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RESEARCH ARTICLE

Characterising riparian buffer zones of an agriculturally modified landscape

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Riparian buffer zones are viewed as an important management tool for waterway protection. However, little qualitative or quantitative assessment has been made of their dimensions or composition. We surveyed 88 small agricultural waterways within the Canterbury region to characterise the width and vegetative composition of riparian 'buffer' zones. Less than 20% of buffer zones were 10 m or wider and approximately 65% ≤ 5 m wide. Mean plant diversity was lowest in buffers ≤ 5 m (four taxa) and highest in buffers 25–30 m wide (11 taxa), although 98% of all taxa recorded in the survey occurred within 5 m of waterways. Exotic pasture grasses, weeds and adventive trees and shrubs dominated riparian areas at all distances from the -side. Furthermore, buffer width and vegetation type did not differ with adjacent land use despite regional efforts to plant native vegetation and regulatory emphasis on reducing water contamination from intensifying land use practices.

Keywords: agriculture; buffer width; New Zealand; riparian vegetation; waterways

Introduction

Riparian zones are the interface between aquatic and terrestrial ecosystems, linking and influencing the ecological functioning of both (Gregory et al. 1991; Richardson et al. 2007). As a buffer between land use activities and waterways, their management can have a large effect on stream water quality relative to their size (Quinn 2003). Riparian buffer zones are commonly viewed as 'the last line of defence' by managers for protecting waterways from degradation (Fortier et al. 2010). Among their key functions, vegetated riparian buffers can trap contaminants in runoff, increase soil infiltration of soluble pollutants and enable deposition of suspended particles within the buffer soil profile. Furthermore, buffers can facilitate biological transformation of pollutants from land use activities via uptake by plant and soil fauna and microbial nitrification and denitrification, thereby reducing pollution risk to waterways (Lam et al. 2011).

Implementation of buffers along agricultural waterways is widely promoted as a 'best management practice' by regional councils and is increasingly portrayed as an important environmental management tool (Parkyn 2004; Collins et al. 2007; Monaghan et al. 2008; Wilcock et al. 2009). Current best practice for protection and remediation of agricultural waterways includes fencing to exclude stock and retaining vegetated stream-side margins (Cooper et al. 1995; Parkyn 2004).

Internationally, numerous studies have demonstrated the effectiveness of buffers at reducing land use impacts on waterways by reducing sediment (Mankin et al. 2007), nitrogen and phosphorus (Peterjohn & Correll 1984; Fennessy & Cronk 1997; Hoffmann et al. 2009), and faecal contaminant

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Supplementary file 1: Table S1. List of vegetative taxa recorded within riparian margins of 88 small agricultural waterways of the Canterbury region of the South Island, New Zealand.

loads to streams and rivers (Collins et al. 2004; Parkyn 2004; Winkworth et al. 2010). Riparian vegetation can also provide shade, habitat and food resources for in-stream fauna (Parkyn 2004; Jowett et al. 2009; Wilcock et al. 2009) and valuable high diversity habitats and migratory corridors connecting terrestrial fauna within landscape matrices (Corbacho et al. 2003). Thus, well managed buffers provide a crucial ecological interface between terrestrial and freshwater ecosystems.

In natural or unmodified landscapes, riparian plant communities are directly influenced by climate, elevation, the regional pool of species, and the hydrological, geo-morphological and disturbance regime of the region (Richardson et al. 2007). Before human settlement, the Canterbury Plains (on the east coast of New Zealand's South Island) were a complex patchwork of lowland native forest, scrubby tussock grasslands and swampy wetlands nearer the coast (Meurk 2008). Extensive deforestation by early Polynesian settlers preceded further deforestation, 'straightening' of rivers and draining of many coastal wetlands following European settlement in the 1840s (Ecroyd & Brockerhoff 2005). Although the Canterbury region has over 27,000 km of river channels which come from alpine, foothill and lowland spring-fed rivers, many naturally meandering river systems have been replaced by irrigation drains and water-races in a landscape now dominated by pastoral farming (Sturman 2008).

