Hämet-Ahti, 1971; Kloot, 1987; Clement & Foster, 1994); decreasing/increasing (Esler, 1987); established vs. not-established (Knops *et al.*, 1995); expanding vs. nonexpanding (Dafni & Heller, 1990); rare/local/common (Corlett, 1988, 1992); having low/moderate/high impact (Brown & Gubb, 1986), etc. Such definitions do not always enable one to

judge whether the given taxa are 'naturalized' or 'invasive' (see later for recommended definitions).

DISCUSSION

A century of 'naturalization'

One reason for the lack of clarity that has developed in the terminology of plant invasions in English is that different meanings are attached to the term 'naturalized' in different languages. With the emergence of English as the primary language of scientific discourse, the transfer of terminology between other (mainly European) languages and English has introduced some confusion (this problem has also arisen in other fields of ecology; see, e.g. Mooney, 1998; p. 3). The SCOPE programme on the ecology of biological invasions in the 1980s (Drake *et al.*, 1989; see also Mooney, 1998; pp. 93–111) brought together perspectives on invasions from many parts of the world. The publication, in English, of many contributions from non-English speaking regions, in the absence of a clear lexicon, helped to compound the confusion regarding terminology. This is especially evident in the volume on 'Biological invasions in Europe and the Mediterranean Basin' (di Castri *et al.*, 1990), which contains a bewildering array of terms and concepts to categorize alien taxa. Starfinger *et al.* (1998) also collated many useful insights from European authors, but again introduced many new (at least to the international literature in English) terms to describe phases of invasion or categories of invasive plants, notably in the chapter by Falinski (1998). One reason for the complicated classification schemes used in Central Europe may be the strong 'classificatory' tradition in this part of the world (see, e.g. Mayr, 1982; Jahn, 1998).

We suspect that another reason is that the magnitude and dimensions of invasions have changed considerably since the term 'naturalized' was first used. The term was already fairly widely used in the English biological literature in the middle 19th century. For example, Darwin (1859) used the terms 'naturalized', 'naturalization' and 'naturalizing' 35 times (27, 7 and 1 times, respectively) in the first edition of '*On the origin of species*'. This was the time

when naturalists were starting to record the widespread phenomenon of introduced taxa behaving 'like a native' (definition 4 in Appendix 1) in new areas. The term 'naturalized' has been applied uncritically since the middle of the 19th century and now its meaning has become imprecise. We are left with a term whose denotation means 'the process whereby a species is made to act like a native', but it has now taken on a slightly different connotation.

It is instructive to consider some meanings attached to 'naturalized' in European languages other than English. Most Central European phytogeographical studies were published in German. In this literature the term 'naturalization' refers to a process of 'existence' of an alien taxon in its adventive region (including its incorporation into native vegetation) which can have various degrees or levels (Schroeder, 1969; Müller, 1995; Trepl, 1995). This usage appears to originate from the work of A. Thellung who, in the early 1900s, attempted to define and discuss terms like 'native', 'introduced' and 'casual' in French, German and English (see Trepl, 1995). The 'naturalization process' as understood by these European authors, is more or less synonymous with what is now more often called the 'invasion process' (see, e.g. Holub & Jirásek, 1967; Sachse, 1995) or what we call the naturalization/invasion process. This view is discussed in detail by Holub & Jirásek (1967) who wrote about '*Grad ihrer Naturalization*' (degree of naturalization) and defined the naturalization of human-accompanying plants ('*Naturalization der Anthropophyten*') as '*eine bis zur Einbürgerung gehende Anpassung der im Gebiete ursprünglich fremden Pflanzen*' (i.e. a process of adaptation of alien plants that can lead to their incorporation into native vegetation). They explicitly mention particular degrees of naturalization, from the stage of 'ephemerophytes' (casual alien plants; see Table 1), to temporarily established aliens, to those that are permanently present in either natural or human-modified habitats. Holub & Jirásek (1967) proposed special terms for plants introduced intentionally ('*Akklimatization*') or unintentionally ('*Xenonaturalization*').

It may be argued that the bewildering array of concepts and terms used to describe non-native plants in Europe is due to the very long

history of human habitation of the region, which has resulted in many taxa being introduced at different times and in differing numbers. The ways that these plants have organized themselves in the environment may seem to demand a complicated hierarchy of concepts and terms to describe the extent to which they are part of the flora. However, standardization of terminology in this area is highly desirable. What follows is an attempt to define a minimum number of useful terms.

