An Integrated Approach to the Ecology and Management of Plant Invasions

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Abstract: *Plant invasions are a serious threat to natural and managed ecosystems worldwide. The number of species involved and the extent of existing invasions renders the problem virtually intractable, and it is likely to worsen as more species are introduced to new habitats and more existing invaders move into a phase of rapid spread. We contend that current research and management approaches are inadequate to tackle the problem. The current focus is mostly on the characteristics and control of individual invading species. Much can be gained, however, by considering other important components of the invasion problem. Patterns of weed spread indicate that many species have a long lag phase following introduction before they spread explosively. Early detection and treatment of invasions before explosive spread occurs will prevent many future problems. Similarly, a focus on the invaded ecosystem and its management, rather than on the invader, is likely to be more effective. Identification of the causal factors enhancing ecosystem invasibility should lead to more-effective integrated control programs. An assessment of the value of particular sites and their degree of disturbance would allow the setting of management priorities for protection and control. Socioeconomic factors frequently play a larger part than ecological factors in plant invasions. Changes in human activities in terms of plant introduction and use, land use, and timing of control measures are all required before the plant invasion problem can be tackled adequately. Dealing with plant invasions is an urgent task that will require difficult decisions about land use and management priorities. These decisions have to be made if we want to conserve biodiversity worldwide.*

Un enfoque integrado a la ecología y manejo de las invasiones de plantas

Resumen: *La invasión de plantas constituye una seria amenaza a nivel mundial tanto para los ecosistemas naturales, como para aquellos bajo manejo. El número de especies involucradas y la extensión de las invasiones existentes hace que el problema sea virtualmente intratable, y probablemente se empeorará a medida que más especies sean introducidas en nuevos hábitats y las plantas invasoras existentes se muevan hacia una fase de rápida dispersión. Nosotros sostenemos que la investigación actual y los enfoques de manejo son inadecuados para abordar el problema. En su mayoría el enfoque actual se centra en las características y control de las especies invasoras a nivel individual. Sin embargo, mucho más puede ganarse si se consideran otros componentes importantes del problema de invasión. Los patrones de dispersión de las malezas indican que muchas especies presentan una larga fase de retardo después de la introducción, antes de dispersarse en forma explosiva. La detección temprana y el tratamiento de las invasiones antes de que la dispersión en forma explosiva ocurra prevendrá muchos problemas futuros. En forma similar, sería más efectivo centrar la atención en el ecosistema invadido y en su manejo, en lugar de hacerlo en las especies invasoras. La identificación de los factores causales que acrecientan la propensión del sistema a ser invadido tiene que conducir a programas de control integrado más efectivos. Una evaluación del valor de cada sitio y su grado de perturbación puede permitir establecer un marco de prioridades de manejo para la protección y el control. Los factores socioeconómicos frecuentemente juegan un papel más importante que los factores ecoló-*

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gicos en las invasiones por plantas. Cambios en actividades humanas en términos de introducción y utilización de plantas, uso de la tierra y tiempos de las medidas de control, son factores requeridos antes de que el problema de la invasión de plantas pueda ser atacado adecuadamente. Tratar con las plantas invasoras es una tarea urgente que requerirá difíciles decisiones sobre el uso de la tierra y las prioridades de manejo. Estas decisiones deben tomarse si queremos conservar nuestra biodiversidad a nivel mundial.

Introduction

Plant invasions have become increasingly recognized as a major threat to both natural and human-exploited ecosystems worldwide (Usher 1988; Usher et al. 1988; Soulé 1990; Westman 1990; U.S. Congress, Office of Technology Assessment 1993). In any particular region, there can be large numbers of invasive plants causing serious environmental damage (either local or widespread) and other plants that have the potential to cause serious damage in the future. In many parts of the world, the full extent of the problem of invasive plants has not been fully documented, but available information indicates its importance. For instance, there are estimated to be over 2000 species of non-native plants in the United States, a substantial proportion of which cause significant economic and ecological damage (U.S. Congress, Office of Technology Assessment 1993). In Australia, 1500–2000 species of plants have been introduced since European settlement; over 200 are considered noxious weeds in one or more states, and many are important environmental weeds (Humphries et al. 1991; Parsons & Cuthbertson 1992). In both the U.S. and Australia, certain invasive plant species have the ability to spread over large areas or to acutely threaten an ecosystem over its continental range, yet plant introductions continue at an alarming rate (U.S. Congress, Office of Technology Assessment 1993; Rejmánek & Randall 1994).

