Managing weeds in riparian zones

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Summary To effectively manage weeds in any system, it is necessary to understand the factors that contribute to system invasibility. Riparian zones are highly susceptible to weed invasion, particularly in managed landscapes. Disturbances associated with flood events, high weed propagule pressure from upstream and adjoining land, and human activities all contribute to this susceptibility. Managing weeds in riparian zones is difficult as herbicide options are limited and there are often multiple weed species present. A survey of riparian sites in Victoria, Australia, found that at a quarter of the sites assessed, more than twenty exotic species were present, across a range of life forms. To deal with this complexity, weed management strategies need to ensure that investment is appropriately targeted at the most effective management activities and scales across the landscape. Guidelines describing the steps required for the development of strategic and operational weed management plans have been produced for riparian areas in south-eastern Australia and are outlined in this paper.

Keywords Invasibility, landscape context, riparian zones, weed management strategies.

INTRODUCTION

Effective weed management requires an understanding of both the attributes of weed species, including reproductive and dispersal mechanisms, and the attributes of the landscape that influence the likelihood of weed colonisation and establishment.

Riparian zones form the interface between terrestrial and freshwater aquatic ecosystems. Hydrological processes are the dominant physical forces that shape riparian communities, and differentiate them from adjacent communities. The highly variable nature of these fluvial processes on both spatial and temporal scales results in heterogeneous and dynamic plant assemblages (Naiman and Decamps 1997, Hood and Naiman 2000, Richardson *et al*. 2007). Although a very small proportion of the overall landscape in area, riparian zones are critically important in many processes, including the flux of water, energy, materials and organisms through the landscape (Gregory *et al*. 1991, Richardson *et al*. 2007).

INVASIBILITY OF RIPARIAN ZONES

Studies from around the world have found that riparian communities are more invasible than adjacent upland communities (Gregory *et al*. 1991, DeFerrari and Naiman 1994, Stohlgren *et al*. 1998, Hood and Naiman 2000, Brown and Peet 2003). Richardson *et al*. (2007) stated that the diversity and abundance of alien plants have increased in riparian zones throughout the world, and discussed the reasons for this increase and its consequences.

Disturbance regimes Floods are the most important disturbance events in riparian zones, although less dramatic changes in water level, which occur over longer time frames, also affect riparian processes. The disturbance caused by flood events provides opportunities for weed establishment in several ways. Floods create new patches of bare ground through the removal and subsequent deposition of sediment; existing vegetation is often removed by flood events, creating areas with decreased competition for light, space and nutrient resources; and floods facilitate the long distance dispersal of plant propagules through the riverine corridor (Hancock *et al*. 1996, Tickner *et al*. 2001, Richardson *et al*. 2007). Weed propagules that are water dispersed can also move through the riverine corridor during normal flows and include seeds and vegetative propagules such as stem fragments.

Edge effects Most riparian areas are narrow, linear corridors and as such have very high edge:area ratios, which increases their vulnerability to invasion (Panetta and Hopkins 1991, Hancock *et al*. 1996, Planty-Tabacchi *et al*. 1996). Long edges provide multiple entry points for weed propagules. For riparian areas embedded within a landscape comprised primarily of native vegetation, weed propagule pressure is relatively low. However, many riparian areas in managed landscapes have been cleared of much of their natural vegetation and as adjacent areas are often productive or urban/peri-urban, weed propagule pressure is extremely high.

Physical factors In addition to the creation of ideal recruitment sites through flood events, other

environmental conditions in riparian areas are also often more favourable for plant growth than those in adjacent areas. Higher levels of soil moisture and nutrients (Tickner *et al*. 2001) and better developed soil structure than in neighbouring upland areas, particularly in the drier parts of Australia, provide conditions that favour the establishment of pioneer species, including many weed species.

