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Riparian Characteristics of Pastoral Streams in the Waikato Region, 2002 and 2007

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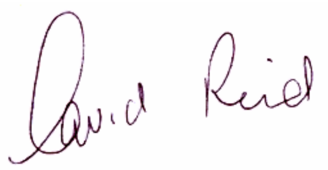

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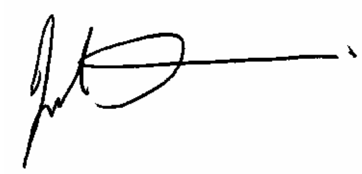

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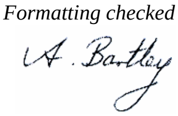

Executive Summary

In 2002 and 2007, Environment Waikato surveyed the riparian margins of more than 300 stream reaches across the Waikato Region. The aim of these surveys was to provide a repeatable and quantitative assessment of the characteristics of fencing, vegetation and erosion in riparian margins through pastoral land in the Waikato Region. This report summarises the survey data, comparing values between different management zones, between land use types (dairy vs drystock farming) and between the two survey years. Results for streams wider than 1 m on dairy farms are compared with data reported in the Dairying and Clean Streams Accord "Snapshots of Progress". Possible causes of stream bank erosion are examined, and the statistical power of the analyses is calculated.

Across the surveyed reaches in the Waikato region, 45% of total bank length was fenced, though 10% of all fencing was deemed ineffective for excluding stock. Thirty-two percent of stream length was fenced on both sides. Between 2002 and 2007, total fencing increased from 37% to 45% (a proportional increase of 21%), and stream length with no fences on either bank decreased from 52% to 43% (a proportional decrease of 18%). Fencing (total bank length fenced, stream length fenced on one side or stream length fenced on both sides) was not significantly greater on dairy farms than on drystock farms, and the increase in fencing between 2002 and 2007 was not significantly greater on dairy farms than drystock farms.

Riparian fencing was significantly greater in some parts of the Waikato Region than others. Lake Taupo and Upper Waikato had significantly higher proportion of bank length fenced than West Coast and Coromandel.

An estimated 21% of streams wider than 1 m on dairy farms were inaccessible to stock, assuming that stock access to waterways may be prevented by riparian fencing, woody vegetation or steep incised banks. Pugging erosion (>50% of the soil surface trampled by stock) was recorded on 24 of 62 sites (39%). The Dairying and Clean Streams Accord (hereafter referred to as the Accord) self-reported data indicate that in 2007/08, 78% of dairy farms in the Waikato had total stock exclusion from waterways wider than 1 m or deeper than ankle-deep (MAF, 2009). One possible reason for this discrepancy is a different approach to recording farms that do not have waterways large enough to meet the Accord criteria. It is not known how such farms are recorded. Based on those sites that were surveyed in both 2002 and 2007, the total proportion of bank length fenced on dairy farms rose from 41% to 52%, and the number of farms with stock excluded by fencing rose from 9% to 15%. The Accord self-reported data indicate that the number of dairy farms with total stock exclusion from waterways increased from 57% to 78% between 2003/04 and 2007/08.

About 44% of total bank length surveyed in 2007 had a riparian buffer of woody vegetation. More than 2.5 times as much bank length had exotic woody vegetation (32%, including willows) as had native woody vegetation (12%). Most (51%) of the woody riparian vegetation occurred as "treeland", i.e., trees >3 m tall, spaced widely and with grass beneath. Dense woody vegetation (i.e., closely spaced vegetation with understorey) was mostly scrub (<3 m tall), while only 4.2% of total bank length in the survey was covered with forest. About 15% of the riparian woody vegetation buffers were >10 m wide on each bank, whereas 34% were <2 m wide. Between 2002 and 2007, no statistically significant change in the proportion of stream bank with riparian woody vegetation was detected. Fifty nine percent of woody exotic vegetation was fenced (preventing stock access), whereas 33% of woody native vegetation was fenced.

Stream bank erosion was measured in categories of active, recent, pugging and total (all of the above combined). Amounts of active, pugging and total erosion had the strongest (negative) correlations with riparian fencing among 12 environmental variables. However, whereas fencing on both banks was strongly correlated with reduced pugging and total erosion, fencing on one only bank was not significantly correlated with erosion. Riparian woody vegetation, which limits access by stock to waterways and strengthens stream banks, was correlated with reduced pugging and total erosion, but not with active erosion. Active erosion was also increased by instream obstructions. Other factors affecting erosion related to geographic factors, such as valley slope and stream order. There were no significant differences in amounts of bank erosion between dairy vs drystock farms.

The power of the performed statistical tests was examined using power analysis. Power refers to the probability of detecting a statistically significant difference between two groups of samples. With the current sample size (289 sites in common between 2002 and 2007), changes in % fencing between survey years could be detected with a power of 0.8 (the generally accepted level in ecology) if the proportional change were greater than 21% for total fenced bank length, 32% for stream length fenced both sides, and 18% for stream length with woody vegetation. Since these are relatively small changes, the current sample size is considered adequate for detecting changes between years. However, between 2002 and 2007, changes in all parameters were lower than these values, thus the power of the performed tests was 0.12-0.75 for fencing measures, and 0.14 for woody vegetation cover. The power of similar tests among the Accord-qualifying sites was lower because only 47 sites were used. To detect a proportional change of >30% between years (a biologically meaningful level of change identified by Environment Waikato) with a power of 0.8, 102 sites would be required for total bank length fenced, 304 sites for stream length fenced on both sides, and 103 sites for stream length with woody vegetation.

To detect a difference of ≥30% between land use types with a power of 0.8 would require a mean sample size of 125 sites for total fenced bank length, 280 sites for stream length fenced both sides, 95 sites for stream length with woody vegetation, and 160, 660 and 700 sites, respectively, for total erosion, pugging erosion and active erosion. The current sample size (91 dairy and 211 drystock sites) has a harmonic mean of n=127 (the harmonic mean is the reciprocal of the arithmetic mean of the reciprocals; it provides the truest average for rates and ratios, and is always smaller than the arithmetic mean). Among management zones and stream orders, the current sample sizes (harmonic mean of n=24.4 and n=36.9 respectively) were adequate to detect significant differences in most measures of fencing, woody vegetation and erosion with a power >0.8. However, a significant difference between a particular pair of management zones or stream orders is harder to detect. The best way to improve the power of such tests is to increase the sample size of the least-sampled zones (i.e., Central Waikato and Coromandel) or stream orders (i.e., drains, fifth- and sixth-order streams).

1. Introduction

Fencing and planting of riparian zones are effective ways of improving the health of waterways. Fencing to exclude stock reduces stream bank erosion and removes direct input of dung (Parkyn and Wilcock, 2004). It also allows dense grass growth in the riparian zone, which increases filtration of particulates and uptake of nutrients from pasture runoff (Smith, 1989). Planting of woody vegetation in the riparian zone further benefits streams by increasing stream shading (which reduces algal growth and lowers water temperatures) and providing input of wood and leaves to the stream ecosystem (Quinn et al. 2009). Implementing these management measures has been shown to result in improved water quality (Williamson et al. 1996), a more diverse and balanced community of aquatic plants and animals (Quinn et al. 2009), as well as greater terrestrial biodiversity (Suren et al. 2004).

Since 2002, Environment Waikato has been actively promoting riparian fencing and planting through its Clean Streams programme (Campbell et al. 2002). In addition, in 2003, the Dairying and Clean Streams Accord set voluntary targets for dairy farmers to exclude dairy cattle from 50% of streams, rivers and lakes by 2007, and from 90% of these waterbodies by 2012 (Cowie et al. 2006). Fonterra reports annually on progress towards the Accord targets through its On-farm Environmental and Animal Welfare Assessment, using self-reported data from dairy farms. These figures are quoted in the annual Dairying and Clean Streams Accord Snapshots of Progress (e.g., MAF 2009). In 2002 and 2007 Environment Waikato conducted its own surveys of riparian characteristics in rural streams throughout the region to gauge the success of its investments (Campbell et al. 2002) in riparian management. The aim of these surveys was to provide a repeatable and quantitative assessment of fencing, vegetation and erosion in riparian margins through pastoral land in the Waikato Region (Grant et al. 2009). The survey covered 8 management zones (i.e., Coromandel, Waihou-Piako, Lower Waikato, West Coast, Waipa, Central Waikato, Lake Taupo and Upper Waikato) and two main land use types (i.e., dairy farming and drystock farming).

This report summarises the results of the 2002 and 2007 surveys. The aims were to:

- compare the amount and type of fencing and riparian vegetation across management zones and land use types;

- compare results of the Environment Waikato survey to self-reported data from the Dairying and Clean Streams Accord snapshots of progress;

- assess changes in fencing and planting over the five years between 2002 and 2007;
- determine the factors most strongly driving stream bank erosion; and
- assess the statistical power of the current survey design and recommend changes to sample sizes.

2. Methods

Sampling methodology of the survey is described by Hill et al. (2009), and is summarised below.

2.1 Site selection

Surveys in 2002 and 2007 involved 380 and 310 sites respectively. Sites were located in a stratified random design, the strata being management zone, Strahler stream order and land use type. Eight management zones divided the Waikato Region (see Fig. 1), and sites were initially distributed evenly among these zones, giving 42 sites per zone (Hill and Kelly, 2002). However, the zone boundaries changed during the 2002 survey, and again between 2002 and 2007 (Fig. 1), and there is an uneven distribution of sites amongst the current zones, ranging from 9 sites in Central Waikato to 69 sites in Waipa. In the original study design sites were also distributed evenly among stream orders (defined by the Strahler system), such that in each management zone there were 6 sites in each of stream orders 0-6 (zero-order streams being drains). However, in the 2007 data set, the number of sites per stream order actually ranged from 21 to 67. In terms of land use type, the final selection of sites included 160 dairy farming and 216 drystock (sheep, beef and deer) farming sites in 2002, and 91 dairy and 211 drystock sites in 2007.

2.2 Data capture

At each site, surveys involved walking alongside the stream for a minimum of 1000 m. The shape of the stream and the length of each stream segment were recorded using a hand-held GPS. A new stream segment was started where there was a change in the direction of the stream, or in one or more parameters listed below.

On each stream segment, several parameters were recorded in the field for each stream bank and for the stream channel. Bank parameters included fencing type, vegetation type and stream bank erosion type (see Table 1 for the categories under each parameter). Stream channel parameters included channel width, channel shape, stream bed substrate, stream order (defined by the Strahler system), aquatic vegetation covering >50% of stream channel, obstructions to stream flow, stock accessways to (or over) the stream. Land use type (dairy, deer, sheep or beef farming) in the catchment also was noted. In addition to field-derived parameters, some catchment properties were retrieved from databases. These included Land Use Capability class, soil grouping and valley gradient.

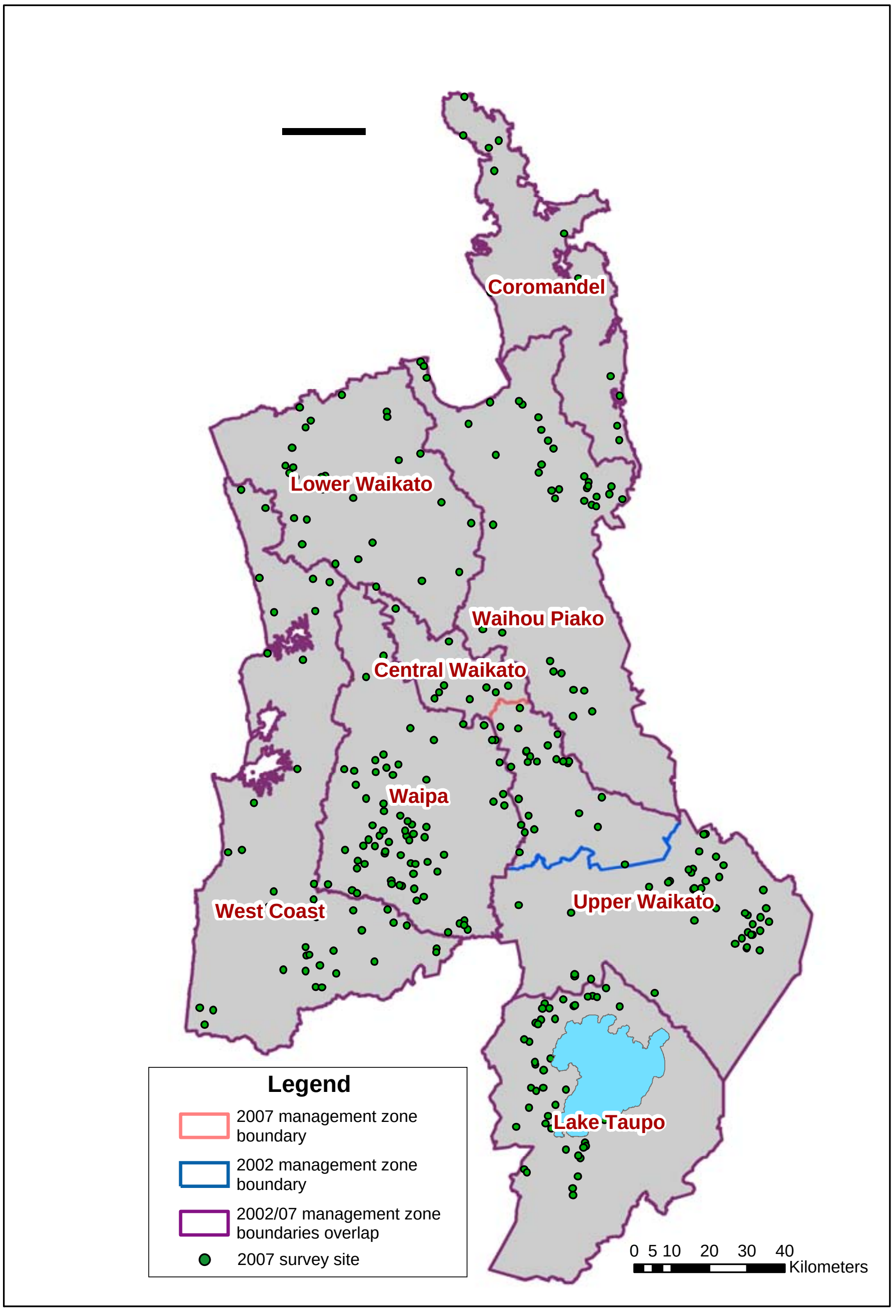

Figure 1: Management zones and survey sample sites. Note the change in one boundary, between Central and Upper Waikato, between 2002 and 2007.

Table 1: Description of categories in several parameters used in the riparian survey (from Grant et al. 2009). Only those parameters used in this report are listed.

Parameter	Category	Description
Fencing status	Temporary	Fence is easily removed, posts may be warratahs or wooden stakes
	Permanent	Fence is permanently in place, with larger concrete or wooden posts
	None	No fence
Fencing effectiveness	Effective	Fence is robust and will stop stock movement
	Ineffective	Although a structure exists it is not robust and stock will move through/across structure
Vegetation type	Woody Native	Predominance of native trees/shrubs
	Woody Willow	Predominance of Willow species
	Woody Exotic	Predominance of exotic (non-native) tree and shrub species
	Pastoral Grass	Consisting of low (<1m) grass and/or weed species
	Native grasses	Consisting of native grass species
Vegetation structure	Forest	Tall dense vegetation, trees close together
	Treeland	>3m high, widely spaced trees with grass in between
	Scrub	Low stature vegetation (<3m) and close together
	Shrubland	Low stature (<3m), widely spaced, grass in between
	Grasses	Grass including small, low lying weeds <1m in height
	Wetland	Raupo/sedges
Erosion	No Erosion	No erosion present
	Recent	Likely to add sediment to the waterway when in flood
	Active	Adding sediment to the waterway at the present time
	Pugging	Over 50% of the soil is trampled by stock

Parameter	Category	Description
Obstruction type	Non-living debris	Such as dead wood, plastic, metal, fencing materials
	Living vegetation	Such as Willows in the stream flow
	Dams	Including small farm dams, concrete walls stopping flow etc.
	Side drain	Any side entries are marked
	Culvert	Any pipes tunnelling the stream water
Accessway type	Bridge	Bridge over stream
	Ford	Areas of controlled and regular animal crossings through the water

2.3 Data analyses

Survey data were provided by Environment Waikato in two forms. The first was a summary table that gave a single value for each parameter at each site. Length-based parameters such as fencing and erosion were summarised as percentage of channel length or bank length at each site, whereas point features were summarised as number per metre of channel length at each site. This summary table provided the data for summary statistics of fencing, riparian vegetation and erosion, and for the multiple regression of factors driving erosion. The second form of the data was a spreadsheet of the raw data showing the score, or presence/absence, of each parameter in each stream segment. This spreadsheet was used to explore relationships between erosion and various individual parameters, because point features, such as obstructions and accessways, and longitudinal features, such as fencing and vegetation type, were expected to affect erosion mostly in their immediate vicinity. Therefore, the relationship between erosion and these features was expected to be expressed most strongly at the stream segment scale rather than the site (farm) scale.

A number of stream sites were less than the required 1000 m in length. Five sites less than 400 m long were removed from the analyses, as it was thought they may be unrepresentative of the streams on which they were located. The remaining sites ranged between 400 and 1650 m long, with 90% of sites between 735 and 1181 m long.