The number of species involved and the scale of the problem make invasive plants one of the major problems facing land managers. Despite this, there is no overall framework within which research and management priorities can be set. A report by the Office of Technology Assessment of the U.S. Congress (1993) stated that "Although much information on non-indigenous species exists, overall it is widely scattered, sometimes obscure, and highly variable on quality and scientific rigor" and that "Summary lists for most non-indigenous species do not exist for most types of organisms. This gap is especially large for non-indigenous insect and plant species . . ." Weed science is an active area with many practitioners, but many work on the control of individual species or in limited geographical areas. There is also little overlap between weed science and ecology or conservation biology. Ecologists have largely failed to devote the effort to plant invasions that the current and potential effects of these invasions demand. We aim to provide a preliminary framework that will catalyze further work in this area. We first examine the problem of plant invasions and discuss its components. From this analysis we develop a framework for setting priorities for management action. We discuss the need for a shift in emphasis from an individual species approach to an ecosystem and socioeconomic approach, and a shift in emphasis from control to prevention.

Research into and management of plant invasions largely center on the characteristics of the invading plant and the development of efficient control measures. Control measures can include physical, chemical, and biotic methods, but generally all are aimed at the particular plant species regarded as problems. We argue that plant invasions have three other important components: (1) the spatial and temporal dynamics of the spread of invading populations, which is frequently overlooked in control programs; (2) the structure and dynamics of the ecosystems being invaded; and (3) the effects of human activities on these components (Fig. 1).

The Invading Plant

Control

Most of the emphasis in weed science is on developing methods of control of individual invading species. Control can be physical, chemical, or biological. Physical removal may involve mechanical methods, such as mowing, or manual removal such as hand-pulling or burning (U.S. Congress, Office of Technology Assessment 1993). Manual removal has been advocated as the most envi-

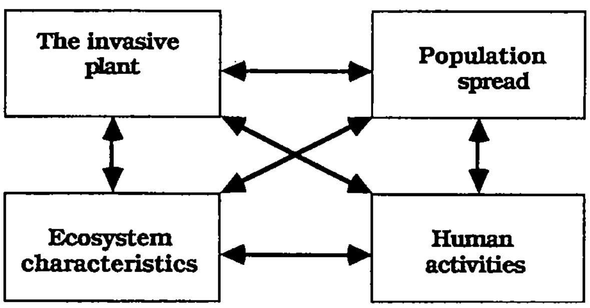

Figure 1. Components of plant invasions.

ronmentally friendly method of weed removal in native vegetation in Australia (Bradley 1988; Buchanan 1989), but this type of control is labor intensive and can be applied only to relatively small areas where large volunteer groups or other bodies are available. Given the large areas where weed control is required, physical removal can often play only a small part in a control program.

Herbicides remain the most commonly used form of control, despite possible adverse environmental effects. Newer herbicides are less toxic, have shorter residence times, and are more specific. Thus, for example, judicious herbicide use can now eliminate undesirable plant species while rendering little effect on native or desirable plant species. Research into chemical control includes the development of more efficient and environmentally friendly herbicides, but it also requires study of target species to assess their susceptibility at various stages in the life cycle. The impact of herbicide or herbicide residuals on other ecosystem components such as soil organisms receives relatively little study. Although herbicides can be applied more readily to larger areas than physical control, many broad-scale problems may not be treatable with herbicides. This is particularly the case in marginal grazing lands where the productive capacity is low and herbicide use is not economically feasible.

