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A Survey of the Riparian Characteristics of the Auckland Region

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A Survey of the Riparian Characteristics of the Auckland Region

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1 Executive Summary

The vast majority of Auckland's stream length flows through rural land uses and State of the Environment monitoring has indicated that such streams have lower ecological health than those draining forested catchments. It is recognised that much of this deterioration in ecological health results from the absence of riparian vegetation and unrestricted access of livestock to streams and their riparian margins. These impacts can be greatly reduced by effective riparian management, and it is acknowledged that restoration of degraded rural streams represents a considerable opportunity to enhance the quality of the Auckland stream network.

This issue is recognised in the ARC's Proposed Auckland Regional Plan: Air, Land and Water, which signals an intention to notify a plan variation/change to discourage stock access to lakes and rivers. Furthermore, the Plan specifies that information is required, with respect to stock access, to benchmark the extent of the problem. Hence this study was carried out to address this information requirement, thereby informing policy development and providing a baseline against which to monitor subsequent changes in stock access.

The study was undertaken by field teams surveying 60 randomly selected stream sites in each of three main pastoral land use types (rural residential, dairy and drystock), resulting in 180 sites in total. The surveyors walked 500 metres of stream bank at each sample site and recorded the type of fencing, riparian vegetation and whether stream bank erosion was present. Analysis of variance was used to explore the differences in measured characteristics amongst the land use types. Correlation and modelling techniques were used to investigate the relationships between stream bank erosion and the measured characteristics and River Environment Classification variables.

The study found that 25% of the surveyed stream length had an effective fence on both banks with no significant difference amongst the land use types for this measure. The absence of an effective fence was the most common situation identified by the survey, with 46.9% of stream length or 51% of bank length unfenced. Streams in drystock land use had significantly less fencing than those in both dairy and rural residential land use. This was a consistent pattern seen in the results, whereby many of the measures of fencing extent and type were similar for streams in dairy and rural residential land uses, with streams in drystock land use having lower values for the fencing measures.

Analysis of the subset of sampled sites which met the Clean Streams Accord definition of a stream indicated that streams in dairy land use had the greatest extent of stock exclusion, herein considered to be an effective fence on both banks, than rural residential and drystock, although the difference was not statistically significant. The extent of stream length with an effective fence on both banks was 26% for dairy streams, which is less than that reported by the Clean Streams Accord partners.

The study found that nearly half of the Region's rural stream banks are affected in some way by erosion, although only 5.4% of stream banks were subject to active erosion. There were significant differences amongst the land use types for all of the

erosion measures assessed in the study. Streams in rural residential land use had the least stream bank erosion for all measures. Drystock streams had the greatest extent of erosion recorded, with 54.6% of drystock stream banks affected by erosion. Of this, 9.6% was recorded as active erosion, significantly more than both rural residential and dairy streams.

As would be expected on rural streams, pastureland (61.5%) was the most common vegetation type found on stream banks, followed by exotic woody vegetation (19.8%), native woody vegetation (13.2%) and wetland vegetation (5.5%). There were significant differences amongst the land use types for all of the different vegetation types. There was significantly more exotic woody vegetation on rural residential streams banks, and significantly less native woody vegetation on dairy streams. Drystock streams had the greatest extent of wetland vegetation.

Of the 12 environmental factors available for analysis, six were significantly correlated with the extent of stream bank erosion. These six variables were those based on land use and the extent of fencing and woody vegetation. Similarly, the general linear modelling exercise identified that the best performing model (r^2 = 50.6%) was based on the "predictor" environmental variables; effective fence, land use and woody vegetation. The correlation and modelling analyses indicated that variables relating to land management practices were significantly related to the extent of stream bank erosion, whereas large-scale physical variables were not. This is an important set of results, suggesting that stream bank erosion may be reduced through changes in land use and improvements in riparian management.

This study has met its primary objective identified in the introduction by benchmarking the type and extent of fencing, riparian vegetation and erosion on rural stream banks in the Auckland Region. This information is now available to be considered in a wider review of the Auckland Regional Council's riparian management policies. This study has identified evidence of the environmental benefits of riparian fencing and vegetation in reducing stream bank erosion, providing further support for having a robust policy framework that promotes riparian planting and fencing.