Summary statistics (means and 95% confidence intervals) were calculated using Microsoft Excel™ 2003, whereas t-tests, analysis of variance (ANOVA), correlation and multiple regression were performed using SPSS™ v11, and cross-tabulations and power analyses were conducted using Statistica™ Release 8. In most cases, parametric analyses were used in preference to non-parametric. Although the data for most variables were non-normally distributed (e.g., many of the percentage data had high occurrence of 0 and 100% values), which breaks an assumption of parametric analyses, the large sample sizes meant that the parametric analyses were reasonably robust (Zar, 1984). Where there was doubt, due to low sample sizes or particularly skewed data, results were confirmed by performing the equivalent non-parametric analysis.

Relationships between bank erosion and categorical factors were analysed using t-tests and Analysis of Variance. Relationships between bank erosion and continuous variables (those with numerical values) were analysed by Spearman rank correlation, using summary values of % bank erosion per stream site.

Whereas some factors (e.g., valley gradient, stream order) affected whole stream sites, other factors (fencing, riparian vegetation, obstructions and accessways) were expected to affect most strongly the stream segment immediately adjacent to where they were located. Therefore, associations between the latter variables and bank erosion were further analysed by cross-tabulation, using individual stream segment data from the 2007/08 survey. Cross-tabulations (also called contingency tables) are used to show associations between two or more categorical variables. If the first variable has x possible values and the second y possible values, the cross-tabulation will show in a x by y table the proportion of observations belonging to each combination of variables 1 and 2. If the two variables are associated with each other, then some combinations will be over-represented while others are under-represented. Expected frequencies of observations based on chance alone (i.e., no association between variables) can be calculated, and the actual frequencies can be shown as ratios of "observed over expected." Ratios >1 show a positive association, and ratios <1 show negative association, between values of the variables. In this report, observed/expected ratios greater than 1.3 or less than 0.7 were considered meaningful indicators of positive or negative associations, respectively. The statistical significance of associations between the variables can be tested using a χ^2 test, and the strength of association can be summarised by statistics such as Cramer's V. In the cross-tabulations, "ineffective fencing" was combined with the "no fencing" category.

2.3.1 Different measures of riparian fencing, vegetation and erosion

Fencing, riparian vegetation and bank erosion data were analysed primarily in terms of % of bank length. This means that the total bank length occupied by fence (or riparian vegetation or erosion) on left and right banks was added together and expressed as a %

of total (left + right) bank length. In Fig. 2, where half of the left bank and all of the right bank are fenced, total fencing would be 75%. However, for some analyses the configuration of fencing is important as well as the total amount. For example, stock are totally excluded from streams only where both left and right banks are fenced. Therefore some figures and tables report fencing as % of stream length fenced both sides, fenced one side or unfenced. In Fig. 2, 50% of stream length is fenced both sides, 50% is fenced one side and 0% is unfenced.

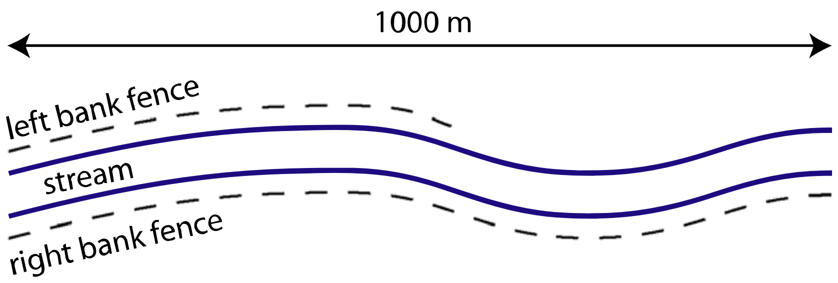

Figure 2: Example stream reach. Stream length is 1000 m, whereas total bank length is 2000 m (2 x 1000 m). Total fencing is 75% (1000 m on right bank plus 500 m on left bank, divided by 2000 m total bank length). Stream length fenced both sides is 50%; stream length fenced one side only is 50%; unfenced stream length is 0%.

2.3.2 Effective and ineffective fencing

Some fencing recorded in the field surveys was ineffective, meaning that stock could pass through it. Since this is the most relevant measure for the purposes of this report, most figures and analyses are based on effective fencing. However, in the 2002 data set, effective fencing could not be separated from ineffective fencing, therefore comparisons between 2002 and 2007 use figures for all fencing (the sum of effective and ineffective fencing).

3. Results and discussion

3.1 Summary statistics for fencing

Across the Waikato region, 45% of total bank length was fenced in 2007 (Fig. 3; total fencing). Fencing on both banks, which represents complete stock exclusion from a stream reach, occurred along 32% of stream length. About 4% of fencing was ineffective, therefore values for "effective+ineffective" fencing can be estimated by adding 4% to the values for "total fencing" and "fenced both banks" (or subtracting 4% from values for "no fence") in Fig. 3. Data corresponding to figures are presented in the Appendix.

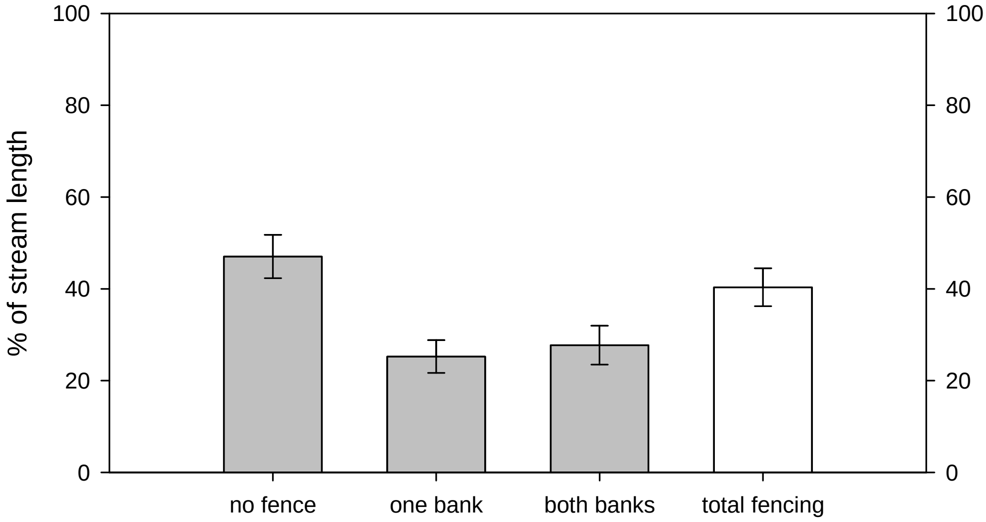

Figure 3: Effective fencing in all zones and land use types (mean ± 95% confidence intervals) across the Waikato region in 2007. The first three categories (no fence, one bank, both banks) are shown as % of stream length. Total fencing is shown as % of bank length (which is two times stream length).

Over the five years between 2002 and 2007, total fencing increased from 37% to 45% ($t=4.07$, $df=288$, $P<0.001$), while stream length fenced on both sides increased from 26% to 33% ($t=2.67$, $df=288$, $P=0.008$) and unfenced stream length decreased from 52% to 43% ($t=-3.54$, $df=288$, $P<0.001$) (Fig. 4). Rates of change, therefore, were 1.6% per year increase in total fencing, 1.4% per year increase in stream length fenced both sides and 1.8% decrease in unfenced stream length.

Some of the change in fencing between years occurred due to temporary fencing being added or removed. Some individual sites experienced large changes in % fencing for this reason. Over all sites, temporary fencing increased from 5.4% of total fencing in

2002 to 10.2% of total fencing in 2007. Removing temporary fencing from the values above and in Fig. 4 leaves total fencing at 35% in 2002 and 40% in 2007.

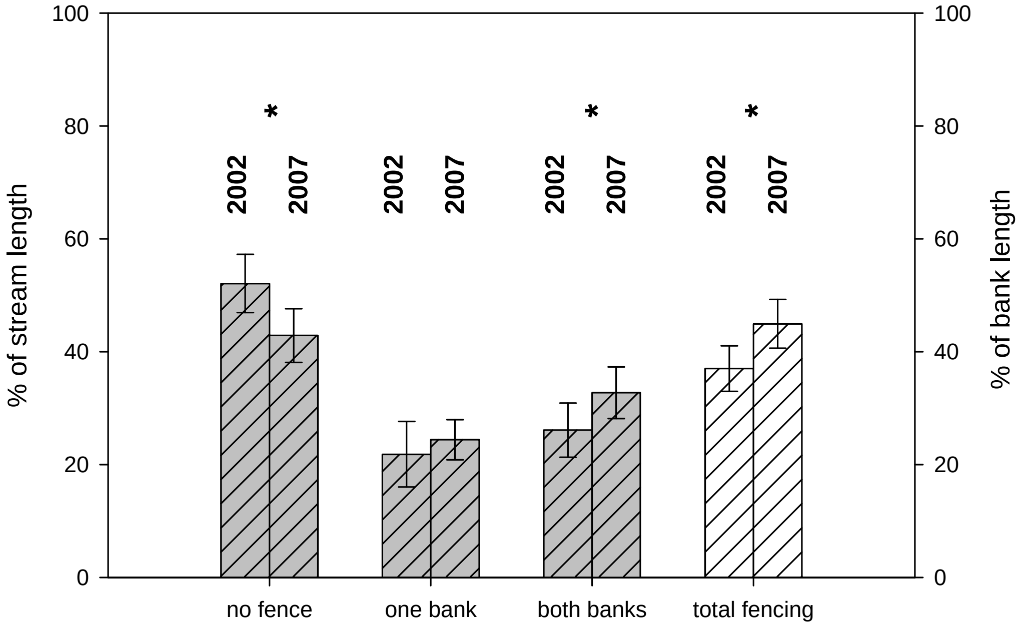

Figure 4: Comparison of fencing (effective+ineffective fencing combined) (means ± 95% confidence intervals) in 2002 and 2007 across the Waikato region. The first three categories (no fence, one bank, both banks) are shown as % of stream length. Total fencing is shown as % of bank length (which is two times stream length). Asterisks indicate where pairwise t-tests showed a significant difference between 2002 and 2007 (experiment-wise $p<0.05$).

3.2 Fencing on dairy *vs.* drystock farms

Across the region, no significant difference between dairy and drystock farms was found in terms of total fencing ($t=1.113$, $df=192$, $p=0.267$) or stream length fenced on both banks ($t=-0.431$, $df=193$, $p=0.667$) (Fig. 5). However, stream length fenced on one bank was 13% higher on dairy than drystock farms ($t=3.305$, $df=154$, $p=0.001$), and unfenced stream length was 12% lower on dairy than drystock farms ($t=2.27$, $df=181$, $p=0.024$).

Between 2002 and 2007, total fencing increased on both dairy and drystock farms (Fig. 6). Considering only sites that remained in the same land use type between years, the increase in total fencing was statistically significant for both drystock (paired samples $t=2.883$, $df=151$, $p=0.005$) and dairy farms (paired samples $t=2.565$, $df=66$, p=0.013). Total fencing was not found to increase more on dairy farms than on drystock farms between 2002 and 2007 (no significant interaction between year and land-use type in two-way analysis of variance; F=0.259, df=438, p=0.611).

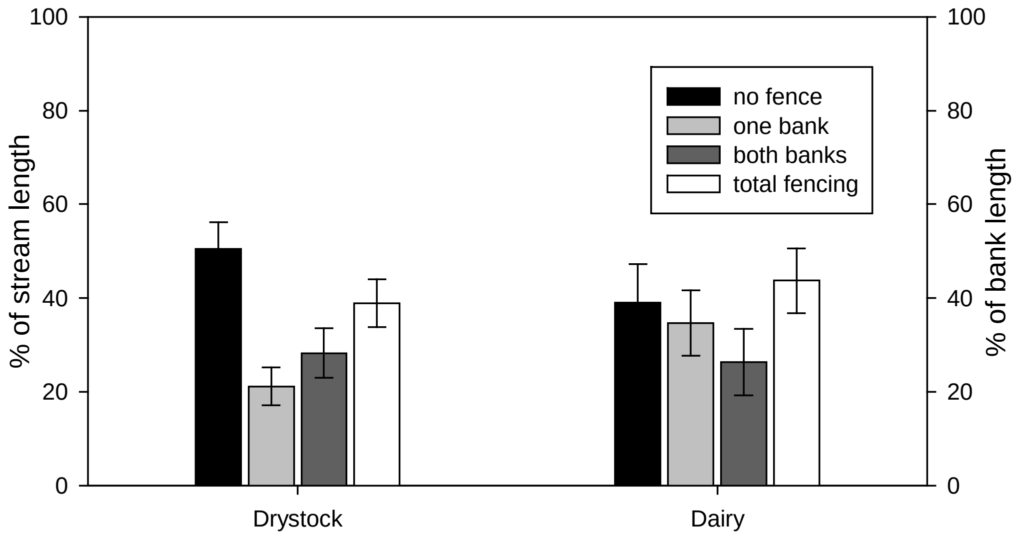

Figure 5: Effective fencing (means ± 95% confidence intervals) across the Waikato region, comparing drystock to dairy farms in 2007. The first three categories are shown as % of stream length. Total fencing is shown as % of bank length (which is two times stream length).

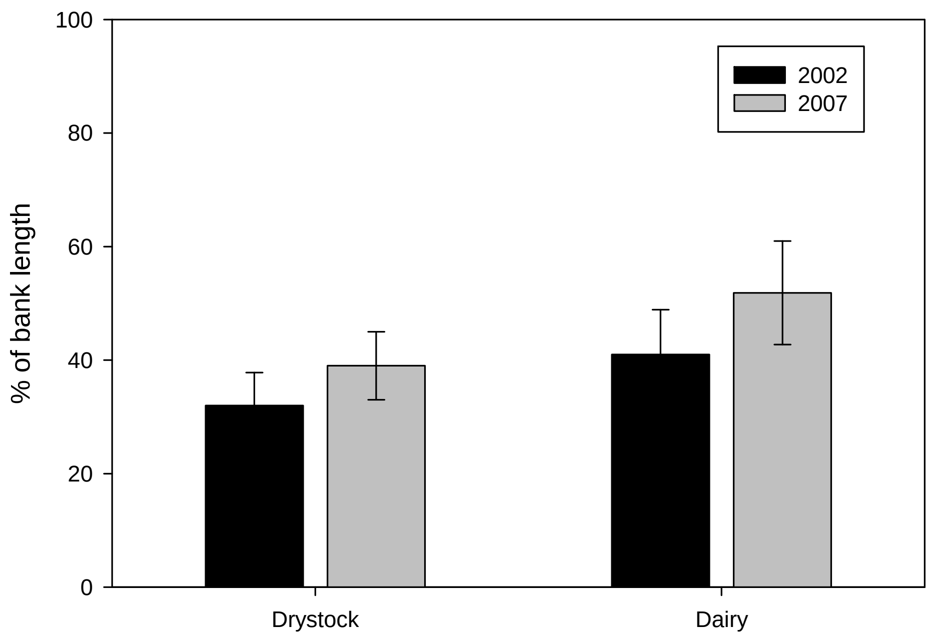

Figure 6: Changes in % total bank length fenced (effective+ineffective fencing combined) (means ± 95% confidence intervals) from 2002 to 2007 on drystock and dairy farms. Only sites that did not change in land use type between years were used.

3.3 Fencing in different management zones

Among the eight management zones (geographic areas of the Waikato region), Lake Taupo had the greatest, and Coromandel the least, proportion of bank length with fencing (Fig. 7). Coromandel and Central Waikato were removed, because of their small sample size, prior to performing a parametric ANOVA on the remaining zones. This ANOVA was significant (F=5.052, df=5,274, p<0.001) and Tukey's HSD showed that the % of bank length fenced was significantly higher in Lake Taupo than in West Coast or lower Waikato, and also higher in the Upper Waikato than in West Coast (Fig. 7).

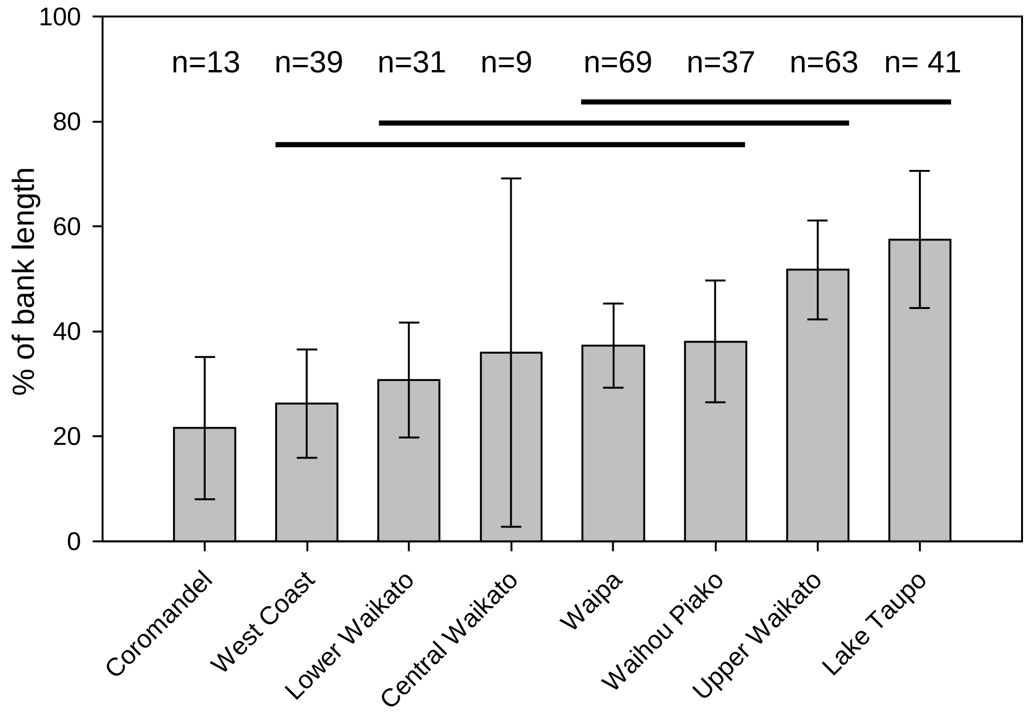

Figure 7: Effective riparian fencing in different management zones of the Waikato region in 2007 (means ± 95% confidence intervals). Values are total fencing (sum of both banks) as a percentage of total bank length. Sample sizes are indicated above the bars. Zones connected by a horizontal bar are not significantly different to each other at α=0.05, according to Tukey's HSD post-hoc test. Note that Coromandel and Central Waikato were excluded from post-hoc tests due to small sample sizes.