Biocontrol methods involve searching for predators or pathogens that control the invading plant's population growth in its native range and that can be safely introduced into the invaded area to act as a control agent. This strategy requires the development of a considerable body of detailed information about the invading plant's biology, genetics, native range, and ecological interactions. Organisms attacking the plant at various life-cycle stages have to be considered and tested, and their impact on the environment to which they will be introduced has also to be assessed. The process of searching for and developing biocontrol agents is lengthy and complicated (Briese 1993; Malecki et al. 1993). When successful, biocontrol can have a major impact on the invading plant (for example *Cactoblastis cactorum*'s control of *Opuntia*; Dodd 1940; Monro 1967), but failures far outnumber successes (Julien 1992). The effectiveness of control agents may also vary markedly on a regional scale (Bossard & Rejmánek 1994). The introduction of biocontrol agents is, itself, not without risk (Miller & Aplet 1993), and it is possible for biocontrol agents themselves to become harmful invading species. For instance, *Cactoblastis cactorum*, which successfully controlled *Opuntia* in Australia, now poses a potential threat to prickly pear cacti throughout the United States following its invasion of Florida from the West Indies, where it was introduced as a control agent (Kass 1990). The effects of the introduction of biocontrol agents on nontarget components of ecosystems have seldom been investigated in detail. The low success rate (one in six worldwide; Crawley 1989; Julien 1992), the amount of research and development time and resources needed for each weed species, and the need to assess potential ecosystem-wide risks, mean that biocontrol will never become a major component of control strategies except for a very few species.

All the various options available for weed control have various associated risks. Control measures are rarely initiated before a large infestation is evident. Often no one measure will be sufficient in itself, and the development of integrated pest management strategies for invasive plants needs to be hastened. This involves not just control of the plant itself, but consideration of broader ecosystem characteristics and processes.

Identification

As well as control measures for established weed species, it is desirable to attempt to limit the introduction of potential weeds. There have been numerous attempts to develop predictive means of identifying species that are liable to become invasive. Various studies have examined seed, juvenile, and adult traits to determine if a clear invasive syndrome can be recognized (Baker 1965; Noble 1989; Perrins et al. 1992*a*). But attempts to predict which invading species are likely to become important weeds have largely been unsuccessful. A broad set of characteristics of successful invaders can be put together, yet this still does not provide a useful mechanism for predicting the responses of individual species (Perrins et al. 1992*b*; Lodge 1993*a*; Lodge 1993*b*). Likely invasiveness has been shown to be related to such factors as the distributions of species in their native habitats, weediness elsewhere, and length of time since introduction (Panetta & Mitchell 1991*a*, 1991*b*; Scott & Panetta 1993). Successful invasion depends not only on the characteristics of the invading species but also on the characteristics, dynamics, and history of the site being invaded. This suggests that invasions are individualistic in nature, depending on the chance congruence of a number of plant and site factors at a particular time (Crawley 1987)—the occurrence of an "invasion window" (Johnstone 1986). Studies within particular plant groups indicate that some separation between invasive and noninvasive species may be possible, but again they show that factors other than plant characteristics can be as important in determining the outcome of potential invasions (Richardson et al. 1990, 1995; S. Reichardt, unpublished data). A useful approach may be the identification of functional groupings of invaders on the basis of their response to particular disturbances or management actions.

While the continued development of means of assessing the invasibility of plant species is an important component of a strategy to limit invasions, this enterprise has to be tied to other components discussed below.

Nevertheless, there is a good case for the development of stronger quarantine laws and more rigorous implementation of existing laws that restrict the transport and import of species that are likely to be invasive. This is especially important in view of the current move towards freer world trade. For quarantine regulations to be effective, there also needs to be a move toward adequate screening methods and assessment of the potential benefits of a species against the risks involved with its impact. This is especially true for species that are deliberately introduced for use in agriculture, forestry, or horticulture. Importers reap the benefits derived from the import of nonnative species but have no responsibility for any effects the species might have should they prove invasive. Risk evaluation requires careful development, but it could be based on the likelihood of the species being invasive and causing significant environmental damage. The development of lists of "clean" species that are known to be benign and "dirty" species known to be invasive has been discussed in detail in a report by the U.S. Congress, Office of Technology Assessment (1993).