Early stream-side management in Canterbury focused on bank stabilisation and protection from erosion, draining land to increase agriculture, and providing shelter trees for stock and crops. Native riparian vegetation was cleared and replaced with introduced species such as willow (*Salix* spp.), poplar (*Populus* spp.), macrocarpa (*Cupressus macrocarpa*) and gorse (*Ulex europaeus*) (Phillips & Daly 2008). Exotic weeds and garden 'escapees' make up the diverse species that now occupy Canterbury's riparian areas (Sullivan et al. 2009). The success of these exotic species can be attributed partly to similarity in climatic conditions between Canterbury and their countries of origin (Wilson et al. 1992), dispersal mechanisms that favour the Canterbury Plains environment (Sullivan et al. 2009) and co-evolution with a diverse, seed-dispersing, exotic bird fauna (MacLeod et al. 2008).

Few studies have assessed the width, composition and effectiveness of riparian zones within Canterbury's agricultural landscape (Greenwood et al. 2012). However, there is increasing emphasis on riparian management and planting to minimise adverse agricultural impacts (ECAN 2005a,b). In this study, we characterise the buffers of small streams and waterways within the Canterbury Plains.

Methods

Study area and site location

The study was conducted in the Canterbury Plains on the east coast of New Zealand's South Island. Topographically the area is dominated by extensive alluvial floodplains. The area has been farmed since settlement in the 1860s and, traditionally, cropping (e.g. wheat, barley) and low intensity sheep and seasonal dairying have been common (Dynes et al. 2010). However, improved irrigation technologies over the past 25 years have aided dramatic intensification of dairy farming and more intensive cropping practices (Wilcock et al. 2011).

Potential sites (waterways) were first identified on topographic maps (NZMS 260 series 1:50,000) and using ARCview (ArcMap 9.3). Sites were selected randomly based on the following criteria: they needed to include representatives from dairy, sheep, cropping and other farming land uses; be accessible by public road; and be associated with a permanent flowing waterway. A field survey was then conducted during a single visit to each location between November 2010 and January 2011 (austral late spring/early summer). The final 88 sites surveyed were representative of the range of buffer sizes encountered and the vegetative composition typical within the landscape. They included streams, irrigation drains and water-races (the latter two being important due to their prevalence across the Canterbury region).

Sampling methods

At each waterway a 5 m buffer reach that was representative in width and vegetation type of the visible stream reach was randomly selected for surveying. A transect was measured across the full buffer width, defined as the distance from the stream edge to where agricultural activity started and where land use activity was restricted for stream protection purposes (Naiman & Decamps 1997).

All plant taxa within 1 m of either side of each transect were recorded and identified in the field, except in a limited number of cases where samples were returned to the laboratory for subsequent checking (Poole & Adams 1994; Popay et al. 2010). Rare taxa (usually a single plant) which could not be confidently identified were excluded from the analysis. For several herbaceous exotic taxa the seasonal timing of the field survey prevented absolute identification due to indistinguishable species-specific characteristics among similar plants. Subsequently, all taxa were allocated to an operational taxonomic unit (OTU) which was the lowest identifiable strata of genera or family of the plant (see Table S1 which contains a full species list). For example, plants of the carrot family were allocated to Apiaceae. We considered that, in such cases, greater taxonomic resolution would not add value to the study. Additionally, for the purposes of this study, native grasses were distinguished from exotic pasture grasses, and each were allocated to a single group.

A cover score for each OTU was allocated based on a visual estimation of its percentage cover within each transect. Cover scores were: 1 = 1%–5%; 2 = 6%–10%; 3 = 11%–20%; 4 = 21%–50% and 5 = > 50% cover. Operational taxonomic units scoring a 5 within any 5 m section were recorded as 'locally dominant'. Cover estimates for buffer zones greater than 5 m wide were carried out in 5 m sections along the total transect width. To broadly characterise riparian vegetation, each OTU was then assigned to either 'exotic' (alien to New Zealand) or 'native' (indigenous) according to Poole & Adams (1994) and Popay et al. (2010). To differentiate between short-lived, low stature, herbaceous taxa such as forbs and grasses, and long-lived, woody shrubs and trees, OTUs were further categorised as either 'herbaceous' or 'tree/shrub'.