Total stock exclusion requires fencing on both banks. Stream length fenced on both banks showed similar patterns to total fencing. The greatest proportion of stream length fenced on both banks occurred in Lake Taupo and the lowest proportion occurred in Coromandel. Parametric ANOVA on six zones (excluding Coromandel and Central Waikato) showed a significant difference between the zones (F=8.127, df=5,274, p<0.001). Post-hoc Tukey's HSD tests indicated that Lake Taupo and Upper Waikato had significantly more stream length fenced on both banks than did other zones (Fig. 8). Lower Waikato and West Coast had significantly less stream bank length fenced on both sides than did other zones. Coromandel had the lowest % of stream bank fenced, but was not included in statistical analyses as it had only a small number of sites surveyed.

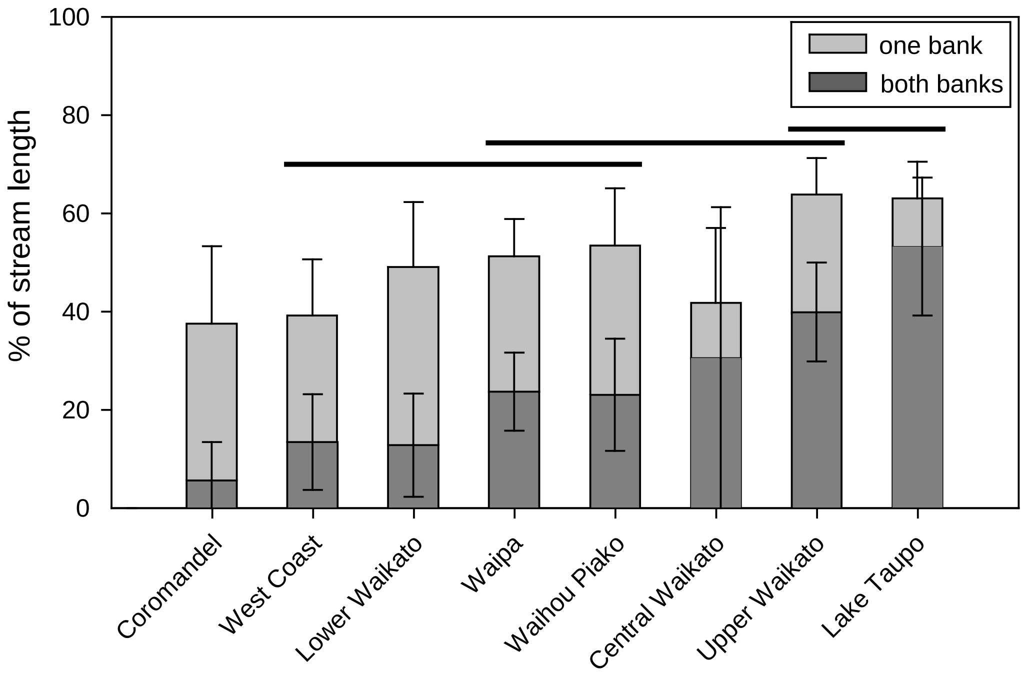

Figure 8: Effective riparian fencing in different management zones of the Waikato region by fencing type in 2007 (means ± 95% confidence intervals). Top of upper bar indicates % of stream length that has a fence on one or both banks. Zones connected by a horizontal bar are not significantly different to each other at α=0.05, according to Tukey's HSD post-hoc test. Note that Coromandel and Central Waikato were excluded from post-hoc tests due to small sample sizes.

Between 2002 and 2007, across all zones there was a significant increase in total fencing (F=4.43, df=514, p=0.036). Total fencing increased in most management zones (Fig. 9), but there were apparent decreases in two zones (Lake Taupo and Central Waikato). Changes between years were caused by several factors. Large changes in % fencing at certain sites were due to removal or addition of temporary fencing, whereas smaller changes were due to slight differences in the stream lengths surveyed between survey years and to recording errors in the field (Reece Hill, pers. comm.). The decreases in proportion of total fencing in Lake Taupo and Central Waikato were probably due to these factors, and/or the boundary change that resulted in reassignment of 22 sites from Central to Upper Waikato. These decreases in the proportion of total fencing were not statistically significant (two-way ANOVA

Management Zone F=20.513, df=514, p<0.001; Year F=4.43, df=514, p=0.036; Management Zone*Year F=1.767, df=514, p=0.118).

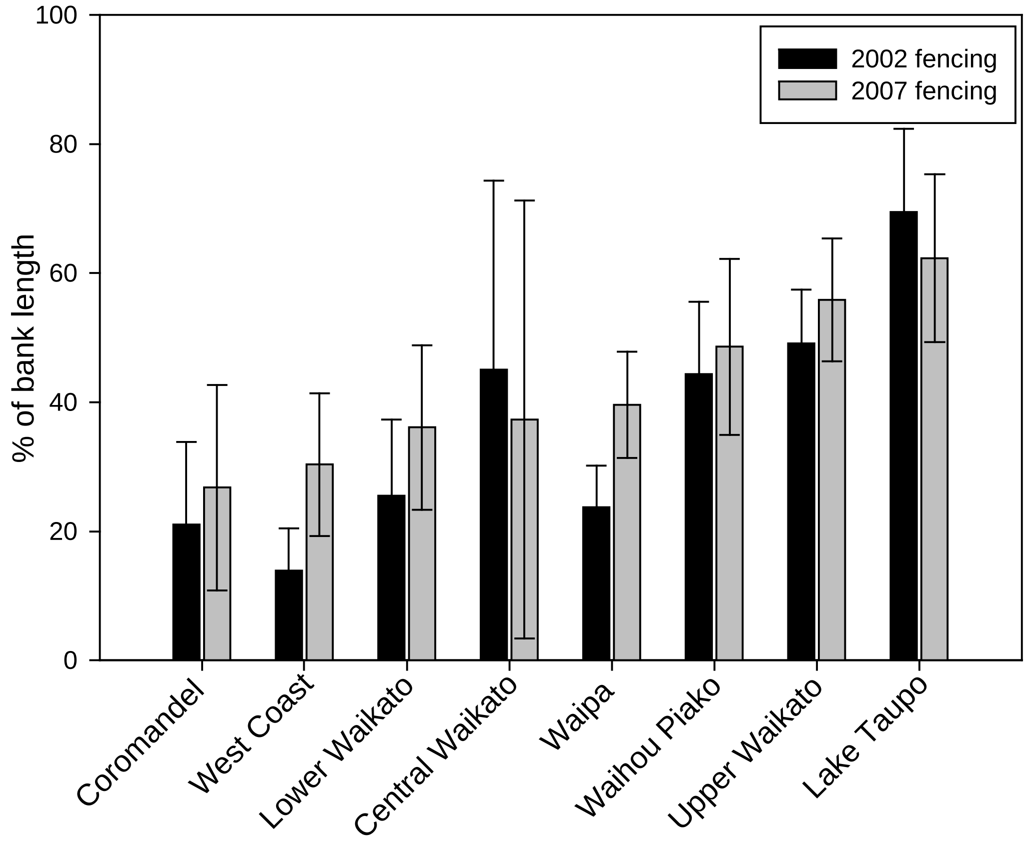

Figure 9: Comparison of total fencing (effective and ineffective fencing combined) in 2002 vs 2007, within each Waikato management zone. Error bars are 95% confidence intervals.

3.4 Comparison with Dairying and Clean Streams Accord data

According to Fonterra's annual On-farm Environmental and Animal Welfare Assessment (Fig. 2 in MAF, 2009), about 78 % of farms in the Waikato region had total stock exclusion from Accord waterways in 2007/08. Accord waterways include all streams on dairy farms "deeper than a red band gumboot (ankle-deep), wider than a stride (1 metre) and permanently flowing" (MAF, 2009). Dairy sites in the 2007 survey reported here were filtered to retain only those matching these criteria, leaving 62 sites. To compare the data in the current survey with the Dairying and Clean Streams Accord results, it was assumed that total stock exclusion required fencing on both banks. Only 6 farms (10%) had >99% of their surveyed stream length effectively fenced on both banks, while 14 (23%) had >50% of their stream length effectively fenced on both banks (Table 2a). Of the total qualifying stream length, 26% was effectively fenced on both sides, 38% was effectively fenced on one side and 36% was either unfenced or ineffectively fenced (ineffective fencing is fencing that stock can move through). These numbers were slightly different if ineffective fencing was included as fencing (Table 2b).

It is possible that high steep banks or thick riparian vegetation may prevent stock access to some streams. When forest and scrub vegetation types were included with fences as barriers to stock access, the number of farms with total stock exclusion from >99% of stream length increased to 8 (12%) (Table 2a). According to Quinn (1999), streams with "VE" channel type, and streams wider than 5 m with "UFL" channel type are likely to have banks too steep to allow stock access. When these channel types were included with fencing and thick riparian vegetation as effective barriers to stock access, the number of farms with stock totally excluded from >99% of their stream length rose to 13 (21%) (Table 2a). Of the total qualifying stream length, 35% had total stock exclusion either by fencing, by thick riparian vegetation or by steepness of banks (44% if ineffective fencing was included as well as effective fencing).

Allowing that there may be other factors not apparent in the riparian survey data set that prevent stock from gaining access to streams, I examined "pugging erosion" as evidence of stock access. "Zero" pugging erosion (meaning <50% of the soil surface trampled by stock at all bank segments) was recorded in 38 (61%) of 62 sites. This figure is likely to overestimate stock exclusion, as a record of "zero" pugging erosion at a site does not necessarily indicate that stock were excluded there.

3.4.1 Changes between 2002 and 2007

Between 2002 and 2007, the total amount of riparian fencing on dairy farms increased by 26% (from 41% to 51.8% of total bank length; Fig. 6). Among 47 farms with Accord-qualifying waterways that were surveyed in both years, the number of farms with stock totally excluded from waterways by fencing increased from 4 (9%) to 7 (15%) (Table 2c). Over a slightly shorter period (2003/04 to 2007/08), Fonterra's On-farm Environment and Animal Welfare Assessment reported that the number of farms with total stock exclusion from waterways increased from 57% to 78% (cited in EW, 2008).

Table 2a: The number of dairy farms in 2007 with total stock exclusion from 99%, 90%, 75%, or 50% of their stream length. Numbers in parentheses are the number of farms expressed as percentage of the total number of qualifying dairy farms in the survey (62 farms).

	Percentage of stream length per farm with total stock exclusion			
	>99%	>90%	>75%	>50%
Exclusion by fencing only	6 farms (10%)	8 farms (13%)	8 farms (13%)	14 farms (23%)
Exclusion by fencing and thick vegetation	8 farms (13%)	9 farms (15%)	10 farms (16%)	17 farms (27%)
Exclusion by fencing, thick veg and steep banks	13 farms (21%)	14 farms (23%)	16 farms (26%)	23 farms (37%)

Table 2b: As above, but including ineffective fencing as fencing. Ineffective fencing is fencing that stock can move through.

	Percentage of stream length per farm with total stock exclusion			
	>99%	>90%	>75%	>50%
Exclusion by fencing only	9 farms (14%)	13 farms (21%)	15 farms (24%)	19 farms (30%)
Exclusion by fencing and thick vegetation	11 farms (18%)	14 farms (23%)	16 farms (26%)	22 farms (35%)
Exclusion by fencing, thick veg and steep banks	16 farms (26%)	19 farms (31%)	22 farms (35%)	28 farms (45%)

Table 2c: Changes in stock exclusion by fencing only, from 2002 to 2007 among 47 Accord-qualifying sites.

	Percentage of stream length per farm with total stock exclusion			
	>99%	>90%	>75%	>50%
2002	4 (9%)	4 (9%)	5 (11%)	11 (23%)
2007	7 (15%)	11 (23%)	12 (26%)	15 (32%)

3.5 Riparian vegetation

About 44% of total bank length in the 2007 survey had a riparian buffer of woody vegetation (Fig. 10). More than 2.5 times as much bank length had exotic woody vegetation (32%, including willows) as had native woody vegetation (12%).

Most of the woody riparian vegetation occurred as “treeland”, i.e., trees >3 m tall, spaced widely and with grass beneath (Fig. 11). Dense woody vegetation was mostly scrub (<3 m tall); only 4.2% of total bank length in the survey was covered with forest, i.e., trees >3 m tall, closely spaced with dense understorey. Riparian wetlands (4.1%) covered a similar percentage of bank length as forest.

About 15% of the riparian woody vegetation buffers were >10 m wide on each bank, whereas 34% were <2 m wide (Fig. 12).

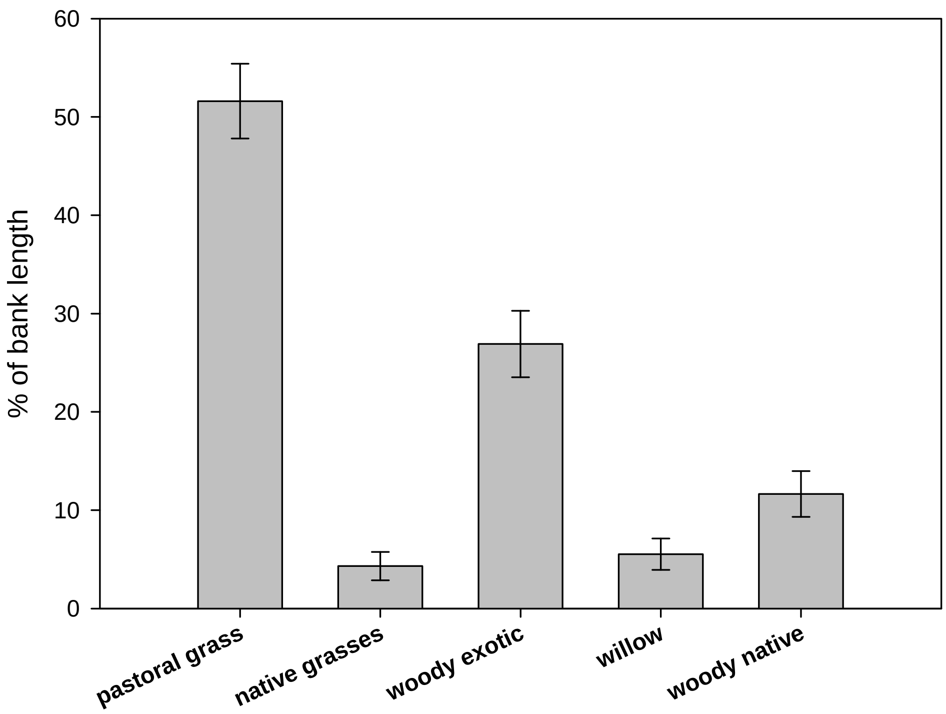

Figure 10: Percentage of total bank length covered by different types of riparian vegetation. Error bars are 95% confidence intervals.

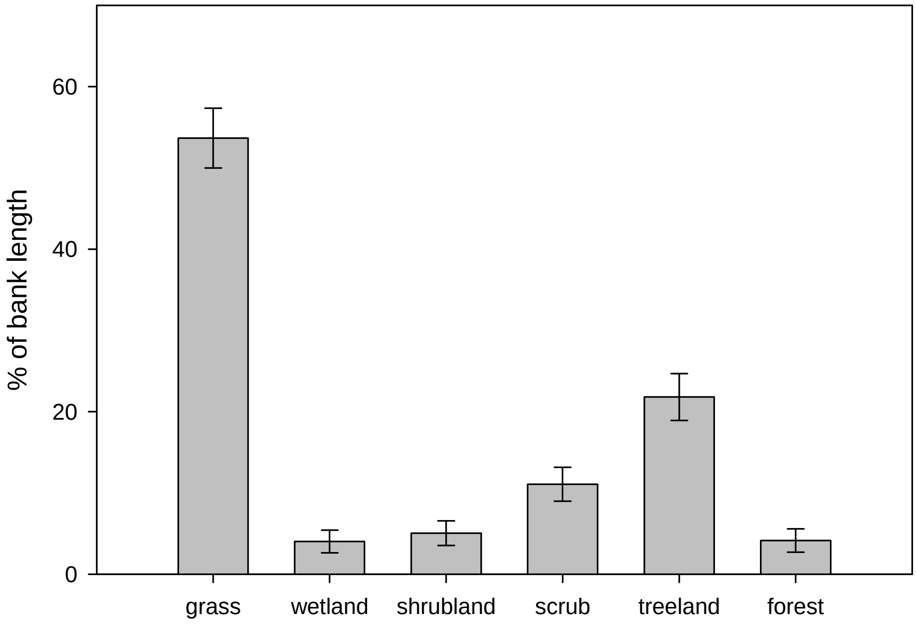

Figure 11: Percentage of bank length covered by different types of riparian vegetation structure (means ±95% confidence intervals). Treeland and forest are comprised of trees >3 m tall, whereas shrubland and scrub are <3 m tall. In treeland and shrubland, woody plants are widely spaced with grass beneath, whereas in scrub and forest, woody plants grow densely.