Spread

Examination of the dynamics of range extension for invasive species for which information exists indicates a recognizable pattern of population spread (Fig. 2) in which populations remain small and localized, often for long periods, before a sudden explosive range expansion (Auld et al. 1983; Mack 1985; Auld & Tisdell 1986; McFadyen & Harvey 1990; Braithwaite et al. 1989; Griffen et al. 1989; Hobbs 1993; Lonsdale 1993). Factors determining the shape of the curve of population growth for particular species are poorly understood, and few comparative studies have been conducted (Perrins et al. 1993; Pysek & Prach 1993). The initial phase of slow spread illustrated in Figure 2 is often termed the lag phase and can last 70–100 years. Such a pattern could be the result of a number of factors. First, the invading species may maintain a stable, low population level for a number of years, during which time genotypes develop that are able to spread rapidly. Second, the invading species may maintain a stable population until an episodic event or a certain set of environmental conditions occur and allow rapid population spread. Finally, the invading species may have a population that is growing more or less continuously but is not noticed until it becomes widespread—a population undergoing exponential growth would exhibit such behaviour. There is little evidence that the first case occurs, but both of the other two cases are possible. In fact, there are clear instances in which rapid spread has been initiated by episodic events such as floods (Griffin et al. 1989) or by events such as the introduction of pollinators (McKey & Kaufmann 1991). It is hard to assess the importance of the

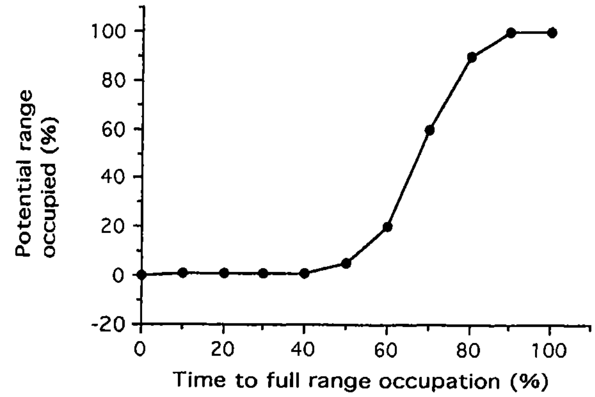

Figure 2. Stylized representation of the spread of an invasive plant species over time.

third case because historical data are generally the only source of information available. Clearly, research is required to determine the level of monitoring necessary to detect population spread, and hence the change from slow to rapid spread.

Because it is difficult to predict which species will become problem weeds from species characteristics alone, we need to develop a predictive capability based on other factors. Early recognition of the transition to rapid spread would allow early control of invasions. Some work has been conducted into factors that accelerate the rate of spread of invaders. For instance, the area of infestation will be a geometric function of time if numerous widely spaced foci of invasion develop and a linear function if spread is mainly from a single focus (Mack 1985; Moody & Mack 1988). Examples of rapid plant spread show a mixture of short-distance dispersal around a primary focus and long-distance spread to new sites, with subsequent short- and long-distance dispersal from the secondary sites (Wilson & Lee 1989). Where data are available on both the number of infestations and the areal extent of the invasion over time, it is clear that the number of infestations starts increasing rapidly some time before the rate of areal spread increases (for example, for *Mimosa pigra* in Northern Australia; Braithwaite et al. 1989; Lonsdale 1993). Monitoring to detect widely spaced secondary foci could provide a means of early detection of potential problems. The question becomes one of when action should be taken: for instance, should eradication measures be initiated when the species develops one additional population, several additional populations, more than 10 additional populations? It seems that there is a greater likelihood of success if measures are taken as early as possible. Similarly, species that are currently not abundant but that are present in many localities should also receive priority attention.

The importance of early control of invasive species needs to be brought to the attention of managers, who may be unwilling to divert resources from other apparently more pressing problems. Because large numbers of introduced species may still be in the lag phase, there is the potential for many more species to become problems. Early detection and control must become an important component of the management of plant invasions (Hobbs 1993). Chippendale (1991) demonstrated that early intervention can significantly reduce the social cost of weed invasions (Fig. 3). If managers are informed of this kind of analysis and presented with success stories in which weed problems have been successfully tackled early, the value of early intervention should become self-evident. Early detection requires an informed and vigilant public. Hence, education and information transfer on invasive species is a priority for action. Together with detection of spread, management actions to prevent or reduce spread should be taken. This involves activities such as setting up buffer zones around susceptible or valuable areas and implementing hygiene procedures. Restriction of road construction or vehicle movement is another obvious way to reduce invasions because vehicles are well-known dispersal agents (Amor & Stevens 1976; Amor & Piggin 1977; Lonsdale & Lane 1991). Methods to control or eliminate already established invaders may be more drastic or costly and less popular than preventive measures.