At each site, adjacent land use was categorised as that visible at the time of the survey within dairying, sheep, other grazing (e.g. beef cattle, horses, deer or alpaca), and cropping or other land use (e.g. stock forage).

Data analysis

To derive a numerical indicator of relative dominance within the landscape for each OTU, cover scores were weighted according to their value as follows: 1 (* 0.05), 2 (* 0.05), 3 (* 0.1), 4 (* 0.3) and 5 (* 0.5). This generated a cover score index (CSI) for OTU regional dominance comparisons. Data were tested for normality and heterogeneity and failed, despite transformation, thereby requiring non-parametric analysis. Kruskal-Wallis one-way ANOVAs and Spearman rank order correlation were performed (R, v2.14.2) to determine if other factors (land use, waterway type or waterway width) were correlated with buffer width. Detrended correspondence analysis ordination (PCOrd, v4.01) was used to examine possible differences in plant communities between farming activities.

Results

Of the 88 buffer zones surveyed, 17% were < 2 m wide, 48% were 2–5 m wide and only 6% were ≥ 25 m. (Fig. 1A). Plant taxa diversity across the 88 sites was analysed within 61 OTUs. Mean taxonomic richness was highest in buffers 25–30 m wide (11 OTUs) and lowest in buffers ≤ 5 m wide buffers (four OTUs) (Fig. 1B). Despite the paucity of taxa in narrow buffer zones, 98% of all OTUs recorded in the survey occurred within 5 m of the stream-side.

Of the 61 OTUs analysed, 26 comprised native taxa and 35 exotic taxa. Exotic taxa were present at 99% of sites and generally dominant at all distances from waterways, whereas native taxa occurred at only 45% of sites and were dominant at 19% of these (Fig. 2; Table 1). Although herbaceous and tree/shrub categories were each represented by 30 OTUs, the diversity of plant species within the former group was higher (c. 75 herbaceous plant taxa compared with 33 trees or shrubs). Per cent cover of herbaceous taxa was also higher than that of trees and shrubs, at 61% and 39%, respectively (Fig. 3).

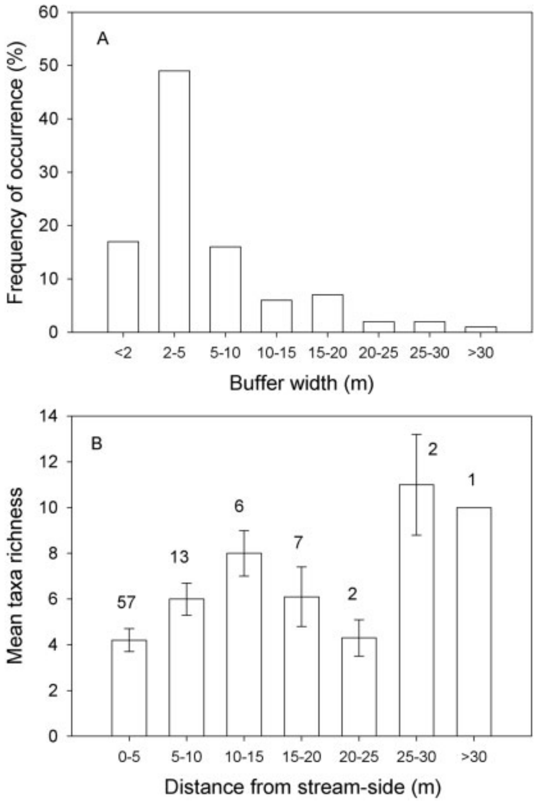

Figure 1 Comparisons of buffer widths and riparian diversity. **A,** Frequency of occurrence of differing buffer widths of 88 small agricultural waterways; **B,** mean taxonomic richness of riparian vegetation within each buffer width range (± 1 SE; *n* = number of sites) in the Canterbury region.