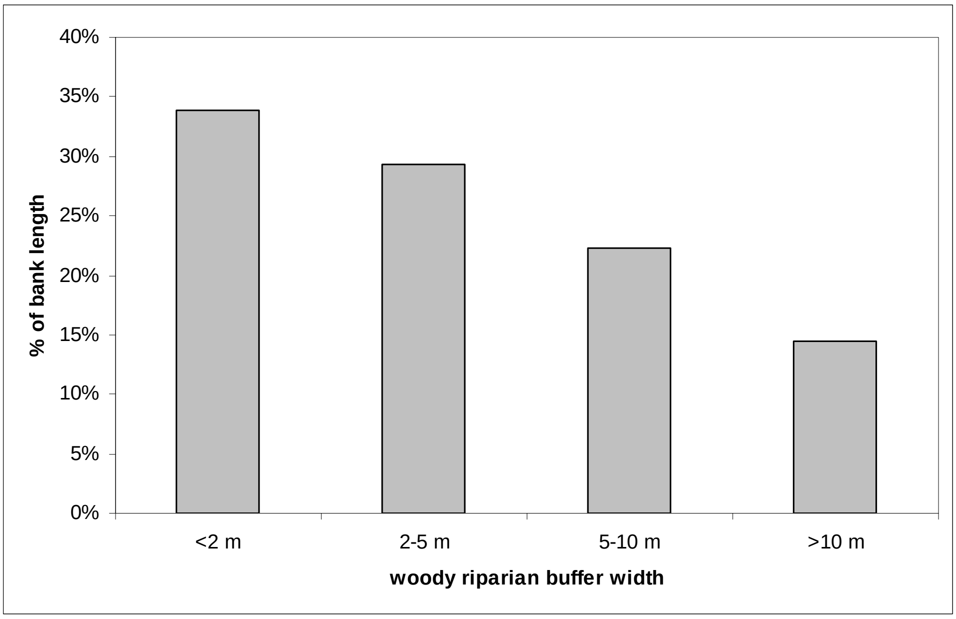

Figure 12: Widths of woody riparian buffer vegetation in the 2007 survey, for each bank separately.

3.5.1 Riparian vegetation change 2002-2007

Overall, 42% of bank length had riparian woody vegetation in 2002, whereas 44% of bank length had riparian woody vegetation in 2007. This difference was not statistically significant (paired samples t-test t=1.618, df=288, p=0.107).

3.5.2 Riparian vegetation on dairy vs drystock farms

On average, dairy farms had significantly less bank length with woody vegetation (t=0.3216, df=300, p=0.001), and significantly more with pasture grass, than drystock farms (t=3.178, df=300, p=0.002, Fig. 13). The data also suggested that dairy farms may have less forest and scrub than drystock farms, but these differences were not significant at the p=0.007 level (t=2.287, df=292, p=0.023 and t=2.583, df=222, p=0.010 respectively, equal variances not assumed; a significance level of 0.007 was used for each of seven t-tests to maintain the overall experiment-wise error rate at α=0.05).

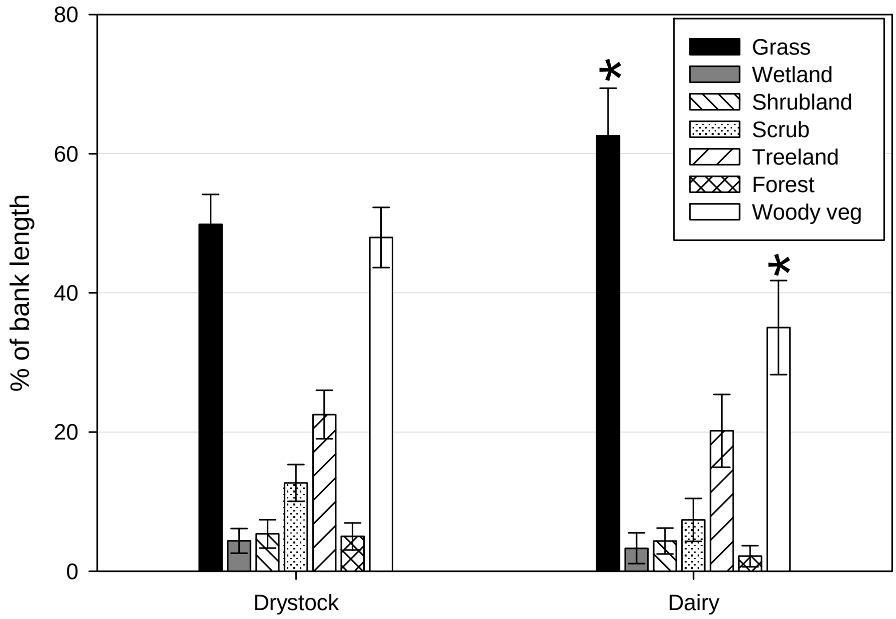

Figure 13: Percentage of bank length on drystock and dairy farms covered by different types of riparian vegetation structure (means ±95% confidence intervals). See figure 10 for definitions of different vegetation types. Asterisks indicate where significant differences occurred between dairy and drystock farms (t-test p<0.007).

3.5.3 Riparian vegetation across management zones

The highest proportions of bank length with woody vegetation were found in Lake Taupo, Coromandel and Upper Waikato (Fig. 14). A Kruskall-Wallis test (non-parametric equivalent of ANOVA) indicated there were significant differences in % woody vegetation between management zones (χ^2=48.234, df=7, p<0.001). Tukey's HSD post-hoc tests on the six zones with sample sizes >30 showed that Lake Taupo had significantly more woody riparian vegetation than all other zones other than Upper Waikato, and that Upper Waikato had more woody vegetation than all zones other than Taupo and Waipa (Fig. 13).

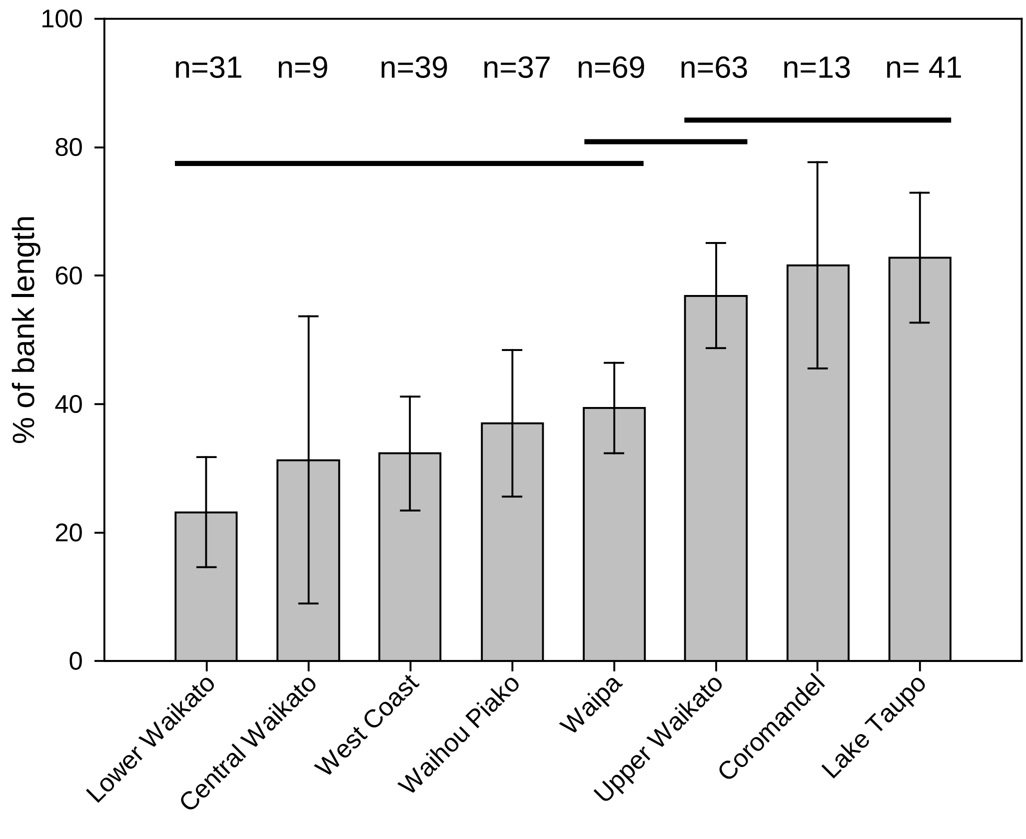

Figure 14: Percent of bank length with woody vegetation in different management zones. Management zones joined by horizontal bars are not significantly different to each other, according to Tukey's HSD post-hoc test (Central Waikato and Coromandel were omitted from post-hoc tests due to small sample sizes). Sample sizes are indicated above the bars. Error bars are 95% confidence intervals.

3.5.4 Riparian vegetation and stream order

There was an overall trend of increasing woody vegetation with increasing stream order (Fig. 15). After drains and sixth order streams were removed due to small sample sizes, ANOVA with Tukey's HSD post-hoc tests showed that first order streams were significantly different from fifth order streams in terms of % bank length with woody vegetation (F=2.798, df=254, p=0.027).

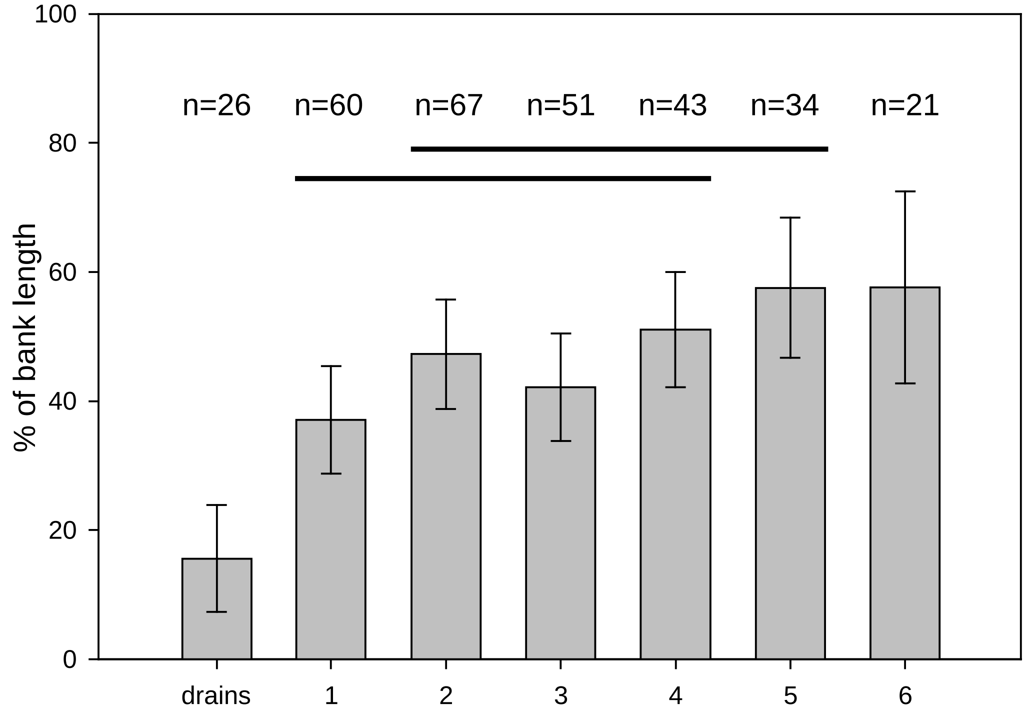

Figure 15: Percent of bank length with woody vegetation (means ±95% confidence intervals) along drains and stream orders 1-6. Stream orders connected by a horizontal bar are not significantly different to each other at α=0.05, according to Tukey's HSD post-hoc test (drains and sixth order streams were omitted from this analysis).

3.5.5 Association between riparian fencing and riparian vegetation type

The proportions of different vegetation types that were fenced *vs.* unfenced was calculated to estimate the extent that riparian vegetation was protected from grazing. Forest, scrub and shrubland were positively associated with fencing, whereas grass was negatively associated (i.e., less fencing than expected occurred along grassed banks; Table 3a).

Vegetation type gives slightly different information from vegetation structure, differentiating between native and exotic vegetation, but not between shrub-sized and tree-sized vegetation. Native grasses in the riparian zone were fenced much more frequently than pastoral grasses, and surprisingly, were the most strongly associated with fencing among all vegetation types (Table 3b). Also, contrary to expectations, exotic woody vegetation was fenced almost twice as frequently as native woody vegetation.

Table 3a: Proportions of different vegetation structure types that are fenced, and observed/expected ratios from a cross-tabulation analysis of fencing *vs.* vegetation structure. Ratios >1 indicate a positive association, whereas ratios <1 indicate negative association.

	Total proportion fenced	Cross-tabulation observed/expected ratios	
		effective fence	no fence
Grass	33%	0.8	1.1
Wetland	38%	0.9	1.1
Shrubland	46%	1.3	0.8
Scrub	54%	1.4	0.7
Treeland	48%	1.1	0.9
Forest	57%	1.4	0.7

Table 3b: Proportions of different vegetation types that are fenced, and observed/expected ratios from a cross-tabulation analysis of fencing *vs.* vegetation structure. Ratios >1 indicate a positive association, whereas ratios <1 indicate negative association.

	Total proportion fenced	Cross-tabulation observed/expected ratios	
		effective fence	no fence
Pastoral Grass	31%	0.8	1.2
Native Grasses	63%	1.5	0.6
Woody Willow	45%	1.1	0.9
Woody Exotic	59%	1.4	0.7
Woody Native	33%	0.8	1.2

3.6 Stream bank erosion

About 32% of the total bank length surveyed across all sites showed signs of erosion (Fig. 16). Recent erosion (past erosion that is now revegetated but may still add sediment when a stream is in flood) accounted for most of the observed erosion. Pugging erosion (from cattle treading) was more common than active erosion (unvegetated soil that is currently eroding and actively adding sediment to the stream).

Changes in stream bank erosion between 2002 and 2007 could not be analysed due to uncertainty about whether the definitions of recent and pugging erosion types had remained consistent between surveys.

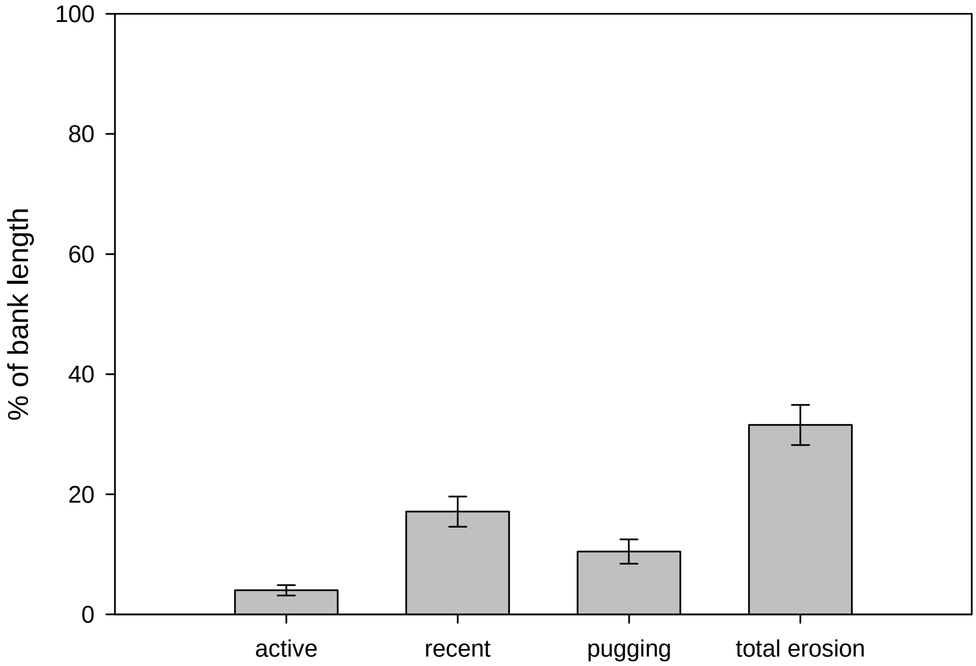

Figure 16: Percent of bank length showing erosion of different types (means ± 95% confidence intervals) in 2007. Data are averaged across both land use types and all management zones. Error bars are 95% confidence intervals.