Ecosystem Management

The Invaded Ecosystem

Two issues need to be considered in the context of the invaded ecosystem. First, methods of managing ecosystems to prevent or control weed invasion need to be developed. Second, a system for the assignment of protection and control priorities needs to be developed based on ecosystem vulnerability and value in terms of production or conservation. These measures shift the focus of weed control away from the actual species toward the overall system in which the invader is only one component.

This concept of focusing on the invaded ecosystem rather than the invader has yet to be fully embraced by conservation managers. It is becoming clear that ecosystems vary in their susceptibility to invasion and that this susceptibility can be altered by management activities. It is often unclear which characteristics of ecosystems contribute to their resistance or vulnerability to invasion. Of course, not all invasions can be directly linked to particular ecosystem modifications, and many invasions may represent simply the exploitation of a new environment by an aggressive nonnative species. But ecosystem characteristics and their modification often do have a direct bearing on the success or failure of particular invasions, and some generalizations concerning this are emerging.

It is becoming generally accepted that disturbance is a major factor affecting the invasibility of natural ecosystems (Rejmánek 1989; Hobbs 1991; Hobbs & Huenneke 1992). Natural disturbances such as floods and storms may be important in some cases, but human-induced disturbances such as changed grazing or fire regimes, fragmentation, nutrient enrichment, and road construction are also of major importance. Not all disturbances enhance invasibility, and disturbance type, size, and distribution can all influence the likelihood of invasion (Hobbs and Atkins 1991; Bergelson et al. 1993; De Ferarri & Naiman 1994). Cale and Hobbs (1991) and Humphries et al. (1991) have argued that attempts to control weeds without addressing the causes of the invasion are doomed because they treat symptoms rather than causes. The changes in ecosystem structure or processes that allow the initiation or intensification of weed invasion have to be addressed before effective weed control can be achieved.

For example, MacLeod et al. (1993) suggest that control of woody weed invasion in Australian rangelands may require removal of grazing pressure and reinitiation of periodic fires. Brown and McIvor (1993) also advocate periodic fire as a potential way of limiting weed spread, but this in turn demands that sufficient fuel be allowed to build up. This generally can happen only in the absence of stock grazing. MacLeod et al. (1993) further argue that it may, in fact, be very difficult to reverse the process of invasion in these systems. Where invasion is initiated and enhanced by the predominant management regime (current patterns of stock grazing), one must inevitably question whether that management regime is appropriate. Ecosystem management questions

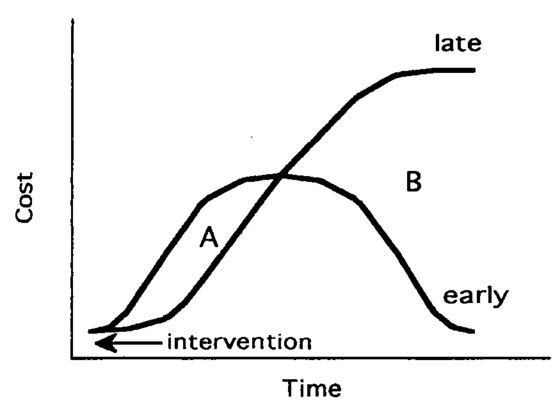

Figure 3. Total social cost of a plant invasion (incorporates the costs of damage due to the invasion and the costs of control) in relation to timing of intervention (early versus late). Costs of early expenditure (area A) and the resulting benefit (area B) (after Chippendale 1991).

are, of course, strongly influenced by socioeconomic factors.

A further example of the need to consider the underlying causes of invasions before embarking on extensive and costly control measures is given by Doren et al. (1991). In this study, experimental manipulation of the fire regime was carried out in an attempt to control invasion, but this had no effect. The invasions were, in fact, promoted primarily by the practice of rock ploughing, carried out from the 1950s through the 1970s, which crushed the limestone substrate and presumably altered nutrient and hydrological regimes. No feasible management activities are likely to alter the impact of this massive disturbance.