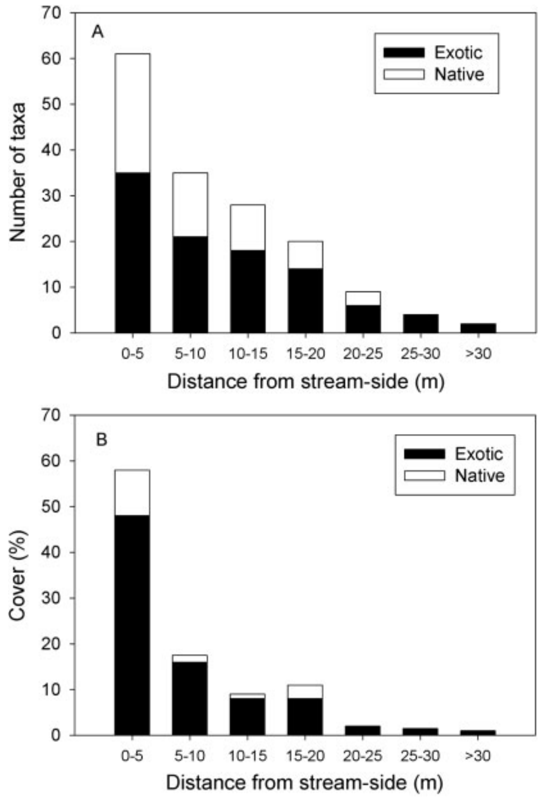

Figure 2 Comparisons of exotic and native plant diversity and cover. **A,** Taxonomic richness of exotic and native riparian vegetation of differing buffer widths (*n* = 88); **B,** percentage cover of exotic and native vegetation of each buffer width range in the Canterbury region.

Exotic pasture grasses were present at 95% of sites and locally dominant at 44% of these. Herbaceous taxa, while present at 72% of sites, dominated only 5% (Table 1). Gorse and willow were the most frequently occurring single taxa (32% and 25%, respectively). Adventive trees and shrubs

Table 1 Occurrence of plant groups in riparian margins of 88 small agricultural waterways of the Canterbury region of the South Island, New Zealand (CSI highest possible score = 75, see ‘Methods’ section for calculation).

Vegetation category	Present (%)	Locally dominant (%)	Regional dominance (CSI)
Pasture grasses	95	44	38
Exotic herbaceous weeds	72	5	16
Adventive trees and shrubs	40	7	8
Gorse	32	5	5
Willow	25	14	9
Planted exotic trees	19	8	11
Native flaxes and sedges	34	14	8
Native shrubs and trees	24	5	10

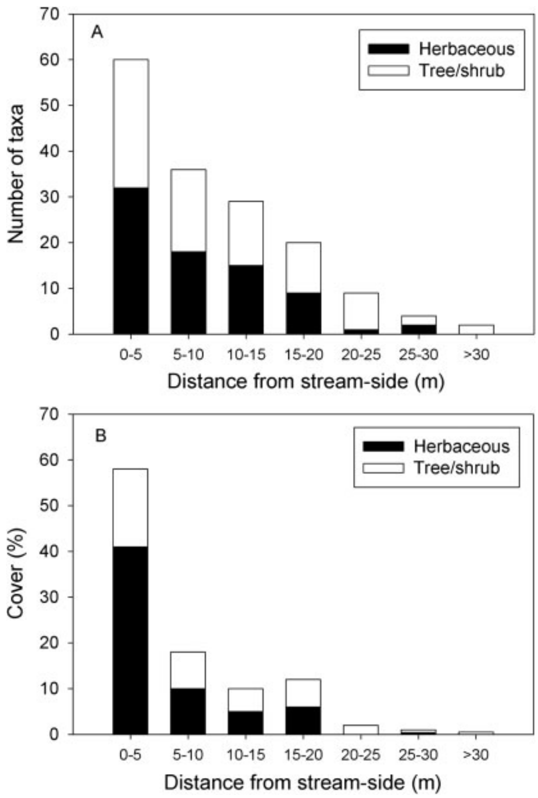

Figure 3 Comparison of herbaceous and shrub diversity and cover. **A**, Taxonomic richness of herbaceous and tree/shrub riparian vegetation of differing buffer widths (n = 88); **B,** percentage cover of herbaceous and tree/shrub vegetation of each buffer width range in the Canterbury region.