3.7 Factors associated with erosion

3.7.1 Land use type and erosion

The patterns for percentage of bank length eroded were almost identical between dairy and drystock farms (Fig. 17), and no significant differences were found between the two landuse types in any erosion category (Table 4).

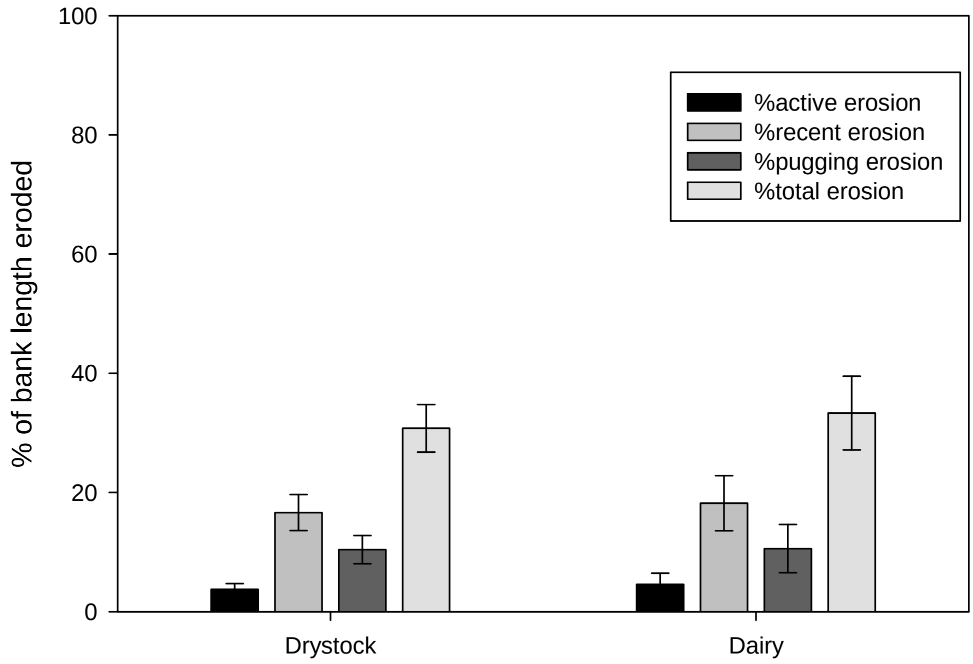

Figure 17: Percent of bank length showing erosion of different types on drystock vs dairy farms (means ±95% confidence intervals).

3.7.2 Land use capability and erosion

Land use capability (LUC) is a composite measure that summarises the suitability of land for productive uses such as arable cropping and pastoral farming (Lynn et al. 2009). It combines land erodibility, wetness, properties of soil such as stoniness and fertility, and climate. LUC classes 1 through 8 represent a gradient of decreasing suitability for pastoral farming, with Class 8 being unsuitable. Land erodibility generally increases from class 1 to class 8. In this analysis, the eight LUC classes were merged into two groups, classes 1-4 and classes 5-8. Total erosion was higher in LUC 5-8 than LUC 1-4, but of the three measures of erosion (active, recent and pugging) only recent erosion was significantly higher in LUC 5-8 than LUC 1-4 (Table 4).

Table 4: T-tests and Analysis of Variance of simple relationships between the three erosion types and categorical variables (land-use type, land use capability class, soil type). T is the test statistic for the t-test, which was used for categorical variables with 2 possible values. F is the test statistic for ANOVA, which is the equivalent test for categorical variables with more than 2 possible values. p is the probability that the test statistic was due to chance alone. T-tests and ANOVA all had 300 degrees of freedom. Asterisks indicate the test statistic was significant at $p<0.05$.

		Erosion type			
		active	**recent**	**pugging**	**total**
Land-use type	t	0.858	0.564	0.075	0.695
	p	0.392	0.573	0.940	0.488
Land-use capability	t	-1.288	-2.137(*)	-1.223	-2.721(**)
	p	0.199	0.033	0.222	0.007
Soil type	F	3.903(*)	2.700	1.651	4.676(*)
	p	0.021	0.069	0.194	0.010

3.7.3 Soil and erosion

Sites in this survey were located on eight different soil orders (based on NZ Soil Classification attributes; Hewitt, 1998). To simplify the analysis, orders were grouped according to their likely erodibility. Group 1 included Brown and Granular soils, group 2 included Pumice, Allophanic and Podzol soils, and group 3 included Organic, Recent, Raw and Gley soils. Active erosion and total erosion were slightly higher among sites on Group 1 soils than sites on Group 3 soils (according to Tukey's HSD, see Table 4 for ANOVA test statistics).

3.7.4 Valley gradient and erosion

Total erosion increased progressively with increasing valley gradient (gradient values derived from the River Environment Classification; Table 5, Fig. 18). Pugging erosion was expected to decrease with increasing gradient due to more difficult access to streams in steeper valleys. However, pugging erosion actually increased with increasing gradient. Active erosion, which was expected to increase with increasing gradient due to the greater erosive power of the stream, showed a negative correlation with gradient, though active and recent erosion combined (Fig. 18) increased between medium and high-gradient valleys.

Table 5: Simple (bivariate) correlations between the three erosion types and continuous parameters. Correlation coefficients are Spearman's rho. * means significant at α=0.05, ** means significant at α=0.01. Actual p values are shown beneath the correlation coefficients. Sample size for all correlations was 302.

		Erosion type			
		active	**recent**	**pugging**	**total**
Valley gradient	corr. coeff.	-0.136(*)	0.061	0.149(**)	0.164(**)
	p	0.018	0.292	0.01	0.004
Stream order	corr. coeff.	0.170(**)	0.019	-0.259(**)	-0.095
	p	0.003	0.74	<0.001	0.098
%fencing total	corr. coeff.	-0.287(**)	-0.431(**)	-0.349(**)	-0.532(**)
	p	<0.001	<0.001	<0.001	<0.001
%unfenced	corr. coeff.	0.285(**)	0.396(**)	0.365(**)	0.52(**)
	p	<0.001	<0.001	<0.001	<0.001
% fenced one side	corr. coeff.	0.041	-0.002	-0.006	-0.049
	p	0.478	0.974	0.92	0.398
%fenced both sides	corr. coeff.	-0.285(**)	-0.395(**)	-0.308(**)	-0.458(**)
	p	<0.001	<0.001	<0.001	<0.001
%woody vegetation	corr. coeff.	-0.203(**)	-0.184(**)	-0.329(**)	-0.284(**)
	p	<0.001	0.001	<0.001	<0.001
Obstructions: living & nonliving debris	corr. coeff.	0.345(**)	0.157(**)	0.077	0.151(**)
	p	<0.001	0.006	0.2	0.008
Obstructions total	corr. coeff.	0.381(**)	0.298(**)	0.370(**)	0.383(**)
	p	<0.001	<0.001	<0.001	<0.001
Bridges	corr. coeff.	-0.036	0.012	0.374(**)	0.177(**)
	p	0.54	0.84	<0.001	0.002
Fords	corr. coeff.	0.184(**)	0.149(**)	0.100	0.136(*)
	p	0.001	0.010	0.084	0.018

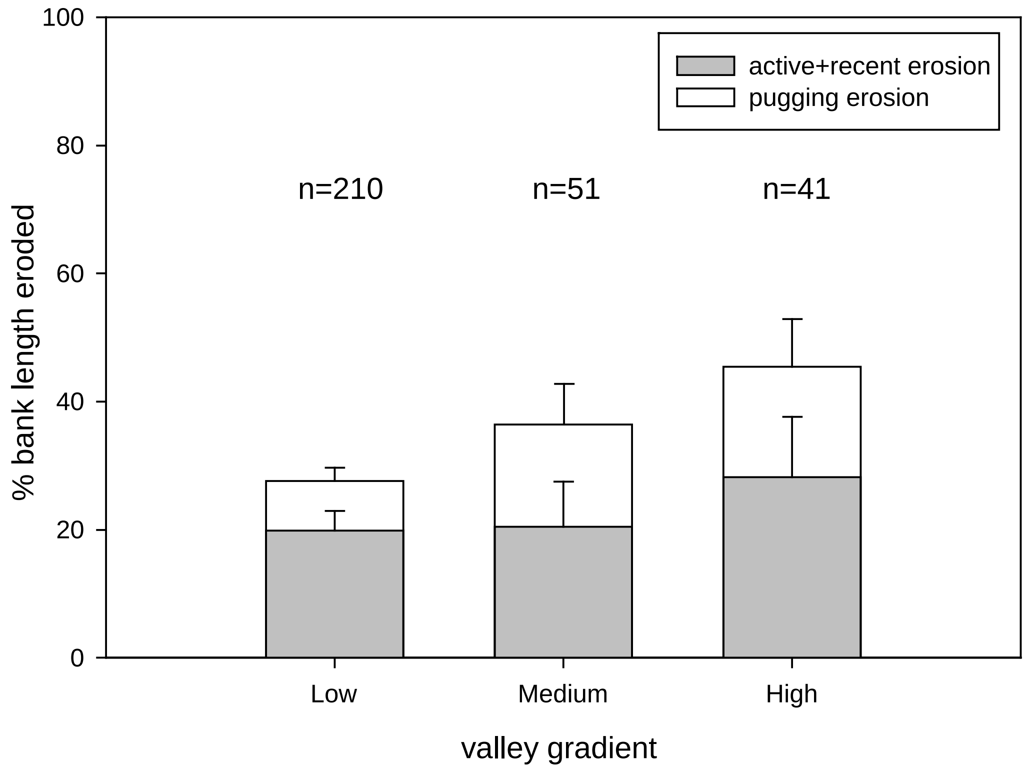

Figure 18: Relationship between bank erosion (mean ±95% confidence intervals) and valley gradient (according to River Environment Classification). Total erosion is the sum of pugging, active and recent erosion, and is indicated by the top of the white bars. Sample sizes are shown above the bars.

3.7.5 Underlying geology and erosion

Among the sites in this survey, pugging, non-pugging (active and recent) and total bank erosion were at similar levels in hard sedimentary, soft sedimentary and volcanic acidic geological types (Fig. 19). However, statistical analyses were not possible due to the low numbers of sites for most geological types, and the patterns should be interpreted with caution. The number of sites in mudstone and alluvium were too small to be confident the values in Fig. 18 truly represent these geological types.

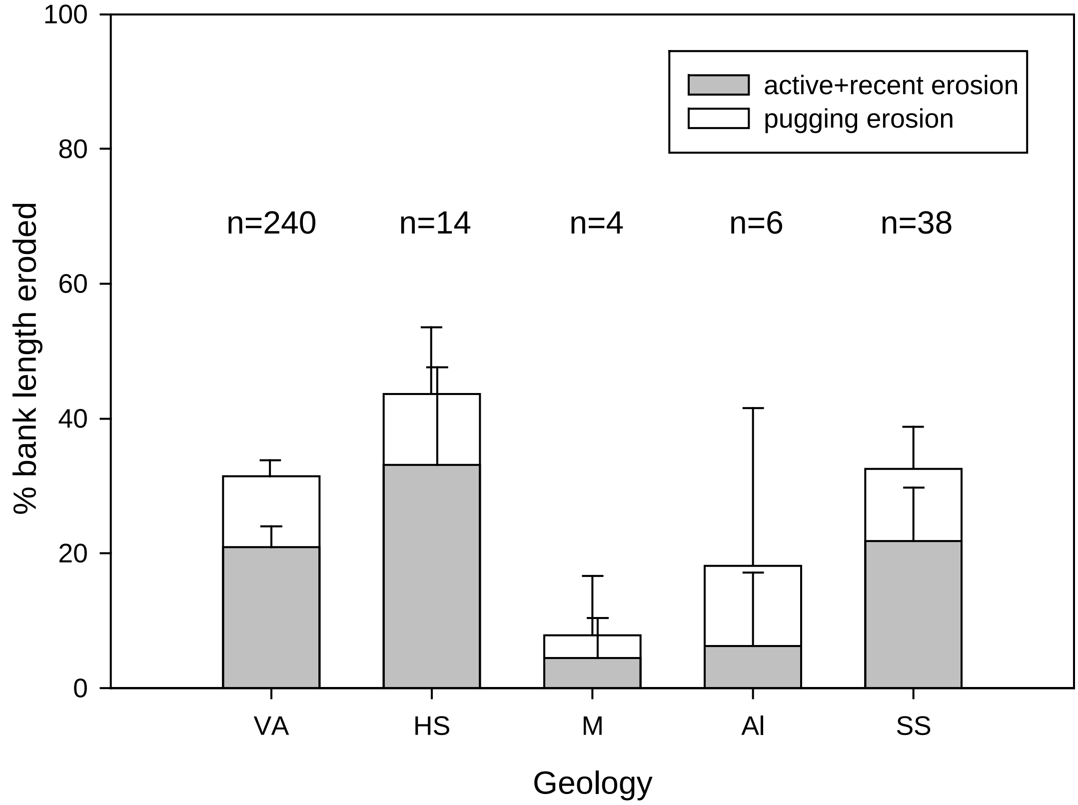

Figure 19: Proportion of stream banks with pugging and recent+active erosion (means ± 95% confidence intervals) in streams draining different geological types, derived from the River Environment Classification. Total erosion is the sum of active, recent and pugging erosion, and is indicated by the top of the white bars. Abbreviations are: VA volcanic acidic; HS hard sedimentary; M mudstone; Al alluvium; SS soft sedimentary. Sample sizes are shown above the bars.

3.7.6 Stream order and erosion

A positive correlation was found between active erosion and stream order, whereas no significant correlations were found between recent erosion, total erosion and stream order, and a negative correlation was found between pugging erosion and stream order (Table 5; Fig. 20).

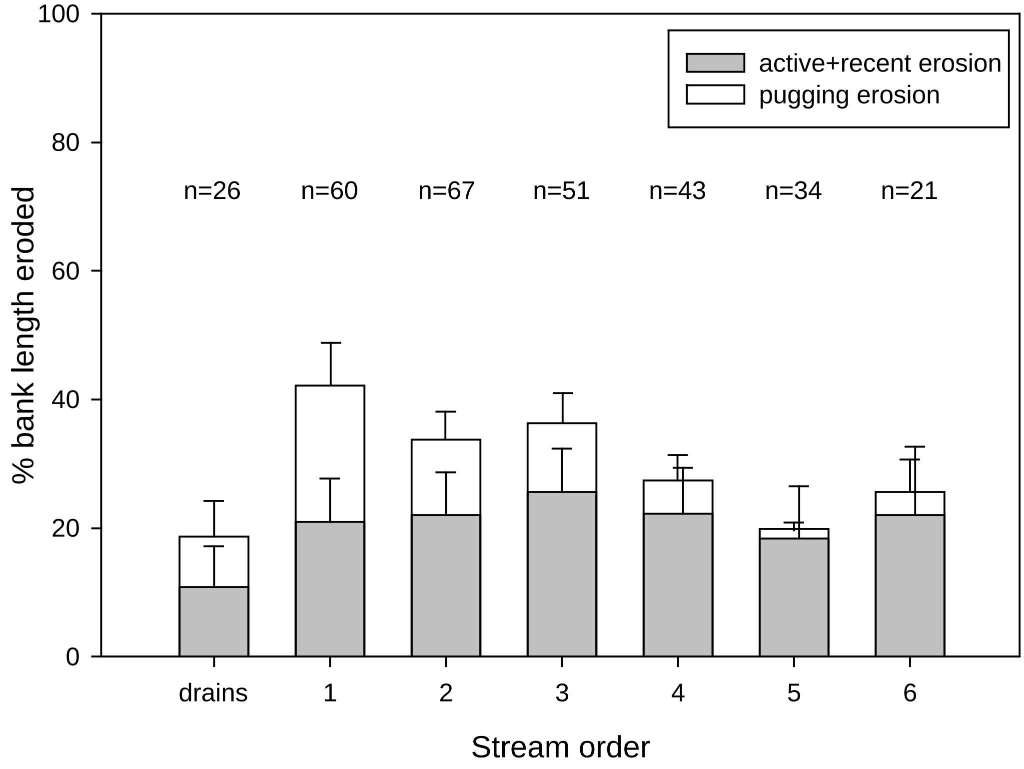

Figure 20: Pugging and active+recent erosion (means ± 95% confidence intervals) for different stream orders.

3.7.7 Fencing and erosion

Correlations between three measures of fencing (% of total bank length fenced, % of stream length unfenced and % of stream length fenced both sides) and bank erosion were highly significant ($p<0.001$) and of similar magnitude (Table 5). Correlations were slightly stronger with pugging erosion (Spearman's rho=0.31 to 0.37) than with active erosion (Spearman's rho=0.29), as was expected, since active erosion was influenced by the action of stream flow, which was not expected to be strongly affected by fencing. No significant correlation was found between % of stream length fenced one side and bank erosion.

Effect of fencing on erosion of adjacent *vs.* opposite bank

For the stream segment data set, fencing data from each bank were combined and summarised as fencing on neither bank, fencing on left bank only, fencing on right bank only and fencing on both banks. Erosion data were simplified into eroded *vs.* uneroded, and summarised as eroded neither bank, eroded left bank only, eroded right bank only and eroded both banks. Cross-tabulation analysis showed that fencing on both banks was positively associated with "neither bank eroded" (Table 6). Conversely, "no fencing" was positively associated with erosion of left, right and both banks. As expected, fencing on one bank only was associated with reduced erosion of the adjacent bank, however contrary to expectations, it was associated with increased erosion of the opposite bank.