Identification of underlying causes of ecosystem modification that enhance invasion is thus an important part of the process of developing adequate management strategies. There is still considerable scope for research into these causal linkages. The above examples also indicate that some assessment of the reversibility of ecosystem change needs to be made so that the likelihood of success of control programs can be estimated. Not only should the reversibility of the factors leading to invasion be considered, but also the reversibility of changes caused by the invader itself. Invading species are capable of altering ecosystem properties, often in dramatic ways. Species such as *Mimosa pigra* and *Thunbergia grandiflora* completely alter the structure of the ecosystems they invade (Humphries 1993).

Ecosystem function can also be radically altered. For instance, Graf (1978) and Loope and Sanchez (1988) documented changes in fluvial geomorphology following invasions of a water course by *Tamarix* spp. Changes to nutrient cycling following plant invasions have been noted by Versfeld and van Wilgen (1986), Vitousek and Walker (1989), and Stock and Allsopp (1992). Prevention of regeneration of native species and changes to fire regimes following invasions have also been noted (Baird 1977, Hobbs & Atkins 1991; Woods 1993). Changes to fire regimes following invasion by grass species have caused massive ecosystem-level changes in a number of systems (Hughes et al. 1991; Whisenant 1990; D'Antonio & Vitousek 1992). If ecosystem structure and function have been altered significantly by invading species, control of the invader will not necessarily restore the ecosystem to its pre-invasion state. Removal of the initial factors enhancing invasion of a system may also have little influence. For example, Brandt and Rickard (1994) illustrated how *Bromus tectorum* remained dominant even after long periods without cattle grazing or cultivation. In these cases the distinction between symptom and cause becomes unclear, and the invader itself becomes a major cause of ecosystem disruption.

A further factor to consider in terms of ecosystem management is post-control revegetation. Where weed invasions have been extensive, the removal of one weed species may simply produce ideal conditions for the establishment of other invaders (Stockard & Nicholson 1985). Thus, weed control must be integrated into an overall program of ecosystem management, including the promotion of regeneration of native species.

Management Priorities

Because of the scarcity of resources available for conservation management and restoration, some means of setting priorities for action need to be established. We suggest a framework for this, based on the relative degree of disturbance of sites and their relative value in terms of production or conservation (Fig. 4). In this diagram, four distinct regions can be recognized in which the type of action required is fairly evident. In the bottom right of the diagram are sites of high value (as defined by the situation) that are relatively undisturbed (given that few areas are completely free from human disturbance). Such sites are liable to be relatively free of invasion at present, and thus the management objective should be to keep them that way. These sites could be treated as "fortresses," and management resources should be directed at minimizing human-induced disturbance and the dispersal and establishment of invaders. At the top right are sites of high value that are subjected to greater levels of disturbance and that hence are more susceptible to invasion. The management objective here should be to change these sites to high value and low disturbance by

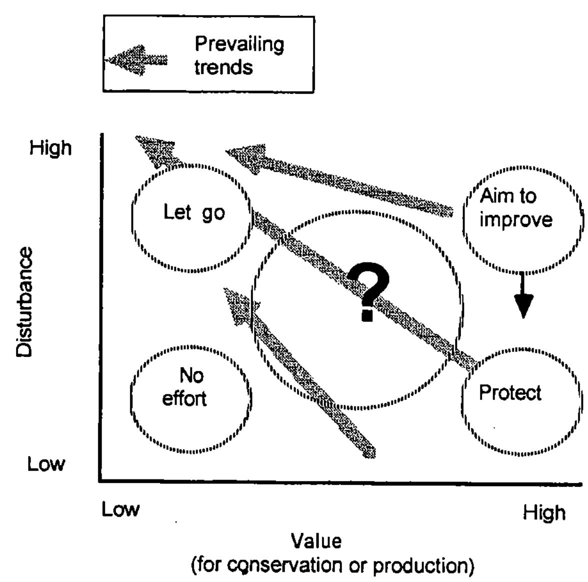

Figure 4. Assessment of management priorities for a region based on the relative value of different sites for conservation (or in some cases production) and their relative degree of disturbance.