Towards a standardized terminology for plant invasion ecology

The current search for robust generalizations and theories in invasion ecology (e.g. Jarvis, 1979; Williamson, 1996; Shigesada & Kawasaki, 1997; Daehler, 1998; Goodin *et al.*, 1998; Pyšek, 1998; Lonsdale, 1999; Rejmánek, 1999a) demands further elucidation of the naturalization/invasion process. To this end, we propose the simple conceptualization of the process as shown in Fig. 1 (terminology given in Table 1). Following this scheme, invasion is a process requiring a taxon to overcome various abiotic and biotic barriers. Phases of the process can be defined on the basis of the relevant barrier(s) that are (or are not) overcome. **Introduction** means that the plant (or its propagule) has overcome, through human agency, a major geographical barrier (A in Fig. 1). Many introduced taxa survive as **casuals** (also 'waifs', 'persisting after cultivation'); such taxa can reproduce sexually or vegetatively, but fail to maintain their populations over longer periods. Casuals therefore must rely on repeated introduction for their persistence. Naturalization only starts when environmental barriers (B) do not prevent individuals from surviving and when various barriers to **regular** reproduction (C) are overcome. Therefore a taxon can be considered successfully **naturalized** after overcoming barriers A, B and C. At this stage populations are sufficiently large that the probability of extinction due to environmental stochasticity is low (MacArthur, 1972; Menges, 2000; see also Panetta & Randall, 1994 with regard to *Emex australis*). Several authors have attempted to define the degree to which an alien taxon is naturalized. For example, in *Flora Europaea*

Table 1 Recommended terminology in plant invasion ecology

Alien plants ¹	Plant taxa in a given area whose presence there is due to intentional or accidental introduction as a result of human activity (synonyms: exotic plants, non-native plants; nonindigenous plants).
Casual alien plants	<i>Alien</i> plants that may flourish and even reproduce occasionally in an area, but which do not form self-replacing populations, and which rely on repeated introductions for their persistence (includes taxa labelled in the literature as 'waifs', 'transients', 'occasional escapes' and 'persisting after cultivation', and corresponds to De Candolle's (1855, p. 643) usage of the term 'adventive' ²).
Naturalized plants	<i>Alien plants</i> that reproduce consistently (cf. <i>casual alien plants</i>) and sustain populations over many life cycles without direct intervention by humans (or in spite of human intervention); they often recruit offspring freely, usually close to adult plants, and do not necessarily invade natural, seminatural or human-made ecosystems.
Invasive plants ³	<i>Naturalized plants</i> that produce reproductive offspring, often in very large numbers, at considerable distances from parent plants (approximate scales: > 100 m; < 50 years for taxa spreading by seeds and other propagules ⁴ ; > 6 m/3 years for taxa spreading by roots, rhizomes, stolons, or creeping stems), and thus have the potential to spread over a considerable area.
Weeds	Plants (not necessarily <i>alien</i>) that grow in sites where they are not wanted and which usually have detectable economic or environmental effects (synonyms: plant pests, harmful species; problem plants). 'Environmental weeds' are <i>alien plant</i> taxa that invade natural vegetation, usually adversely affecting native biodiversity and/or ecosystem functioning (Humphries <i>et al.</i> , 1991; Randall, 1997).
Transformers ⁵	A subset of <i>invasive plants</i> which change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem.

Notes:

- 1 Some authors suggest that distinction should be made between non-native plants introduced by humans in prehistorical times and those that arrived recently. For example, in Central Europe, 'archeophytes' and 'neophytes' refer to taxa introduced before or after 1492, respectively (Mandák & Pyšek, 1998). In other parts of the world (e.g. Australia; Kloot, 1987), a distinction is sometimes made between taxa that arrived before or after European colonization. On the time scale of decades (necessarily the focus of our treatment), cases of introduction of alien taxa via means not associated with human activity (e.g. by seeds attached to the plumage of migrating birds, or via passive dispersal in strong winds, or by sea currents) are certainly rare (e.g. spontaneous (re)colonization of the Krakatau Islands; Whittaker *et al.*, 1989). Such events have to be treated as natural phenomena. How far must a taxon have been moved before it may be reasonably termed 'alien'? Clearly, the '> 100 km' suggested in Fig. 1 is a rough approximation. Some plant taxa are noted as 'alien' at localities where native populations occur within 100 km (e.g. *Phragmites australis* in West Virginia; Hutton & Clarkson, 1961). Nonetheless, 100 km can, in our view, be used as a practical cut-off in most cases. Under some circumstances, shorter critical distances may be considered (e.g. 30 km, as 32 km separates Great Britain from the mainland Europe). Taxa can be alien to continents, islands, bio- or ecoregions, states, or counties.
- 2 The term 'adventive' has been later used in a much broader sense (*casual* + *naturalized*) by many authors (e.g. Muhlenbach, 1979; Burda, 1991; Provost, 1998).
- 3 A potential complication with this definition concerns taxa which spread previously, but do not spread currently because the total range of suitable habitats and landscapes has been occupied. Such taxa should still be termed invasive because local eradication will undoubtedly lead to re-invasion.
- 4 This also applies to dioecious taxa reproducing by vegetative propagules (e.g. *Salix* spp. via broken branches; Henderson, 1991; Hussey *et al.*, 1997). For dioecious taxa that rely exclusively on seeds for reproduction, '< 50 years' applies only after the introduction of both sexes.
- 5 Transformers are those taxa that have clear ecosystem impacts. Several categories of transformers may be distinguished: (a) excessive users of resources (water — *Tamarix* spp.; *Acacia mearnsii*; light — *Pueraria lobata*, *Rubus armeniacus*; water and light — *Arundo donax*; light and oxygen — *Salvinia molesta*, *Eichhornia crassipes*); (b) donors of limiting resources (nitrogen — *Acacia* spp., *Lupinus arboreus*, *Myrica faya*, *Salvinia molesta*); (c) fire promoters/suppressors (promoters — *Bromus tectorum*, *Melaleuca quinquenervia*, *Melinis minutiflora*; suppressors — *Mimosa pigra*); (d) Sand stabilizers (*Ammophila arenaria*); (e) Erosion promoters (*Andropogon virginicus* in Hawaii, *Impatiens glandulifera* in Europe); (f) Colonizers of intertidal mudflats/sediment stabilizers (*Rhizophora mangle*, *Spartina* spp.); (g) Litter accumulators (*Eucalyptus* spp., *Lepidium latifolium*, *Pinus strobus*, *Taeniatherum caput-medusae*); (h) Salt accumulators/redistributors (*Mesembryanthemum crystallinum*, *Tamarix* spp.).

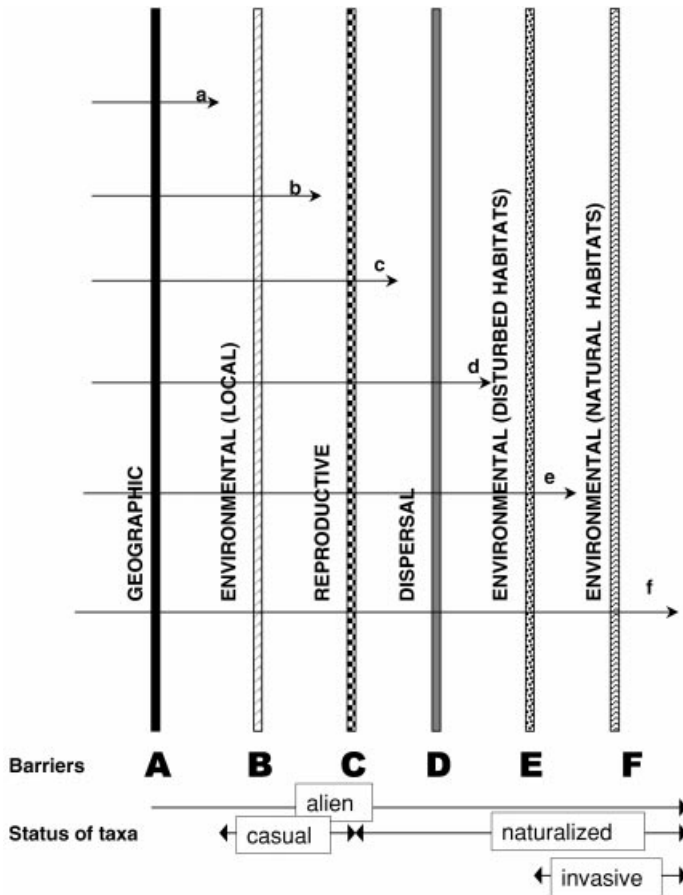


Fig. 1 A schematic representation of major barriers limiting the spread of introduced plants (see text for further details) The barriers are: (A) Major geographical barrier(s) (intercontinental and/or infra-continental; approximate scale: > 100 km; see Table 1, Footnote 1); (B) Environmental barriers (abiotic and biotic) at the site of introduction; (C) Reproduction barriers (prevention of consistent and long-term vegetative and/or generative production of offspring); (D) Local/regional dispersal barriers; (E) Environmental barrier(s) in human-modified or alien-dominated vegetation; and (F) Environmental barriers in natural or seminatural vegetation. Arrows **a** through **f** indicate the paths followed by taxa to reach different states from introduced to invasive in natural vegetation. Crossing of the barriers is not irreversible. For example, climatic fluctuations can either pose new barriers (which could drive alien taxa to extinction at local and/or regional scales), or enable the taxon to survive or spread.