Table 6: Cross-tabulation analysis of fencing and erosion: observed/expected frequencies for stream segments.

	Neither bank eroded	Left bank eroded	Right bank eroded	Both banks eroded
No fencing	0.7	1.2	1.1	1.6
Fencing left bank only	0.9	0.4	2.4	0.7
Fencing right bank only	1.0	1.9	0.6	0.8
Fencing both banks	1.5	0.6	0.4	0.2

3.7.8 Riparian vegetation and erosion

Riparian woody vegetation limits access by stock to waterways and strengthens stream banks. At the stream site level, percent of bank length with woody vegetation was negatively correlated with all three erosion types, among which the strongest correlation was with pugging erosion (Table 5). Pugging erosion was correlated as strongly with % woody vegetation as it was with fencing, but active and recent erosion were correlated less strongly with % woody vegetation than they were with fencing.

Associations between the six types of vegetation structure (wetland, grass, scrub, shrubland, treeland, forest) and the three erosion types (active, recent and pugging) were analysed by cross tabulation at the stream segment level. There was a significant association between vegetation structure and erosion type (χ^2=35110, df=21, p<0.0001; contingency coeff=0.234, Cramer's V=0.139). However, the strength of this association, as indicated by the Cramer's V statistic, is not much above 0.1, which is the threshold often used to indicate when there is a substantive relationship between two variables. According to Cramer's V, the association between vegetation structure and erosion is weaker than that between fencing and erosion (see Section 3.6.1), i.e., it appears that vegetation structure may have a weaker effect on erosion than fencing does.

Pugging erosion was most strongly positively associated with wetland vegetation (Table 7). It was also positively associated with grass, and negatively associated with all types of woody riparian vegetation, especially forest. Grass was weakly associated with increased active and recent erosion, whereas all woody vegetation was associated with reduced active and/or recent erosion. "Forest" had the strongest association of all vegetation structure types with reduced active and recent erosion. The survey defined treeland and forest as taller vegetation types than shrubland and scrub, and forest and scrub as having denser understorey than treeland and shrubland. Lower but denser vegetation (scrub) appeared to be more strongly associated with reduced erosion than taller but more open vegetation (treeland).

Table 7: Cross tabulation analysis of vegetation structure and erosion: observed/expected frequencies for stream segments.

		Erosion type			
		none	**active**	**recent**	**pugging**
Vegetation structure	Wetland	0.8	0.6	0.7	3.0
	Grass	0.9	1.2	1.2	1.3
	Shrubland	1.2	1.2	0.6	0.5
	Scrub	1.2	0.6	0.8	0.4
	Treeland	1.1	0.9	0.9	0.5
	Forest	1.3	0.2	0.6	0.1

3.7.9 Instream obstructions and erosion

Instream obstructions were defined as objects that block >50% of the waterway width, and would impede water flow or act as a trap for debris. Such objects included living and non-living debris, culverts, side drains and dams. These potentially could increase erosion, as water flow diverted around them may cut into stream banks, or they may reduce erosion if they reduce water velocities. At the stream site level, the total number of obstructions was positively correlated with all erosion types (Table 5). The reason for obstructions being correlated with pugging erosion is not clear. The number of debris obstructions (living and non-living debris) was positively correlated with active and recent erosion but not with pugging erosion.

Cross-tabulation analysis of stream segment data was used to determine whether obstructions were associated with non-pugging erosion (active and recent erosion) in their immediate vicinity. Results showed a statistically significant association between obstructions and stream bank erosion (active and recent erosion combined; χ^2=818, df=5, p<0.0001), but no single type of obstruction was found to be strongly associated with increased bank erosion (Table 8). There was a weak positive association between non-living debris and bank erosion, but culverts and dams appeared to be associated with reduced bank erosion, probably due to their effects of armouring banks and reducing water velocities, respectively.

There is concern that willows growing into the stream channel may increase bank erosion. In this data set willows could not be distinguished from other types of living vegetation obstructions, though it could be seen from the Vegetation Type field in the database that up to 58 records, i.e., between 25% and 50% of living vegetation obstructions, were likely to be willows. At the stream site level, there was a weak positive correlation between number of living debris obstructions and %active erosion (Spearman's rho=0.235, p<0.001), but at the stream segment level, no association was found between living vegetation obstructions in stream channels and increased erosion (Table 8). This discrepancy may be due to the obstructions causing erosion in a segment adjacent to the one where the obstruction was recorded.

Table 8: Observed/expected ratios from a cross-tabulation analysis of obstruction type *vs.* stream bank non-pugging erosion (active and recent erosion combined).

	Not eroded	Eroded
No obstruction	1.0	1.0
Culvert	1.2	0.7
Side Drain	1.0	0.9
Non-living Debris	0.9	1.2
Living Vegetation	1.1	0.9
Dam	1.2	0.5

3.7.10 Effect of accessways on erosion

Accessways were defined as structures or tracks that provide a means of moving across a waterway. They included bridges and fords. Fords are sites where stock come into contact with water, and were expected to increase pugging erosion, whereas bridges typically keep stock away from contact with water, and were expected to decrease pugging erosion. Bridges and fords may also be places where debris and sediment accumulate, so both may increase total erosion.

At the stream site scale, the number of bridges was positively correlated with % pugging erosion (Table 5). This suggests that bridge crossing points increase cattle access to streams, which is counter to expectations, as bridges are designed to keep cattle out of streams. However, the correlation may instead imply that streams with high numbers of bridges are those that are easily accessible to stock, or that farms with more bridges also have higher stocking densities. In these cases, pugging erosion may have been even higher if the bridges were not there. It would be useful to measure stock accessibility of streams, and erosion directly associated with accessways, in future surveys. The number of fords per site showed a weak positive correlation with % active and recent erosion, but not with % pugging erosion.

At a stream segment level, cross-tabulation analysis indicated that bridges (χ^2=448, df=2, p<0.001) and fords (χ^2=765, df=2, p<0.0001) were both associated with increased pugging erosion (Table 9). However, only 27 fords were recorded, compared to 369 bridges and 13570 records without accessways, so conclusions with regard to fords must remain somewhat tentative. Bridges were negatively associated with non-pugging erosion at the stream segment scale, though at a stream site scale the number of bridges showed no correlation with non-pugging erosion. The results at both scales suggest that bridges do not exacerbate non-pugging erosion by accumulating debris.

Table 9: Observed/expected ratios from cross-tabulation analysis of accessways *vs.* stream bank erosion.

	Pugging erosion		**Non-pugging erosion**	
	Not eroded	**Eroded**	**Not eroded**	**Eroded**
None	1.0	1.0	1.0	1.0
bridge	0.9	1.4	1.2	0.6
Ford	0.7	2.5	0.9	1.1

3.7.11 Strongest drivers of erosion

Relationships were analysed between erosion and a suite of environmental variables (potential drivers of erosion). Erosion types analysed were active, pugging and total erosion; recent erosion is not reported separately here as values were similar to those for active erosion. The environmental variables included land use type, % total fencing, % fencing both sides, % riparian woody vegetation, frequency of instream debris obstructions, valley gradient, stream order, land use capability class and soil type. None of the environmental variables (except % total fencing and % fencing both sides, which were entered alternately in the regressions) were strongly correlated with each other; Spearman correlation coefficients between all pairs of environmental variables were <0.3 (Appendix Table 4). Further, collinearity tolerances of all environmental variables were >0.62. Low correlations and high collinearity tolerances indicate that there is little redundancy among the environmental variables, therefore selection of a reduced set of environmental variables should not be strongly influenced by chance.

The eight environmental variables together explained 12% of active erosion, 23% of pugging erosion and 34% of total erosion. Reduced sets of environmental variables, identified by the stepwise selection procedure in SPSS™ v11, explained the differences in erosion between sites nearly as well as did the full set of eight variables (Table 10). Ten percent of active erosion, 20% of pugging erosion and 32% of total erosion were explained by the reduced sets of variables.

A slightly different set of environmental variables was identified as driving each of the three erosion types. However some common patterns could be seen. The strongest predictor of all erosion types was fencing, which limits access by stock to waterways. Total fencing had a stronger influence than fencing on both banks in reducing active erosion, whereas fencing on both banks was slightly more effective than total fencing in reducing pugging and total erosion. Riparian woody vegetation was one of the key factors reducing pugging and total erosion, but not active erosion.

Active erosion was also increased significantly by instream debris obstructions. Other factors affecting erosion related to geographic factors, such as valley slope and stream order, that cannot be altered by management practices. Land use type did not strongly affect stream bank erosion.

Table 10: Strongest drivers of active, pugging and total erosion, as identified by the stepwise selection procedure in SPSS. The sets of predictor variables shown here were chosen from among 8 environmental variables.

		b (slope)	Std. error of slope	β (stdised slope)	t value	p value	Partial r
Active erosion	constant	3.32	1.04		3.19	0.002	
	% total fencing	-0.036	0.012	-0.17	-3.06	0.002	-0.18
	Debris obstructions	381	147.8	0.14	2.58	0.010	0.15
	Soil type 1	3.29	1.39	0.13	2.37	0.019	0.14
	Stream order	0.54	0.26	0.12	2.08	0.038	0.12
Pugging erosion	constant	25.9	2.14		12.15	<0.001	
	% fenced both sides	-0.14	0.025	-0.30	-5.52	<0.001	-0.29
	Stream order	-2.99	0.60	-0.27	-4.99	<0.001	-0.26
	% woody veg	-0.068	0.031	-0.12	-2.19	0.029	-0.11
Total erosion	constant	57.1	4.00		14.27	<0.001	
	% fenced both sides	-0.33	0.038	-0.45	-8.87	<0.001	-0.46
	Stream order	-1.85	0.95	-0.10	-1.94	0.053	-0.11
	LUC1-4	-7.56	3.02	-0.13	-2.51	0.013	-0.14
	% woody veg	-0.16	0.048	-0.18	-3.41	<0.001	-0.19
	High valley gradient	9.23	4.52	0.11	2.04	0.042	0.12

3.8 Power analysis

The power of a statistical test is related to its ability to detect a difference between sample means, assuming there is one. Formally, it is 1-β, where β is the probability of making a Type II error, i.e., failing to detect a difference between means when one is present. Typically, in ecology, power of 0.8 is considered acceptable (Quinn and Keough, 2002). The power of a test depends on both the size of the difference between the means, and the variability (standard deviation) of each set of samples. The "standardised effect size" is defined as $E_s = (\mu_1-\mu_2)/\sigma$ where μ_1 and μ_2 are the two sample means and σ is the pooled standard deviation of the samples (the equivalent for a multi-sample test is RMSSE, the root mean square standardised effect). The greater the standardised effect size or RMSSE, the higher the probability that a test will show a significant difference, hence the higher the power of the test. In biological studies, E_s values of 0.2, 0.5 and 0.8 are typically considered as small, medium and large effects respectively (Quinn and Keough, 2002), whereas RMSSE values of 0.15, 0.3 and 0.5 are typically considered as small, medium and large effects respectively.

3.8.1 Power of tests between years

For measures of fencing and riparian woody vegetation, the differences between 2002 and 2007 were small relative to the variability within each year. This resulted in small standardised effect sizes (between 0.04 and 0.16; Table 11). Despite these small effect sizes, the power of analyses for total fenced bank length and unfenced stream length were close to 0.8 because comparisons between years were based on paired samples t-tests, which are more powerful than independent samples t-tests. Riparian woody vegetation, and stream length fenced one side and both sides changed very little between years, so the power of those t-tests was low. Using the current sample size (289 sites), one would be able to detect a standardised effect size of 0.17, which is typically considered a small effect. This means, for example, that a change in total bank length fenced could be detected if it increased by more than 21% of the previous year's value, whereas a change in stream length fenced one side could be detected if it changed by more than 42% of the previous year's value (Table 11).

Power analysis can also be used to calculate how many samples would be needed to detect a significant difference between years for a certain standardised effect size. If bank fencing or riparian woody vegetation increased by 30% of its value in the previous survey, the increase could be detected with sample sizes of 138-580 (for measures of bank fencing) and 102 (for riparian woody vegetation; Table 11). These figures indicate that the current sample size is sufficient to detect a change of 30% between years, with power of 0.8, for total bank length fenced, unfenced stream length and riparian woody vegetation. Figure 21 shows a generalised curve for calculating the number of samples required to detect particular effect sizes.

Increases in fencing and riparian woody vegetation were less easy to detect among Dairying and Clean Streams Accord-qualifying sites, because of the smaller sample size. Only 47 qualifying streams were surveyed in both years, therefore the power of paired samples t-tests between years ranged between 0.07 and 0.23 (Table 12). This means that only large changes in fencing or riparian woody vegetation are detectable. With only 47 sites available, stream length fenced both sides, for example, would need to increase by more than 77% of the previous survey's value, in order to detect a significant change with a power of 0.8 (Table 12).

3.8.2 Power of tests for land use type

For measures of fencing and erosion, the differences between dairy and drystock farming were small relative to the variability within each land use type, resulting in small standardised effect sizes (between 0.01 and 0.29; Table 13). Therefore the power of t-tests for these parameters was far below 0.8. The t-test for differences in % woody vegetation was more powerful than t-tests for fencing and erosion parameters (power = 0.89) because there was a greater difference between dairy and drystock farms for % woody vegetation than for fencing or erosion. Using the current sample sizes (91 dairy samples and 211 drystock samples) and power of 0.8, one would be able to detect a standardised effect size of 0.36 (Fig. 22). This means that differences in % total bank length fenced could be detected if dairy farms differed from drystock by more than 30% of their common mean. Because erosion was more variable than fencing, differences in % pugging erosion would only be detectable if dairy farms differed from drystock by more than 62% of their common mean.

Differences between dairy and drystock farms of 30% of their common mean translate to standardised effect sizes of 0.16 to 0.41, depending on the variability and mean of parameter in question (Table 13). Detecting these effect sizes with power of 0.8 would require 160-700 samples per land use type for measures of erosion, 125-280 samples for fencing measures and 95 samples for % woody vegetation (Fig. 22). Clearly this is achievable for fencing and % woody vegetation but not for erosion measures. Because statistical tests are more powerful when the two groups have equal numbers of samples, it would be more effective to add more dairy farms than drystock farms to the survey.

3.8.3 Power of tests for management zone and stream order

ANOVA tests had sufficient power (>0.8) to detect a significant difference between management zones for % woody vegetation and most fencing and erosion measures (Table 14). The same was true for differences between stream orders (Table 15). However, these results relate to the power to detect a difference between any two management zones or any two stream orders, not between particular pairs of management zones or stream orders. Therefore an increase in statistical power may still be desirable for detecting differences between particular management zones or stream orders. At the current sample size, a medium effect size can be detected with a power of 0.8 (Fig. 23). However, to detect a small effect (RMSSE=0.15) would require 92 samples per management zone or 102 samples per stream order. Management zones have highly unequal sample sizes, therefore the most efficient way to increase the average sample size per zone is to add more samples to the least-sampled zones, i.e., Central Waikato and Coromandel. Adding 21 sites to Central Waikato and 17 to Coromandel would increase the average (harmonic mean) sample size from 24.4 to 38.8, thus reducing the minimum detectable effect size from 0.30 to 0.23. Sample sizes are more equal among stream orders, but drains and sixth-order streams (n=26 and 21 respectively) are slightly under-sampled compared with first- and second-order streams (n=60 and 67 respectively), so extra sampling effort among drains and sixth-order streams would be the most efficient way to reduce the minimum detectable effect size among stream orders.

Table 11: Statistics for calculating the power of paired-samples t-tests for differences between 2002 and 2007 (using all sites that were surveyed in both years), and sample sizes needed to detect smaller effect sizes. Sample size for each year was n=289.

2002 vs. 2007	total fenced	fenced both sides	fenced one side	unfenced	woody veg
common mean of all samples	40.97	29.41	23.12	47.47	42.81
pooled std deviation	36.13	40.51	41.62	42.85	32.26
difference between years (as % of the common mean)	19.35	22.55	11.19	19.43	5.48
standardised effect size	0.16	0.12	0.04	0.15	0.05
power of current analysis	0.75	0.5	0.12	0.73	0.14
at current sample size, what effect size can be detected with power of 0.8?	0.17	0.17	0.17	0.17	0.17
at current sample size, what % difference between means can be detected with power=0.8?	21%	32%	42%	21%	18%
effect size for 20% difference between means	0.14	0.09	0.07	0.17	0.18
Sample size needed to detect 20% difference between means, given current std deviation and power=0.8	375	950	1450	275	235
effect size for 30% difference between means	0.24	0.15	0.12	0.23	0.28
Sample size needed to detect 30% difference between means, given current std deviation and power=0.8	138	340	580	146	102

Table 12: Statistics for calculating the power of paired-samples t-tests for differences between 2002 and 2007 for Accord-qualifying sites on dairy farms, and sample sizes needed to detect smaller effect sizes. Sample size for each year was n=47.