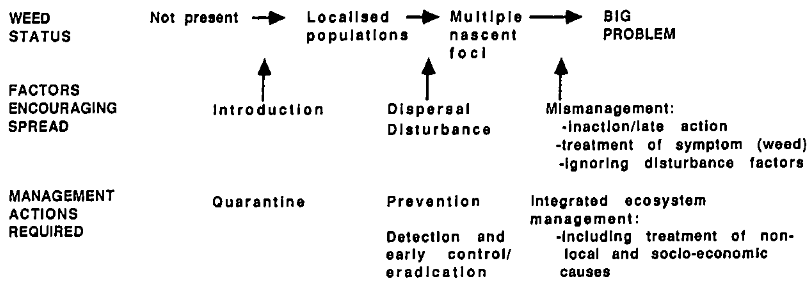

Figure 5. Phases of weed invasion, showing factors encouraging spread and management actions required at each stage.

reducing or removing the disturbing influence, controlling current invasions, and preventing further invasion. Most control-related management activity should be directed at such sites. In the bottom left of the diagram are sites of low value that are subject to low levels of disturbance. These sites should require little or no management input. At the top left are sites of low value that are subject to high levels of disturbance. Although these sites may be subject to rapid change and extensive invasion, they should be regarded as a low priority for management action because attempts to control invasions are unlikely to succeed. These four regions in the diagram may have relatively clear management priorities, but the large area in the middle represents areas where priority assessment is more difficult. The prevailing trend is one of transition from the bottom right to top left as environmental degradation becomes more widespread. Attempts to reverse this trend are liable to be costly and time consuming, and the allocation of resources to these efforts must be based on a rational, cost-benefit approach that takes into account factors such as reversibility, ease of treatment, and likelihood of success.

The ecosystem approach to management of invasive plants needs to be placed in a regional context (Hynes & Scanlan 1993). For instance, water courses and riparian areas represent ecosystem types highly vulnerable to invasion (Humphries et al. 1991; Pysek & Prach 1993; DeFerrari & Naiman 1994). Spread of aquatic and riparian weeds often occurs by transport of seeds downstream. Any control program should therefore concentrate on the upper parts of a catchment first so that control areas are not reinvaded from upstream. Similarly, although a particular area may have relatively low value per se, it may be important in a regional context, and treatment of invasion problems may be necessary to minimize spread into adjacent areas of higher value.

Human Activities

Most of today's weed problems arise from past and present human activities. We argue that socioeconomic factors are the major force driving most plant invasions and preventing their adequate treatment. This concept is illustrated in Figure 5, which shows the course of a plant invasion from early introduction to its development into a major weed problem. At each stage of the invasion, human activities act to encourage spread, and changes in human behaviour are required to deal with current weed problems and to minimize future problems.

The first stage of invasion is introduction of the invading species. Plant species are continually spread around the earth and moved from one region, country, or continent to another. Species have been and continue to be deliberately introduced as agricultural or feed crops and for horticulture. They have been accidentally introduced through seed contamination or inadvertent dispersal. Inadvertent movement of seeds by humans has been recognized as the major factor influencing the distribution of nonnative species in some regions (Chaloupka & Domm 1986). Despite the knowledge that species with a broadly defined range of "weedy" characteristics can be recognized, such species can generally still be introduced and promoted for agricultural or horticultural reasons. Lonsdale (1994) surveyed the history of introduction of exotic pasture species in northern Australia and found that of over 2000 accessions only 5% came to be recommended as useful and 13% were listed as weeds. Two-thirds of the weeds also became weeds of crops. It can happen that agricultural or range scientists promote the use of species for which other scientists are developing weed-control measures. Clearly, therefore, a first step in minimizing future weed problems is the development and rigorous implementation of adequate quarantine legislation (Fig. 6) that covers species that cause environmental damage as well as those that cause economic losses. The cessation of the promotion and use of known or suspected weedy species by government agencies, or at least a sensible assessment of their potential risks, would also be a valuable step forward. This applies both to recent introductions and to species already in horticultural or agronomic use that may be "sleeping giants" whose populations have not yet commenced rapid increase. The early recognition of this phase of rapid increase may allow early eradication or control. Restriction of factors allowing spread and establishment