Human-mediated changes Because of their association with rivers, riparian zones in many places have been highly modified by human activities. In Australia, the hydrological regimes of many rivers have been altered through river regulation, impoundments and extraction (Kingsford 2000, Arthington and Pusey 2003, Lake 2005). These changes in extent of water flow, seasonality of flow patterns and natural flood regimes have resulted in degradation of native riparian communities and increased the likelihood of weed invasion.

Changes in natural disturbance regimes have been coupled with the extensive clearing of riparian and floodplain vegetation for productive purposes and urbanisation (Hancock *et al*. 1996, Webb and Erskine 2003, Lake 2005). Cleared areas not only provide ideal conditions for weed establishment, but changes in vegetation communities adjacent to riparian areas have increased propagule pressure. Extensive weed establishment is especially evident in areas of dense human habitation, as a consequence of inadvertent garden escapes and the deliberate dumping of garden waste (Sullivan *et al*. 2005).

As well, intentional planting of exotic species in riparian areas has been commonplace in the recent past, especially willows (*Salix* spp.) in south-eastern Australia (Webb and Erskine 2003). This deliberate dispersal of weed propagules along riparian corridors has led to increased weed establishment.

MANAGEMENT COMPLEXITIES

The invasibility of riparian zones means it is highly likely that weeds will establish in these areas. Management of weeds in riparian zones is complex as often there are multiple weed species present, herbicide options are limited and access may also be limiting (Ede and Hunt 2008).

A survey of vegetation in riparian zones was undertaken in Victoria, Australia, focusing on sites containing mature native trees (Ede *et al*. 2004). These sites contained a mixture of native and exotic species and ranged in area from 2800–4000 m^2. Across 35 sites there was an average of 15 exotic taxa per site, but a quarter of sites contained more than 20 exotic taxa (Table 1).

Table 1. Number and proportion of exotic taxa found at riparian sites in Victoria.

		Number of sites
Number of exotic taxa	>20	9
	10–20	17
	<10	9
Percent of taxa that were exotic	>50%	7
	25–50%	23
	<25%	5

At seven sites, more than half the taxa present were exotic (Table 1). The proportion of exotic taxa at each site averaged 39% of the total taxa, which is higher than that found by other authors. Between 20–30% of the total species present in the riparian flora of several rivers in France, USA and South Africa were found to be exotic (Planty-Tabacchi *et al*. 1996, Hood and Naiman 2000, Tabacchi and Planty-Tabacchi 2005). In comparison, a meta-analysis of 184 sites from various environments around the world found that an average of 16% of the flora was exotic (Lonsdale 1999).

Weed control options in riparian zones are limited by the presence of multiple weed species, as well as the presence of desirable species. Physical control such as hand-pulling is appropriate for small weed infestations, while large machinery is often used to remove trees such as willows in south-eastern Australia (Ede and Hunt 2008). Biological control agents are available for a small number of commonly found riparian weeds. Chemical control options are limited as there are only a small number of herbicides registered for use around waterways (Ede and Hunt 2008). Some of these herbicides are broad-spectrum herbicides, which must be applied with extreme care to avoid off-target damage to desirable vegetation (Hancock *et al*. 1996).

Access may also present a barrier to effective management, with steep terrain making some sites physically difficult to access while lowland sites can be inaccessible at times due to water-logging.

Ongoing monitoring of sites is required for long-term weed control as the highly invasive nature of riparian zones makes re-invasion by existing or new weed species likely.

WEED MANAGEMENT STRATEGIES

Successful weed management strategies in riparian zones must take into account the many biophysical factors that influence their invasibility. These include their dynamic nature due to fluvial processes; their occurrence in many different parts of the landscape (ranging from headwaters at high altitudes through to lowland

rivers), which determines the structure and composition of the native riparian vegetation community; the multiplicity of potentially invasive species; and the various impacts of human activities. Thus development of prescriptive weed management guidelines for application across all riparian zones is not possible. However, guidelines that provide a structure for the development of appropriate site-based riparian weed management programs have been recently produced for south-eastern Australia (Ede and Hunt 2008). These guidelines divide the process into two phases, the first of which involves Strategic Planning, while the second phase focuses on Operational Planning.