2002 vs. 2007 for Accord-qualifying streams on dairy farms	total fenced	fenced both sides	fenced one side	unfenced	woody veg
common mean of all samples	45.66	28.54	34.25	37.21	42.47
pooled std deviation	34.44	37.49	35.06	39.77	32.41
difference between years (as % of the common mean)	19.49	40.86	16.12	16.5	6.88
standardised effect size	0.18	0.22	0.11	0.11	0.06
power of current analysis	0.23	0.31	0.12	0.11	0.07
at current sample size, what effect size can be detected with power of 0.8?	0.42	0.42	0.42	0.42	0.42
at current sample size, what % difference between means can be detected with power=0.8?	44%	77%	60%	63%	45%
effect size for 20% difference between means	0.19	0.10	0.17	0.16	0.20
Harmonic mean sample size needed to detect 20% difference between means, given current std deviation and power=0.8	225	860	292	310	200
effect size for 30% difference between means	0.28	0.16	0.21	0.2	0.28
Harmonic mean sample size needed to detect 30% difference between means, given current std deviation and power=0.8	102	304	188	207	103

Table 13: Statistics for calculating the power of independent samples t-tests for differences between dairy and drystock farming, and sample sizes needed to detect smaller effect sizes. Sample sizes: dairy n=91, drystock n=211; harmonic mean n=127.

Dairy vs. drystock	**total fenced**	**fenced both sides**	**fenced one side**	**unfenced**	**woody veg**	**active erosion**	**pugging erosion**	**total erosion**
common mean of all samples	44.46	31.82	25.29	42.89	44.05	3.99	10.45	31.52
pooled std deviation	36.83	39.38	31.45	40.71	32.11	7.68	18	29.52
difference between land use types (as % of the common mean)	18.69	14.72	28.69	27.84	29.39	20.74	1.62	8.16
standardised effect size	0.23	0.12	0.23	0.29	0.4	0.1	0.01	0.09
power of current analysis	0.43	0.16	0.45	0.65	0.89	0.14	0.05	0.11
at current sample size, what effect size can be detected with power=0.8?	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
at current sample size, what % difference between means can be detected with power=0.8?	30%	45%	45%	34%	26%	69%	62%	34%
effect size for difference between means of 20%	0.24	0.16	0.16	0.21	0.27	0.10	0.12	0.21
Harmonic mean sample size needed to detect 20% difference between means, given current std deviation and power=0.8	275	600	610	360	220	1500	1150	340
effect size for difference between means of 30%	0.36	0.24	0.24	0.32	0.41	0.16	0.17	0.32
Harmonic mean sample size needed to detect 30% difference between means, given current std deviation and power=0.8	125	280	280	160	95	700	660	160

Table 14: Statistics for calculating the power of ANOVAs for differences between management zones, and the sample sizes needed to detect smaller effect sizes. Sample sizes: Central Waikato n=9, Coromandel n=13, Lake Taupo n=41, Lower Waikato n=31, Upper Waikato n=63, Waihou Piako n=37, Waipa n=69, West Coast n=39; harmonic mean n=24.4.

Management zone	total fenced	fenced both sides	fenced one side	unfenced	woody veg	active erosion	pugging erosion	total erosion
Common mean of all samples	44.5	31.8	25.3	42.9	44.1	3.98	10.5	31.5
pooled std deviation	35.8	37.3	31.0	40.6	30.2	7.36	17.9	28.2
difference between min and max management zones (as % of common mean)	51.7	83.7	71.1	43.8	63.1	92.9	56.8	65.0
RMSSE	0.32	0.41	0.33	0.23	0.51	0.43	0.17	0.38
power	0.87	0.98	0.89	0.55	0.9995	0.99	0.28	0.96
at current sample size, what RMSSE can be detected with power of 0.8?	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Table 15: Statistics for calculating the power of ANOVAs for differences between stream orders, and the sample sizes needed to detect smaller effect sizes. Sample sizes: drains n=26, first-order n=60, second-order n=67, third-order n=51, fourth-order n=43, fifth-order n=34, sixth-order n=21; harmonic mean n=36.9.

Stream order	total fencing	fenced both sides	fenced one side	unfenced	woody veg	active erosion	pugging erosion	total erosion
Common mean of all samples	44.5	31.8	25.3	42.9	44.1	3.98	10.5	31.5
pooled std deviation	36.4	38.8	31.7	40.6	31.0	7.58	17.0	28.7
difference between min and max stream orders (as % of common mean)	42.8	57.5	33.8	47.4	73.0	79.1	93.3	55.7
RMSSE	0.25	0.24	0.12	0.23	0.47	0.24	0.39	0.30
power	0.80	0.76	0.21	0.71	1	0.77	0.997	0.94
at current sample size, what RMSSE can be detected with power of 0.8?	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

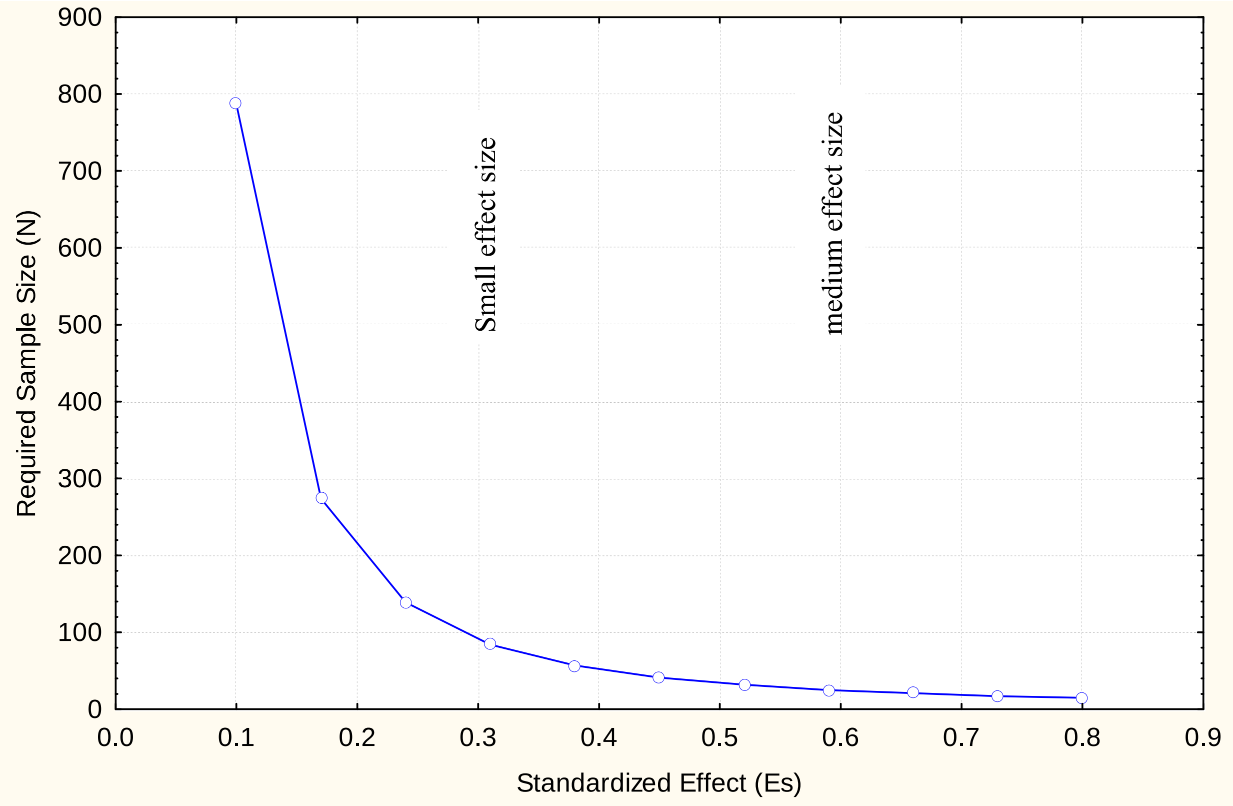

Figure 21: Sample size required to detect standardised effect sizes with a power of 0.8 and α=0.05 for paired-samples t-tests. To convert standardised effect size to a % difference between sample means, multiply by pooled standard deviation/average of all samples (Table 11). The approximate values for E_s conventionally used to indicate small and medium effect sizes are indicated in vertical type.

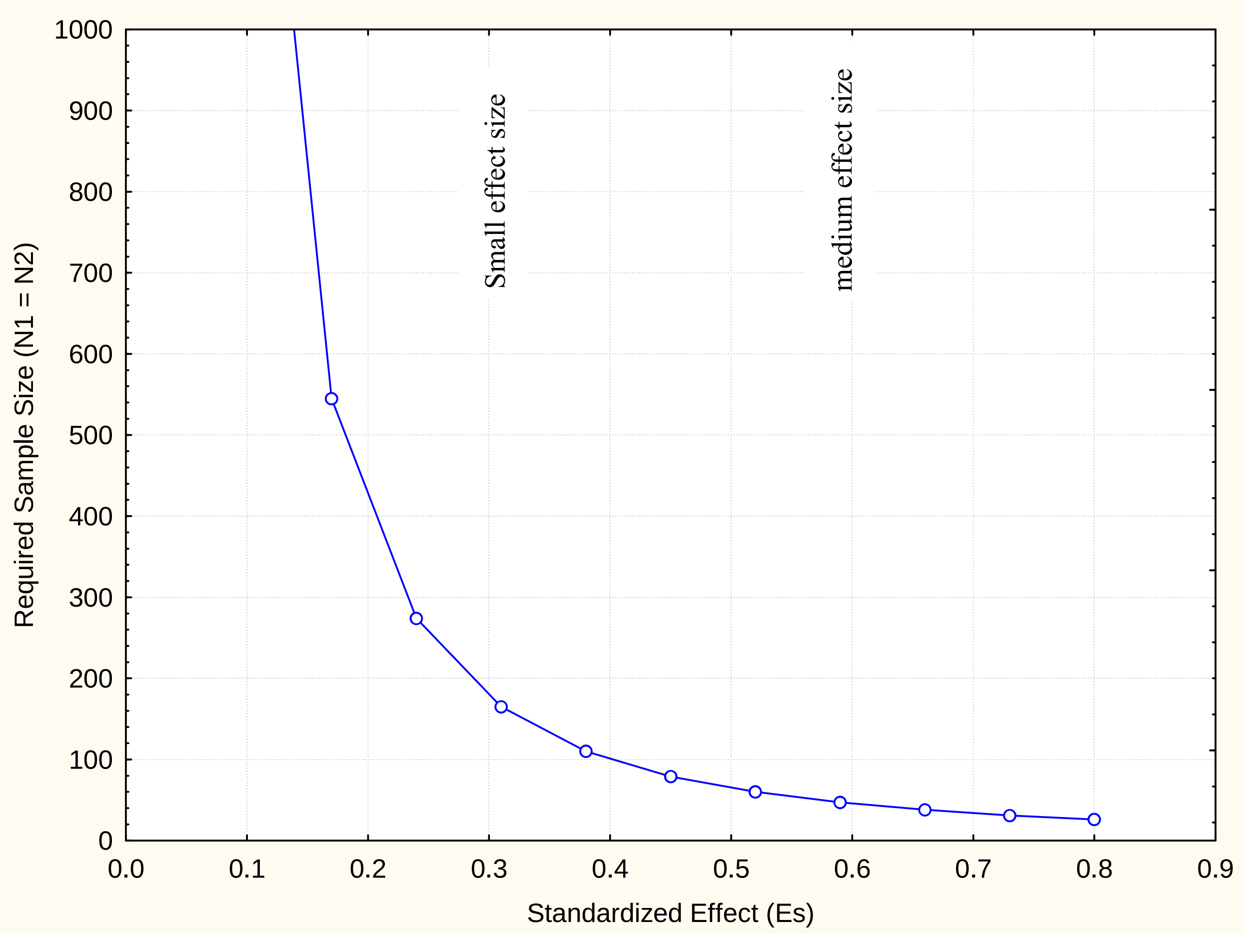

Figure 22: Sample size required to detect standardised effect sizes with a power of 0.8 and α=0.05 for t-tests of 2 independent samples. To convert standardised effect size to a % difference between sample means, multiply by pooled standard deviation/average of all samples (Table 13). The approximate values for E_s conventionally used to indicate small and medium effect sizes are indicated in vertical type.

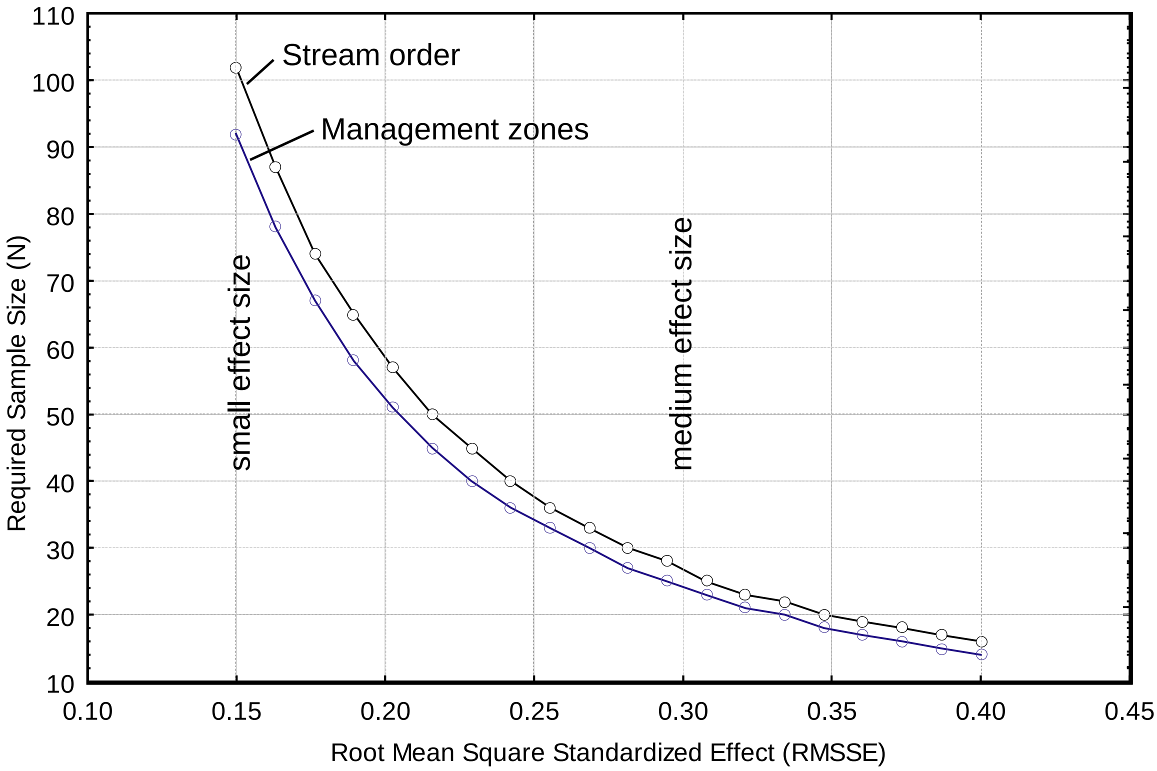

Figure 23: Sample size required to find standardised effects with a power of 0.8 and α=0.05 for ANOVA of 8 independent samples (management zones) and 7 independent samples (stream order). The approximate values for RMSSE conventionally used to indicate small and medium effect sizes are indicated in vertical type.

3.9 Recommendations for future sampling

3.10 Sample sizes

Sample sizes need to be large enough that reasonably-expected and ecologically-meaningful changes in parameters can be detected with a power of >0.8. If a 30% proportional change in fencing or woody vegetation is considered reasonable or ecologically meaningful, then sample sizes of 102-340 are required for detecting changes between years in terms of woody vegetation and most measures of fencing (Table 11). Therefore the current sample size is adequate if all the available sites are used. But if a statistical test is performed on a subset of the data, e.g., Accord-qualifying sites only, or a particular pair of management zones, then sample size of the subset would need to be increased to within this range in order to detect a 30% proportional change between years. For detecting a difference of 30% or more between land use types, the required sample sizes are listed in the last row of Table 13, and for detecting a small effect size between management zones or stream orders, the required sample sizes are shown in Fig. 23.

Statistical power is greater where the groups of samples are more nearly equal. Therefore to increase the power of comparisons between dairy and drystock farming, increasing the number of dairy farm sites is more effective than increasing the number of drystock sites. For example, if the number of dairy farm sites were increased by 20, the harmonic mean sample size of the two groups (on which the power of the test depends) would increase by 27, whereas if the number of drystock farm sites were increased by 20, the harmonic mean would increase by only 3. The same effect applies to management zones. Although the original survey design provided equal numbers of sites per zone, subsequent changes to zone boundaries meant that the final distribution of sites among zones was quite uneven. To maximise the power of the statistical tests, I recommend making the number of sites more nearly equal in each zone. Adding 10 sites each to Central Waikato and Coromandel would increase the harmonic mean sample size of management zones by 9.5, whereas adding 10 sites each to West Coast and Lower Waikato would increase the harmonic mean sample size of management zones by only 1.