(Tutin *et al.*, 1964) a taxon is considered to be 'effectively naturalized' once it has 'established in a single station for at least 25 years, or is reported as naturalized in a number of widely separated localities'. **Invasion**, i.e. spread into areas away from sites of introduction, requires that introduced plants also overcome barriers to dispersal within the new region (D) and can

cope with the abiotic environment and biota in the general area (E). Many then invade disturbed, seminatural communities. Invasion of successional mature, undisturbed communities usually requires that the alien taxon overcomes resistance posed by a different category of factors (Richardson *et al.*, 2000); (barrier F in Fig. 1).

Deciding whether a taxon should be labelled 'naturalized, noninvasive' ('c' or 'd' in Fig. 1) or 'invasive' ('e' or 'f' in Fig. 1) can be problematic. The two phases are not discrete and there may be a continuum of situations for different taxa, or a single taxon may move through the continuum over time or in space. Is it feasible to make the distinction more objective? Heenan *et al.* (1998), when considering the distinction between 'casual' and 'naturalized' species (essentially 'naturalized' and 'invasive' according to the definitions in Table 1) conclude that 'the main issues ... are the amount of sexual or asexual spread, and the distance of propagules from the parent plant'. We agree. Richardson *et al.* (1994), when considering the distinction between naturalized and invasive *Pinus* spp. in the southern hemisphere wrote: 'For a species to be "invasive" [as in Fig. 1 and Table 1] we required clear evidence that it regenerated naturally and recruited seedlings more than 100 m from parent plants ...'. These authors thus excluded many other pine species, including naturalized species, which may have been able to overcome barriers A through C in Fig. 1, but had not been able to disperse far from sources. This distinction works well for pines and for other tree and shrub taxa that rely on seeds for dispersal. However, two additional qualifications are needed. First, because seedling mortality is usually much higher than adult mortality (Silvertown, 1987; Fig. 5.18), finding a few seedlings > 100 m from parents still does not mean that invasion has started. Consequently, 'reproductive offspring' should be used instead of 'seedlings'. Second, 100 m can be a long or short distance, depending on the time since introduction. We therefore suggest that '> 100 m from parent plants' should be associated with the time interval < 50 years. This should *not* be interpreted as > 2 m/yr. More than 100 m is a necessary component of this definition for plant taxa that depend on propagules dispersed by wind, water, animals, and *unintentionally* by humans (e.g. with equipment used in agriculture and forestry). This definition is inevitably somewhat arbitrary but, in our experience in many parts of the world, useful in practice. According to this definition, many (but not all) *Eucalyptus* species introduced to Africa and the Americas are naturalized but

not invasive (M. Rejmánek & D.M. Richardson, unpublished data). Similarly, many woody species reported as 'invasive' from Berlin (Kowarik, 1995) are in fact just naturalized.

Finally, for plant taxa spreading exclusively vegetatively by roots, rhizomes, stolons or creeping stems, a somewhat different definition is needed. Waiting 50 years to see whether a plant clone expands over 100 m is clearly impractical. However, there will probably be general agreement that an alien taxon that spreads *consistently* by means of vegetative growth > 2 m per year is invasive. To incorporate this condition into an operational definition, '6 m/3 years' could be used as a criterion for taxa spreading by the vegetative means listed above. In California, *Ammophila arenaria* and *Delairea odorata* (= *Senecio mikanioides*) certainly belong in this category.