Strategic planning As with any weed program, the first stage of a riparian weed management program is to understand the system being managed, including the scales at which management should be undertaken (Richardson *et al*. 2007).

An asset-based approach assesses the physical, biological and cultural assets (values) of the riparian site, taking into account the landscape context within which the riparian site occurs.

The next stage is to identify all the threats to those assets. This is a key step in a riparian weed management program because it is critical to understand the magnitude of the threat posed by weeds in comparison with other threats in the system (Richardson *et al*. 2007). These may include altered hydrological regimes, intensive land-use (e.g. agriculture or urbanisation) on adjacent land, altered nutrient dynamics or limited connectivity with native remnants. For example a riparian site that abuts suburbia is unlikely to ever be restored to a weed-free state because of the intense propagule pressure exerted by the adjacent land. Similarly the riparian vegetation community associated with a river in which the hydrology has been irreversibly altered by dramatic changes in flows or flood frequency, extent and/or seasonality, is unlikely to sustain the full range of ecological functions, increasing the probability of weed invasion. At sites such as these where changes in the landscape context are significant, weed management may focus on particular weed species that pose a high threat to the site or to off-site areas, but not specifically manage other weed species that pose a lower threat to assets.

Part of the process of assessing the threats to the riparian site includes assessing the feasibility of managing these threats. The feasibility of weed management depends on the weed species to be managed, their reproductive and dispersal strategies, their impacts on the riparian system, the extent and condition of existing native vegetation, the factors that influence the invasibility of the sites such as adjacent land-use and the accessibility of the site.

By determining the assets and threats to those assets, it is then possible to formulate appropriate overall management objectives for the site and to determine what proportion of management activity should be focused on weed control. This process also contributes to the development of management priorities both within sites and between sites. In some areas, off-site weed management is required to protect the riparian corridor from a weed species with the potential to disperse over long distances.

Operational planning For those sites where weed management is appropriate, development of an on-ground program requires consideration of several factors. Assessments of both the spatial and temporal scales of weed management are required, and provision made for long-term weed management if necessary, particularly if re-invasion is likely to occur. This process then allows for identification of the resources (such as labour and chemicals) required to undertake the management.

The most appropriate weed management activities are likely to differ between sites depending on factors such as access, weed species present and their extent, native species present, adjacent land-use and adjacent vegetation. Reproductive and dispersal strategies of the weeds being managed will also affect both the timing and method of management activities. Ideally the chosen method should maximise weed control while minimising off-target damage to other vegetation and the environment, for the least cost. The choice of control method may need to change over the lifetime of the management program as the extent and species of weeds change.

It is important to assess the likely impact of weed control and to undertake control in a way that minimises disturbance to the riparian system. Thus although in many cases it is most effective to initiate control of riparian weeds at their highest point in the catchment and to work downstream over time, there are instances where this is not ideal. This is particularly the case when weed management of a widespread species would result in the significant loss of riverbank vegetation, which could lead to serious bank erosion. Alternative management strategies include managing small stretches at any one time to minimise erosion, or interspersing weed management with active revegetation (either spatially or temporally) to ensure that banks remain unvegetated for the least amount of time.

The dynamic fluvial environment of riparian zones also influences the timing of activities. Water-logging often limits access after flood events, but it may be

important to undertake weed management as soon as possible after a flood to prevent the establishment of new weeds washed into the site.

Monitoring the outcomes of weed management is critical to the evaluation process, allowing for the refinement of both the management program at the site and future riparian weed management programs.

CONCLUSIONS

For a number of biophysical reasons, riparian zones are highly invasible and often contain multiple weed species. Effective weed management requires a strategic approach that incorporates the landscape context of the site and sound operational planning.

ACKNOWLEDGMENTS

The authors acknowledge funding from the CRC for Australian Weed Management; the Australian Government through the 'Defeating the Weeds Menace' research program; and Melbourne Water.

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