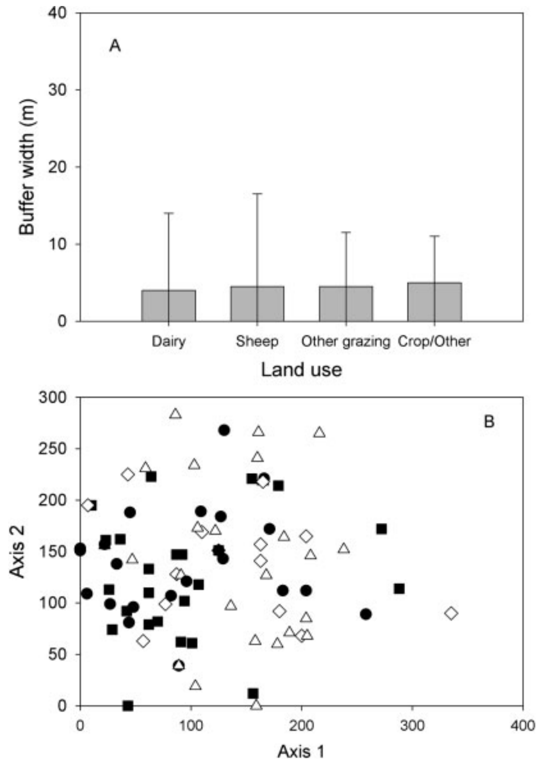

Figure 4 Comparison of buffer width and community composition across differing land uses. **A,** Mean buffer widths (± 1 SE) of 88 waterways within four land use categories; **B,** Detrended correspondence analysis of the plant community composition within each of four land use categories in the Canterbury region. ■, dairy; ●, sheep; Δ, other grazing; ◊, cropping or other land-use.

were more often present (40%) than exotic plantation trees (19%), but neither group was dominant (7% and 8%, respectively). Native sedges (e.g. *Carex* spp.) and flax (*Phormium tenax*) were present at 34% of sites and dominant at 14% of these. By contrast all other native trees and shrubs, although present at 24% of sites, were never dominant. Not surprisingly, the CSI (highest possible value = 75) showed that riparian margins across the region were dominated by exotic pasture grasses, followed by willow, gorse and other mostly exotic vegetation, including broom (*Cytisus scoparius*), eucalypts (*Eucalyptus* spp.), native flax, elderberry (*Sambucus nigra*), poplar, thistles, blackberry (*Rubus fruticosus*) and native sedges (Table 1).

Of the catchment factors measured, only waterway width was significantly correlated with buffer width (r_s = 0.296, P = 0.00524). There was no relationship between farming activity and buffer width (Fig. 4A) or farming activity and plant community composition (Fig. 4B).

Discussion

Buffer widths

The Canterbury region is representative of many areas worldwide that have been subject to large-scale natural habitat conversion to farmland (Bowers & Boutin 2008). Although there is increased awareness among land managers of the benefits of riparian buffer zones for water quality protection and promotion as best management practice, we were surprised that the majority of our buffers (65%) were no greater than 5 m in width, with 17% less than 2 m wide. However, Greenwood et al. (2012), who surveyed 64 streams in Canterbury, also noted that most buffer zones were less than 1 m or between 1–5 m wide.

Comparative data on widths of existing buffer zones is surprisingly sparse in the literature. However, buffers ranging between 3–15 m have frequently been used in experimental studies when exploring optimal buffer widths predicted to provide effective protection from a range of agricultural pollutants. In a study of pesticide contamination of 14 low-order Danish streams adjacent to cropping, minimum buffer widths were predominantly 1–6 m and average buffer strip widths were 5–10 m (Rasmussen et al. 2011).