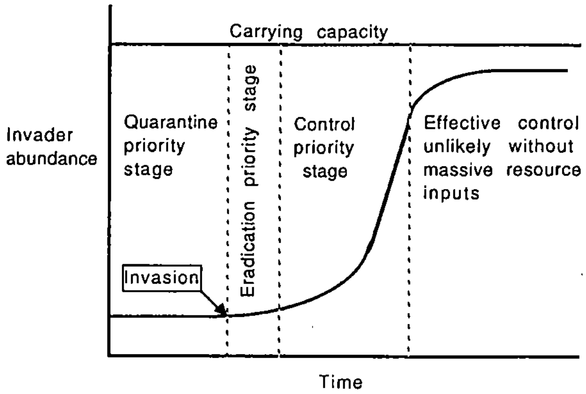

Figure 6. Phases of weed invasion and priorities for action at each phase. Ease of treatment of an invasion problem declines from left to right (after Chippendale 1991).

may also prevent the invader from moving into the phase of rapid spread. For preventative and early detection measures to be successful, much greater levels of awareness of the value of these approaches are needed. Managers and management agencies may have all their available resources directed at dealing with the major weed problems that are already evident, but redirection of resources into prevention and detection is essential if we are to attack effectively the problem of plant invasions.

Lack of early treatment leads to the development of a major weed problem (Figs. 5 and 6), and this process can be exacerbated, as we have discussed, by inappropriate land-management practices (Fig. 5). It is at this late stage of the invasion process that most management resources are currently directed. Most major weed-control programs get underway only after a particular species is an obvious problem, and most biocontrol research is directed at these recognized problem species.

It may be that many weed problems are too intractable to be tackled economically, and invaded areas may have to be relegated to holding operations in which control efforts are abandoned and only further weed spread is restricted. Resources can then be directed instead at preventative methods in priority areas. Changes in prevailing management regimes may also be necessary, which may involve difficult economic and social decisions. For instance, if current patterns of stock grazing are the major force altering ecosystem susceptibility to plant invasions in northern Australia, the long-term viability of this type of management must be questioned. Instead of devoting huge amounts of resources to the ongoing treatment of the weed problems in this area, as demanded by the current socioeconomic set-up, modification of the socioeconomic causal factor (current pastoral practices) may be the only effective solution. This may eventually happen anyway as continued invasions render the industry economically nonviable. Changing the land-use patterns before change becomes inevitable could be approached optimistically as an opportunity for diversification and the development of a socially richer, sustainable land-use based on care rather than exploitation of the land.

Summary

Current research and management approaches to the problem of plant invasions are simplistic and inadequate. The huge potential and actual effects of plant invasions on natural and managed ecosystems demand that a more comprehensive and integrated approach be developed and rapidly implemented. We have presented a first step toward such an approach in the hope that this will stimulate its further development. The following main points have emerged:

(1) An integrated program of prevention, detection, early control, and ecosystem management carried out at all stages of the invasion process is required. The current emphasis is on control measures implemented once a species has become a major problem.

(2) Research on plant invasions needs to be directed at elucidating the linkages between disturbances and invasions and at sorting out causal relationships. Research is also needed on the ecosystem effects of invasions. Although these effects are frequently alluded to, there are remarkably few good data with which to impress policymakers and funding bodies.

(3) Much of the plant invasion problem stems from socioeconomic rather than ecological factors. Attempts to treat weed invasion will fail unless the underlying causes of the problem are identified and dealt with. Socioeconomic analysis may dictate that some weed problems are untreatable, or conversely that their successful treatment may require radical changes in land use.

(4) A rational framework for setting management objectives and priorities must be adopted based on the relative value of different areas (in terms of conservation or production) and the relative likelihood of successful prevention or control. Weed problems are too numerous, too extensive, and too pervasive to allow the dissipation of resources through ad hoc decisions.

Plant invasions are a major threat to biodiversity worldwide. Unless conservation biologists, land managers, and policymakers respond to the problem now, we face a world dominated by a small, aggressive fraction of the world's plant species. This will be a disaster for those who value the unique biotas of different countries and continents.

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