Another issue requires some clarification. Plant ecologists sometimes use 'invasion' in a slightly different context to that discussed above. For example; 'tree invasion and establishment in old fields' (Myster, 1993); 'limited invasion and reproduction of loblolly pines in a large South Carolina old field' (Golley *et al.*, 1994); 'invasion and persistence of bird-dispersed, subtropical thicket and forest species in fire-prone coastal fynbos' (Cowling *et al.*, 1997) or 'shrub invasion of grassland' (Brown & Archer, 1999). We believe that in the context of such studies (local vegetation succession), it is more appropriate to use the term 'colonization' (*sensu* Brown & Gibson, 1983; p. 559: 'the immigration of a [taxon] into a new habitat and the founding of a new population'). Another term that is used is 'encroachment' (e.g. Hodgkin, 1984). There are certainly many opportunities for integrating insights from invasion ecology with those from research on local vegetation dynamics (Rejmánek, 1989; Vitousek, 1990; Richardson & Bond, 1991; Davis *et al.*, 2000). Nevertheless, although successful alien species often behave very much like native colonizers (Thompson *et al.*, 1995), we suggest that separate terms should be maintained in these fields. After Elton's (1958) book on '*The ecology of invasions by animals and plants*' and recent international programmes on biological invasions (Mooney, 1998; pp. 93–111), most ecologists probably equate 'biological invasions' and

even 'invasions' with the dynamics of **alien** species, rather than the colonization of coastal dunes, abandoned pastures or other ecosystems by **native** species.

In palaeoecological publications, the term 'invasion' (Pielou, 1991; Davis *et al.*, 1998) is used interchangeably with 'spread' (Birks, 1989; Tallantire, 1972) and 'migration' (Davis & Sugita, 1997; Cain *et al.*, 1998). As the last-mentioned term seems to appear most often, its preferential usage is recommended. However, as the spatial scales of 'palaeoinvasions' and 'neoinvasions' are often comparable and the context is always clear, the term 'invasion' is certainly appropriate for palaeoecological studies. In fact, its use clearly indicates that co-operation between palaeoecologists and invasion ecologists is for their mutual benefit (Pitelka and the Plant Migration Workshop Group, 1997; Rejmánek, 1999b).

Implications for national policies and international conventions

This paper has focused mainly on the definitions of the terms 'naturalized' and 'invasive' and on proposing a framework for defining these and other phases in the naturalization/invasion process. A related issue that should also be mentioned here concerns the various definitions applied to 'alien' and 'invasive' species in national and international conventions. Article 8(h) of the Convention on Biological Diversity states that: 'Each Contracting Party shall, as far as possible and as appropriate: Prevent the introduction, control or eradicate those alien species which threaten ecosystems, habitats or species'. This implies (but does not define precisely) that species that cause such damage form a subset of alien species, and that methods are needed to manage such species (and not all alien species). The Executive Order on 'invasive species' issued by the President of the USA on 3 February 1999 defines invasive species as 'alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health'. This represents an attempt to define the subset of alien species for which various control measures need to be implemented, and conforms with the usage of some authors who consider plants to

be 'invasive' only when they cause obvious ecological and/or economic damage (e.g. Cronk & Fuller, 1995; p. 1; Mack, 1997). Examples of definitions following this notion are:

'Invasive species: Non-native species disrupting and replacing native species' (Biotech Resources, 1995–98). 'Invasive species means an alien species which becomes established in natural or semi-natural ecosystems or habitat, is an agent of change, and threatens native biological diversity' (IUCN, 1999).

These definitions of 'invasive' differ from that in Table 1 in that they add connotations of impact. Whether there will ever be a standardized procedure for assessment of the impacts of invasive species is difficult to predict (Williamson, 1998; Parker *et al.*, 1999). However, well-established terms for harmful species (native or alien) already exist: **pests** for all kinds of organisms and **weeds** for plants (Holzner, 1982; Randall, 1997). Our estimate is that between 50 and 80% of invasive plant species can be classified as pests or weeds, depending on actual impacts and human perceptions. The remaining species are 'benign invaders' whose environmental or economic impacts are beyond any practical detection limits in most situations. Examples of such 'benign invaders' are *Aira praecox*, *Arabidopsis thaliana*, *Cakile edentula*, *Cypselaa humifusa*, *Elatine ambigua*, *Epipactis helleborine*, *Lindernia procumbens*, *Lythrum tribracteatum*, *Myosotis stricta*, *Petrorrhagia dubia*, *Spergularia platensis*, *Teesdalia coronopifolia*, and *Velezia rigida*.