3.11 Parameters in future surveys

Certain changes to the parameters included in the 2002 and 2007 surveys are recommended in order to improve the analyses performed in this report. Most important is to add an estimate of stock access to stream reaches. For this parameter, I recommend the categories suggested in P2d of the Stream Habitat Assessment Protocols (SHAP; Harding et al. 2009), which incorporate stock exclusion by fencing and natural barriers, structures that reduce the need for stock to access the stream, and the density of stock around the stream. The categories for stock access are: High (unfenced and unmanaged with active livestock use), Moderate (some livestock access), Limited (unfenced but with low stocking, bridges, troughs and/or natural deterrents), Very limited (temporary fencing of all livestock or naturally very limited access), None (permanent fencing or no livestock). I recommend recording ground cover vegetation of the riparian buffer zone (i.e., within the fenced or vegetated area, or up to 10 m from the stream if no fence or vegetation exists). This parameter would be useful for providing evidence of stock access to the stream, as well as for describing the riparian vegetation type. I recommend the categories use in P2d of SHAP: Bare, Short/regularly grazed pasture (<3cm), Pasture grass/tussock with bare flow paths or 2-3 cm tree litter layer, Moderate density grass or dense (>3cm) tree litter layer, High density long grass.

The effect of willows on obstructing stream flow and exacerbating erosion was not easy to determine using the parameters in the 2002 and 2007 surveys. I recommend adding "willow" as a specific category under the "Obstructions" parameter. More generally, there was no direct way to determine the effect of obstructions on stream bank erosion, therefore I also recommend adding another parameter "Erosion associated with obstruction". "Accessways" (bridges, bridges with culverts, and fords) was a useful parameter for determining the extent to which stock have been excluded from streams. However, this parameter would be more useful if a fourth category (stock crossing on stream bed) were added. Adding this fourth category would indicate whether stock crossings are required over a particular stream.

The channel type parameter in the 2002 and 2007 surveys did not prove to be very useful in its current form, as it incorporates too many factors. I recommend splitting this parameter into two key aspects of the channel and valley: channel bank height (in metres) above water level (water depth may need to be measured as well, in order to gain data that are independent of the state of flow), and land slope (in degrees) up to 30 m from the channel. These parameters are included in Protocols P2b and P2d of SHAP. Protocol P2b of SHAP also includes the shapes of the floodplain, bankfull channel and wetted channel, using categories of V-shape, U-shape, box-shape, wide, multi-stage and culvert. These categories are simpler and hence more useful than the channel type categories presently in the survey, and using them would bring the survey protocols in line with SHAP.

The following parameters were not used for the analysis in this report: aquatic vegetation (>50%), channel shape, stream bed type, and bridge attributes. I do not necessarily recommend dropping these parameters from the survey, as the data may be very useful for other studies regarding the effects of riparian protection, for State of the Environment monitoring or for prioritising streams for restoration. However, for such wider purposes, I recommend some further additions to the surveys. First, I recommend measuring shading of the water surface by riparian vegetation, banks and valley slope. Categories used in SHAP P2d are <10%, 10-25%, 25-50%, 50-80% and >80% shade. Shade is an important and easily-measured aspect of riparian condition that affects many aspects of stream ecosystems. I recommend dividing the "woody exotic" vegetation type category into "exotic woody deciduous" and "exotic woody evergreen", because the different leaf fall pattern of deciduous vegetation has important ecological implications for streams. "Weeds" could also be added as another category of exotic vegetation. Information on weed growth could be very useful in understanding the potential negative effects of riparian revegetation projects and the management needs of such projects. Measurements of aquatic plant growth could be refined by separating algae from macrophytes, and scoring each in terms of % cover (e.g., 0-5%, 5-20%, 20-50% and >50%). Algae and aquatic macrophytes are easily-measured visual estimates that integrate the nutrient status and shading of streams, and measuring them more precisely using the suggested categories would allow the survey to detect gradual changes in stream responses to riparian protection.

These surveys provide an opportunity to assess the state of riparian protection and stream response over a wide geographic area, and represent a very valuable database. Adding a few ecological parameters and refining the resolution of some existing parameters, as suggested above, would greatly increase the value of the database, with little extra effort or expense.

4. References

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5. Appendix

Table 1: Average values (with confidence intervals in parentheses) for fencing as % of stream length (no fence, fenced one bank or fenced both banks) or % of bank length (total fencing). N is the number of samples.

			Effective + ineffective fencing				Effective fencing			
		N	**No fence**	**One bank**	**Both banks**	**Total fencing**	**No fence**	**One bank**	**Both banks**	**Total fencing**
	All	302	42.9 (4.6)	25.3 (3.6)	31.8 (4.5)	44.5 (4.2)	47.0 (4.7)	25.2 (3.6)	27.7 (4.2)	40.3 (4.1)
Land use type	Dairy	91	34.5 (8.1)	30.4 (6.8)	35.1 (8.2)	50.3 (7.4)	39.0 (8.3)	34.7 (7)	26.4 (7.1)	43.7 (6.9)
	Drystock	211	46.5 (5.6)	23.1 (4.2)	30.4 (5.4)	42.0 (5.1)	50.5 (5.7)	21.2 (4.1)	28.3 (5.3)	38.9 (5.1)
Management zone	Central Waikato	9	57.0 (38)	11.5 (15.3)	31.6 (31.2)	37.3 (33.9)	58.2 (37.2)	11.5 (15.3)	30.2 (30.4)	35.9 (33.2)
	Coromandel	13	51.5 (21.2)	39.8 (17.5)	8.7 (12.5)	28.6 (15)	62.5 (20.8)	31.9 (15.7)	5.6 (7.7)	21.6 (13.5)
	Lake Taupo	41	34.9 (12.7)	12.0 (8.4)	53.1 (14)	59.1 (12.7)	37.7 (13.2)	9.7 (7.5)	52.7 (13.9)	57.5 (13)
	Lower Waikato	31	46.5 (14.7)	36.9 (13.2)	16.6 (12)	35.1 (11.7)	51.1 (14.8)	36.2 (13.2)	12.6 (10.4)	30.8 (11)
	Upper Waikato	63	32.2 (9.9)	23.2 (7.3)	44.6 (10.1)	56.2 (9.3)	36.1 (10.4)	24.4 (7.4)	39.5 (9.9)	51.7 (9.4)
	Waihou Piako	37	40.3 (13.5)	22.6 (9.8)	37.1 (14)	48.4 (12.9)	46.8 (14.1)	30.4 (11.7)	22.9 (11.3)	38.1 (11.6)
	Waipa	69	45.5 (9.8)	29.9 (7.8)	24.6 (8.1)	39.5 (8.1)	48.8 (9.7)	27.7 (7.5)	23.5 (7.9)	37.3 (8)
	West Coast	39	57.3 (13.7)	26.2 (11.3)	16.4 (10.5)	29.5 (10.8)	60.8 (13.6)	25.9 (11.4)	13.3 (9.6)	26.2 (10.3)

Table 2: Average values (with confidence intervals in parentheses) for fencing as % of stream length (no fence, fenced one bank or fenced both banks) or % of bank length (total fencing) for 2002 and 2007 surveys. Only sites that were in both surveys are used for these values. N is number of samples.

		year	N	No fence	One side	Both sides	Total fencing
	All	2002	289	52.1 (5.2)	21.8 (5.8)	26.1 (4.8)	37 (4)
		2007	289	42.9 (4.8)	24.4 (3.6)	32.7 (4.6)	44.9 (4.3)
Land use type	Dairy	2002	67	40.9 (9.5)	36.2 (8.5)	22.9 (8.3)	41 (7.9)
		2007	67	34.8 (9.9)	26.8 (7.7)	38.4 (9.9)	51.8 (9.1)
	Drystock	2002	152	60.2 (6.8)	15.6 (5.4)	24.2 (6)	32 (5.8)
		2007	152	50.3 (6.7)	21.4 (4.8)	28.3 (6.2)	39 (6)
Management zone	Central Waikato	2002	31	55 (24.3)	13.5 (43.3)	31.5 (24)	38.2 (10.7)
		2007	9	57 (38)	11.5 (15.3)	31.6 (31.2)	37.3 (33.9)
	Coromandel	2002	12	61.8 (21)	34.3 (17.9)	3.9 (6.3)	21.1 (12.7)
		2007	12	55.8 (20.7)	34.8 (14.8)	9.4 (13.4)	26.8 (15.8)
	Lake Taupo	2002	38	27.7 (12.5)	5.7 (6.1)	66.6 (13.8)	69.5 (12.8)
		2007	38	31.4 (12.8)	12.6 (9.1)	56 (14.6)	62.3 (12.9)
	Lower Waikato	2002	27	63.1 (15.7)	24.2 (13.1)	12.7 (11.4)	24.8 (12)
		2007	28	46.2 (15.5)	35.4 (13.5)	18.4 (13.2)	36.1 (12.7)

	year	N	No fence	One side	Both sides	Total fencing
Upper Waikato	2002	38	31.8 (11.9)	20.8 (11.1)	47.4 (12.9)	57.8 (11.1)
	2007	61	32.7 (10.2)	22.9 (7.4)	44.4 (10.1)	55.8 (9.5)
Waihou Piako	2002	35	37.9 (12.5)	35.6 (11.2)	26.5 (12.5)	44.3 (11.2)
	2007	35	42.1 (14.1)	18.7 (8.5)	39.2 (14.4)	48.6 (13.6)
Waipa	2002	68	64 (9.9)	24.6 (10.1)	11.4 (6.1)	23.7 (6.5)
	2007	68	45.8 (9.9)	29.3 (7.9)	25 (8.2)	39.6 (8.2)
West Coast	2002	38	76 (10.9)	20.2 (9.8)	3.8 (3.9)	13.9 (6.5)
	2007	38	56.2 (13.8)	26.9 (11.5)	16.9 (10.8)	30.3 (11)

Table 3: Average values for vegetation type (native grasses, pastoral grass, woody exotic, woody native, willow), vegetation structure (wetland, grass, scrub, shrubland, treeland, forest) and woody vegetation, with confidence intervals in parentheses. N is number of samples.

			Vegetation type					**Vegetation structure**						**% woody veg**
		N	**Native Grasses**	**Pastoral Grass**	**Woody Exotic**	**Woody Native**	**Willow**	**Wetland**	**Grass**	**Scrub**	**Shrubland**	**Treeland**	**Forest**	
	all	302	4.3 (1.4)	51.6 (3.8)	26.9 (3.4)	11.6 (2.3)	5.5 (1.6)	4 (1.4)	53.7 (3.7)	11.1 (2.1)	5 (1.5)	21.8 (2.9)	4.1 (1.4)	44.1 (3.7)
Land use type	Dairy	91	3.2 (2.5)	61.7 (6.8)	21.7 (5.5)	5.3 (2.4)	8.1 (3.8)	3.3 (2.2)	62.6 (6.8)	7.4 (3.1)	4.3 (1.9)	20.2 (5.2)	2.1 (1.5)	35 (6.8)
	Drystock	211	4.8 (1.8)	47.3 (4.5)	29.2 (4.2)	14.4 (3.1)	4.4 (1.6)	4.3 (1.8)	49.8 (4.3)	12.7 (2.6)	5.4 (2)	22.5 (3.5)	5 (1.9)	48 (4.3)
Stream order	drain	26	1.9 (2)	82.6 (8.7)	13.7 (8)	1.6 (2.4)	0.1 (0.2)	0.3 (0.5)	86.9 (6.8)	3.1 (3)	2.4 (2.9)	7.3 (5.2)	0 (0)	15.6 (8.3)
	1	60	5.2 (3.1)	57.7 (8.6)	26.7 (7.6)	6.6 (3.4)	3.8 (2.9)	10 (4.8)	57.1 (8.4)	8.9 (4.5)	3.7 (3)	18.6 (6.3)	1.6 (2.1)	37.1 (8.3)
	2	67	4.7 (3)	48.1 (8.8)	30.3 (8.1)	15.4 (5.8)	1.6 (1.6)	3.8 (2.6)	50.7 (8.3)	13.4 (4.8)	5.7 (3.4)	19.5 (6.2)	6.9 (4.3)	47.3 (8.5)
	3	51	3.7 (3.3)	54 (11)	20.2 (7.9)	15.6 (8.5)	6.4 (4.5)	2.7 (3.2)	55.8 (10.2)	8.1 (4.2)	6.6 (5.9)	20.4 (7.7)	5.3 (5)	42.1 (9.9)

		N	Native Grasses	Pastoral Grass	Woody Exotic	Woody Native	Willow	Wetland	Grass	Scrub	Shrubland	Treeland	Forest	
	4	43	1.7 (2.4)	47.2 (8.5)	32.2 (10.2)	11.1 (5.2)	7.7 (4.7)	1.8 (2.6)	47.7 (8.5)	14.2 (6.2)	4.9 (3.8)	25.7 (7.4)	5.6 (3.7)	51 (8.9)
	5	34	4.4 (3.5)	38 (10.9)	31.7 (10.1)	16.5 (9.6)	9.3 (5.6)	1.6 (2.7)	41.9 (10.9)	16.8 (8.8)	7 (5.9)	28 (9.3)	4.7 (4)	57.5 (10.9)
	6	21	10.4 (13.4)	32 (12.5)	30.6 (15.4)	10.2 (6.1)	16.8 (13.3)	3.8 (7.2)	38.4 (13.8)	11.3 (7.7)	3.3 (2.7)	41.8 (15.3)	1.3 (1.9)	57.6 (14.9)
Management zone	Central Waikato	9	1.5 (2.2)	67.1 (21.6)	13.5 (8.9)	6.7 (10.4)	11.1 (12.8)	5.1 (11.5)	68.1 (22.5)	3.4 (3.9)	1.1 (2)	16 (16.7)	6.2 (12.8)	31.3 (22.4)
	Coromandel	13	1.8 (2.4)	36.6 (15)	6.3 (4.6)	49.8 (17.8)	5.5 (11)	3.4 (5.1)	34.8 (13.8)	6.6 (7.5)	8.3 (5.3)	45.8 (17.4)	1.1 (1.3)	61.6 (16.1)
	Lake Taupo	41	6.6 (4.6)	30.6 (10.6)	47.4 (11.2)	14.4 (7.4)	1 (1.2)	7.3 (5.7)	36.4 (10.4)	15.1 (6.8)	7.6 (6.6)	21.3 (8.3)	12.3 (7.6)	62.8 (10.1)
	Lower Waikato	31	4 (3.6)	72.9 (9.2)	13.3 (6.4)	5.3 (4.2)	4.6 (3.6)	3.3 (3.7)	74.1 (8.5)	6.7 (5.1)	2.1 (2.3)	13.1 (5.1)	0.7 (1.4)	23.2 (8.6)
	Upper Waikato	63	3.5 (2.3)	39.6 (8.7)	43 (8.6)	7.7 (4.1)	6.2 (3.5)	2.1 (1.6)	41.3 (8.3)	23.2 (6.5)	4.5 (2.1)	22.1 (6.1)	5.7 (3.6)	56.9 (8.2)
	Waihou Piako	37	4.2 (5.6)	58.6 (11.3)	18.9 (7.3)	11.4 (7.4)	7 (5.6)	0.9 (1.5)	62.5 (11.4)	2.7 (2.3)	4.5 (5.1)	28.6 (10.5)	0.8 (1.2)	37 (11.4)
	Waipa	69	3.7 (2.7)	56.9 (7.3)	21.3 (6)	10.9 (4.6)	7.1 (4.1)	5.9 (3.6)	57.4 (7.1)	8.4 (3.2)	7 (4)	18.7 (6.3)	2.6 (1.7)	39.4 (7)
	West Coast	39	6.2 (5.8)	61.5 (9.2)	17.7 (7.4)	10.2 (5.2)	4.4 (4.3)	3.8 (4.3)	63.6 (8.6)	6.8 (3.7)	2.5 (2.1)	21.2 (6.8)	2.1 (2.2)	32.3 (8.9)

Table 4: Bivariate correlations among predictor variables and between predictor and erosion variables in multiple regression. Values are Spearman's rho correlation coefficients. Description of variables: land use type is either dairy or drystock farming; LUC1-4 means land use capability classes 1-4; Soil group 1 includes brown, granular and ultic soils; soil group 2 includes pumice, allophonic and podzol soils.

	Land use type	debris obstructions	% riparian woody veg	valley gradient medium	valley gradient high	LUC1-4	Soil group 1	Soil group 2	% fenced total	% fenced both sides	% active erosion	% pugging erosion	% total erosion
Stream order	-0.06	0.12	0.3	-0.18	-0.24	-0.05	-0.03	-0.14	-0.07	-0.09	0.17	-0.26	-0.1
Land use type		0.15	-0.19	-0.1	-0.15	0.14	-0.09	-0.06	0.11	0.09	0.03	-0.01	0.06
debris obstructions			-0.04	-0.1	-0.05	0.11	0.05	-0.07	-0.19	-0.15	0.34	0.08	0.15
% riparian woody vegetation				0.01	0.08	-0.2	-0.05	0.18	0.23	0.2	-0.2	-0.33	-0.28
valley gradient medium					-0.18	-0.13	-0.01	0.22	0.01	0.03	-0.09	0.09	0.04
valley gradient high						-0.3	-0.01	0.18	-0.13	-0.1	-0.09	0.1	0.16
LUC1-4							-0.14	-0.27	0.12	0.07	-0.02	-0.03	-0.13
Soil group 1								-0.41	-0.14	-0.13	0.23	0.08	0.14
Soil group 2									-0.03	0.05	-0.19	0.01	0
% fenced total										0.89	-0.29	-0.35	-0.52
% fenced both sides											-0.27	-0.33	-0.47