The minimum buffer width required might be expected to vary with the land use activity and its associated pollutant risk, buffer slope and soil type as well as the type and density of riparian vegetation. For example, grass filter strips of 1–4 m can achieve 20%–70% reductions in suspended sediment and total phosphorus (Wilcock et al. 2009), with maximum benefits achieved at widths of 6 m or more (Yuan et al. 2009). However, retention of the more mobile nitrogenous species in runoff and subsurface flow can require greater buffering width, although denitrification within the first few metres can play a dominant role in nitrate–nitrogen depletion. Wilcock et al. (2009) also reported that grass filter strips of 1–4 m may achieve 80%–95% reductions in faecal bacteria associated with dairy shed effluent (*E. coli* and *Campylobacter*), while others report that although 5 m buffer strips reduced delivery of faecal microbes in dairy farm effluent by ≥ 94% during low flow simulations, buffers would need to exceed 5 m in order to markedly reduce their delivery to waterways along preferential flow paths and during high-flow events (Collins et al. 2004). In general, buffers of 4–6 m may retain sediment or particulate-associated pollutants effectively, but removal of dissolved nitrogen and phosphorus has been shown to require greater widths to prevent waterways being affected. Additionally, landscape topography and surface-flow convergence also influence pollutant movement through the buffer zone and are important considerations determining buffer success (Yuan et al. 2009).

To our knowledge, there are currently no definitive guidelines in New Zealand on the width of buffer zones required for differing land use activities. Environment Canterbury, Canterbury's regional government, recommends 2–3 m of 'set-aside' dense pasture grass in combination with fencing, as minimum protection of small agricultural waterways in flat landscapes, with sloping or inadequately drained soils requiring wider margins (ECAN 2005a). Buffer widths of 15–30 m along all waterways were recommended in the USA following an extensive review of contaminant retention studies. These wider buffers were expected to provide good control of sediment, phosphorus, nitrate and other contaminants, plus provision of environmental conditions necessary for maintaining aquatic habitat, such as temperature control through shade, woody debris resources and wildlife corridors (Wenger 1999). Unfortunately, in intensely farmed landscapes such as the Canterbury Plains, 15 m buffer widths are unlikely to be acceptable to most land owners.

Vegetative diversity in riparian communities

Ecological theory suggests that the assembly of biological communities is determined in part by environmental conditions that function as a series of filters (Booth & Swanton 2002). In riparian margins, plant diversity can depend on a range of factors including available seed source, plant dispersal mechanism and disperser availability, as well as light availability, soil moisture and nutrient availability. In production landscapes these are further modified by anthropogenic mechanisms (Parendes & Jones 2000). Species survival may also depend on the dominant vegetation type and environmental limitations or advantages imposed by it. For example, willows may reduce both richness and diversity by 'shading out' light-loving taxa, whereas open riparian margins with long grass and high light may provide an ideal habitat for weeds.

In our study, willows were the most prolific exotic tree and dominated riparian areas across the agricultural landscape. Willows and poplars, in particular, were planted specifically for river protection and soil conservation purposes by river boards and government agencies from about the 1930s onward (Phillips & Marden 2006). However, recent research has investigated the value of using indigenous vegetation in fulfilling stream-bank engineering functions, as willow and poplar begin to create hazards and negatively impact stream health as they near the end of their useful lives (Czernin & Phillips 2005).