Elton's (1958) classic book on invasions is a clear starting point for invasion ecology as a new discipline. Unfortunately, Elton never defined the terms 'invasion' or 'invader'. Most of his examples are introduced species that had profound economic and/or environmental impacts since the best data are available for such taxa. However, Elton (1958) also discussed the spread of some alien species which do not have any obvious impacts (e.g. *Lamium album* and several fresh-water shrimps). He also used the term 'invaders' with reference to the intermixing of faunas during the Pliocene. Therefore, it seems that he applied the terms 'invasion' and 'invader' rather broadly, without obligatory connotations of impact. This is also how the term 'invasion' was understood by other ecologists of

the time ('Invasion — The movement of plants from one area to another, and their colonization in the latter; Clements, 1949; p. 284), and how it was originally defined by Goeze (1882; p. 109). This is how the term is used by most ecologists today, and how it is commonly used in textbooks with reference to alien species [e.g. 'Invasions of exotic species into new geographical areas sometimes occur naturally and without human agency. However, human actions have increased this trickle to a flood ... Many introduced species are assimilated into communities without much obvious effect' (Townsend *et al.*, 2000; p. 500)].

There may well be a need for a universally acceptable, and objectively applicable, term for the most damaging invasive plant taxa within given regions, or globally. In our view, a potentially useful term to use in this regard is '**transformer species**', proposed by Wells *et al.* (1986) and referring to a subset of invasive plants which 'change the character, condition, form or nature of a natural ecosystem over a substantial area' (see examples in Table 1). It is these species, comprising perhaps only about 10% of invasive species, that have profound effects on biodiversity and that clearly demand a major allocation of resources for containment/control/eradication.

Based on the above, we suggest that 'invasive' should be used with reference to the 'biogeographic/demographic' status of a species without any connotation of impact.

We believe that the simple scheme proposed in Fig. 1 and Table 1 captures the most important concepts and defines them in ways that will permit widespread application and acceptance. We hope that authors will consider using the terms 'alien', 'naturalized' and 'invasive' as defined here. If they prefer different terminology then, at least, precise definitions should be provided.

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Appendix I Definitions of 'naturalized' in dictionaries and encyclopedias of ecology, floras and other volumes

- 1 Scott (1966) CONCISE ENCYCLOPEDIA: BIOLOGY
'The successful establishment of animals and plants ... in an area in which they had not previously existed. In the restricted sense ... used only when the process is fully intentional and planned by human agency. In the broader sense ... also includes ... those whose introduction is entirely accidental and whose presence at the time of introduction may be unknown ...'
- 2 Gray (1967) THE DICTIONARY OF BIOLOGICAL SCIENCES
'The enforced adaptation, usually with human aid, of an organism to a foreign environment'
- 3 Walker (1989) CHAMBERS BIOLOGY DICTIONARY
'Introduced from another region but growing, reproducing and maintaining itself in competition with the native vegetation'
- 4 Allaby (1994) THE CONCISE OXFORD DICTIONARY OF ECOLOGY
'Applied to a species that was originally imported from another country but now behaves like a native in that it maintains itself without further human intervention and has invaded native communities'
- 5 Huston (1994; p. 322) BIOLOGICAL DIVERSITY
'... are able to establish in existing plant communities and become **naturalized** and of these 10 only five are actually able to spread beyond the site of introduction'
- 6 Lever (1994; p. 279) NATURALIZED ANIMALS
'**Naturalization**: The introduction of animals and plants to places where they are not indigenous, but in which they may flourish under the same conditions of those that are native. More particularly, the establishment of self-perpetuating populations unsupported by and independent of man of an introduced species in a free-living state in the wild'
- 7 Cronk & Fuller (1995; p. 15) PLANT INVADERS; THE THREAT TO NATURAL ECOSYSTEMS
'Once introduced, an invasive plant must become established beyond the site of initial introduction to form large self-sustaining populations in natural or seminatural vegetation [...] This stage is known as **naturalization** ...'
- 8 Sell & Murrell (1996; p. 376) FLORA OF GREAT BRITAIN AND IRELAND (VOLUME 5)
'An alien plant which has become self-perpetuating in the British Isles'
- 9 Williamson (1996; p. 33) BIOLOGICAL INVASIONS
'Established — with a self-perpetuating population, **naturalized**, feral and breeding successfully, released and breeding successfully'
- 10 Crawley (1997; p. 617) PLANT ECOLOGY (2nd ed)
'*alien* plant species that have formed *self-replacing* populations based on recruitment from seed or spread of vegetative fragments'
- 11 Lincoln, Boxshall & Clark (1998) A DICTIONARY OF ECOLOGY, EVOLUTION AND SYSTEMATICS
'used of an alien or introduced species that has become successfully established'
- 12 Olejniczak (1998) THE ENCYCLOPEDIA OF ECOLOGY AND ENVIRONMENTAL MANAGEMENT
'Describing species that have established themselves and are flourishing following their introduction to a non-native region'

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