Riparian habitats are known to be particularly susceptible to invasion by exotic plant taxa and can act as sources, havens and corridors for weed dispersal (Stohlgren et al. 1998; Truscott et al. 2008). We found that exotic taxa such as gorse, elderberry, blackberry and broom all dominated the sites they occurred at for up to 10 m from the stream. The frequent occurrence of many of these could be attributed to their co-evolution with exotic frugivorous and omnivorous plant predators such as blackbirds (*Turdus merula*), starlings (*Sturnis vugaris*), greenfinch (*Carduelis chloris*) and house sparrows (*Passer domesticus*). These may aid dispersal of exotic weeds in production landscapes through the use of fenceposts as stepping stones across the landscape, and stream-side margins as habitat corridors (MacLeod et al. 2008). Similarly, studies conducted in agricultural regions of Australia found that over 60% of riparian vegetation comprised exotic invasive groundcover (Burger et al. 2010), and that many plant invasions are mediated by plant–frugivore interactions with exotic bird species (Buckley et al. 2006).

Interestingly, although native taxa were present at almost half of the sites surveyed, they contributed very little to vegetation cover and have previously been found to be limited to small disconnected patches (Greenwood et al. 2012). This is somewhat surprising following decades of advocacy by environmental agencies for native species to be planted in preference to exotic species. We found few continuous stretches of native vegetation, most planted sites having a groundcover of exotic grass and weeds. More than 10 years ago Quinn (2003) reported the dominant riparian vegetation of 313 Canterbury streams as grass at 48% of sites, followed by willow (26%), low shrubs (9%), native trees (8%) and wetland plants (2%). We found similar 'within-site' dominance by exotic pasture grasses, adventive shrubs and native trees (44%, 7% and 5%, respectively). Willow, however, dominated many fewer sites (14%) and there were more native flaxes and sedges (13%). This slightly higher percentage of native vegetation in buffer zones of 3–6 m may be partly due to the persistence of natural riparian vegetation or, alternatively, to recent (1–10-year-old) restoration plantings, as native plantings become the preferred option for stream-side management. However, while local government and water agencies actively encourage planting of native riparian vegetation, very few of our reaches (12.5%) seem to have been planted as part of these initiatives.

As agriculture and land-management practices continue to intensify, a growing scientific literature suggests that buffer width and complexity should take into account the intensity and type of land use activity. Creating wider buffers with zoned riparian vegetation, for example low-stature herbaceous vegetation up-slope and down-slope of a shrub/tree zone, can provide greater above- and below-ground complexity than single species or grass buffers. Enhanced surface complexity of herbaceous vegetation can improve pollutant trapping and infiltration rate, while shrubs and trees provide infiltration depth and seasonal endurance, resulting in higher contaminant removal efficiency and thus greater waterway protection (Correll 2005; Mankin et al. 2007). Incorporating plantings of indigenous vegetation in mixed buffers can fulfil water protection aims while also improving indigenous plant and animal (insects and birds) diversity. However, buffer zones less than 5 m wide are less likely to support self-sustaining vegetation or suppress weeds due to edge effects, whereas those over 10 m wide are more effective and are recommended for minimal maintenance and greater habitat diversity. Although some New Zealand studies have recommended 15 m wide or more as optimal (Parkyn et al. 2000; Davis & Meurk 2001; Parkyn 2004; Reeves et al. 2006), our survey within the Canterbury region shows that, currently, such buffers are rare.

Conclusions

The majority of riparian buffer zones in agricultural Canterbury are less than optimal in width and complexity to cope with a range of agricultural contaminants. Our findings indicate that, in general, land owners have not modified either their buffer widths or the type of vegetation within buffers in response to changing land use activity and intensity.

While some grassy buffer zones may be sufficiently wide to intercept and retain sediment, suspended solids and faecal contaminants, they may not adequately retain other agricultural pollutants, particularly soluble nutrients in subsurface flows and runoff. At present there are many unmanaged riparian margins along which sustainable riparian buffer zones could be established without the need to shift fencelines. There must be greater emphasis placed on planning and planting buffer zones specifically to mitigate increases in land use intensity. Use of native vegetation for this role is integral, as it provides a potentially powerful tool for mitigating decades of damage from land use transformation and preventing future waterway degradation, as well as providing a holistic approach to enhancing stream habitat.

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Supplementary data

Supplementary file 1: Table S1. List of vegetative taxa recorded within riparian margins of 88 small agricultural waterways of the Canterbury region of the South Island, New Zealand.

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