2 Introduction

The current best estimate of the length of permanent streams in the Auckland region is 16650 km[1]. The majority of this stream length (63%) flows through rural pastoral land uses (ARC, 2005). The ARC's State of the Environment monitoring has indicated that streams draining pastoral catchments typically have lower ecological health, measured using macroinvertebrates, than streams in native or exotic forest catchments (ARC, 2005 & 2008). Unrestricted access of livestock to the stream and riparian margin results in deterioration in ecological health of pastoral streams (Davies-Colley & Parkyn, 2001). There are a wide range of inter-related adverse effects arising from livestock access to streams, which ultimately result in decreases of water, biological and habitat quality (see review by Davies-Colley & Parkyn, 2001). The absence of continuous vegetated riparian margins further contribute to this degradation, without which streams are exposed to high inputs of solar radiation and reduced inputs of terrestrial carbon.

The impacts of unrestricted livestock access on rural streams can be appreciably reduced by effective riparian management (Davies-Colley & Parkyn, 2001) and it is recognised that the restoration of degraded rural streams represents the greatest opportunity to enhance the quality of the Auckland stream network (ARC, 2005). The ARC has current guidelines for riparian zone management (ARC, 2001), however these do not specifically address the issue of livestock access and have little statutory power.

In response to the impacts of livestock access on aquatic systems and the lack of enforceable plan provisions, the ARC intends to notify a change to Chapter 5 of the Air, Land and Water Plan to introduce policies and rules for the management of livestock access to aquatic systems in the Auckland Region. This plan change will give effect to discouraging livestock access to the beds of lakes, rivers, streams and associated wetlands through an approach including advocacy, partnerships and, if necessary, regulation. To assess the efficacy of any change in policy and management there must be an understanding of the current condition, to provide a baseline against which to monitor subsequent changes. Ongoing policy effectiveness monitoring will be an essential component of any non-statutory approach.

Therefore, the purpose of this study was to benchmark the current status of livestock access to permanently flowing pastoral streams in the Auckland Region, providing information on the extent of the problem, together with a baseline against which to measure any change. This has been achieved by collecting quantitative information on the spatial distribution of selected riparian characteristics. The principle driver of the study was a requirement to provide information on the extent of livestock exclusion from streams by riparian fencing. However, to maximise the information provided by

[1] The figure is derived from a digital elevation model based on light detection and ranging (LiDAR) survey of the Auckland region (ARC, 2009). The estimate of 16650 km should be considered in association with the 95% confidence level range of 14113 km to 20190 km. These figures update the 9427 km estimate derived from the NZ Topological Series NZMS 260 river layer, which underestimates the actual length of stream resource in the Auckland Region (see Storey *et al.*, (2008) for discussion of this issue).

the study, information on the nature and extent of riparian vegetation and stream bank erosion was collected simultaneously. This will allow the description of the current riparian vegetation and the extent of bank erosion on the Region's pastoral streams, as well as allowing the investigation of the relationship between stream bank erosion and land management practices.

This study represents the first comprehensive investigation of riparian characteristics of Auckland streams. However, previously the Ministry for the Environment (MfE), and more recently the Ministry for Agriculture and Food (MAF), reported on the extent of livestock exclusion on dairy farms as part of the Dairying and Clean Streams Accord (for example, MfE, 2007; 2008; MAF, 2009). The Accord is an agreement between the Ministry for the Environment, Ministry of Agriculture and Forestry, Local Government New Zealand and Fonterra established in 2003 to reduce the impacts of dairy farming on aquatic environments throughout New Zealand (MfE, 2003a). The Accord describes targets for, *inter alia*, excluding livestock from 50% of streams, rivers and lakes by 2007 and 90% by 2012 (MfE, 2003a). The most recent progress report states that dairy livestock have been excluded from 70% of Accord-defined waterways on dairy farms in the Auckland Region (MAF, 2009).

The information provided by the Accord progress reports, which were published annually by MfE, has received criticism recently, primarily because of the perceived ambiguity of the data collection and interpretation approaches (Deans & Hackwell, 2008). The latest progress report (MAF, 2009) has revised the measure of performance for stock exclusion and this study will allow a comparison of the extent of fencing on dairy farm streams in Auckland with the corresponding stock exclusion data reported by the Accord partners.

3 Methodology

3.1 Sampling strategy

To meet the aim of the study, the riparian characteristics of a sample of randomly selected sites stratified across three pastoral land use categories were surveyed. The land use categories rural residential, drystock (beef and sheep) farming and dairy farming were selected as they represent a range of common disturbance pressures associated with livestock management. Drystock and dairy farms are the most common type of agriculture by farm number (Statistics New Zealand, 2002) and are therefore major uses of pastoral land in the Auckland region. Rural residential was considered to be a low disturbance land use, dairy farming a high disturbance land use and drystock farming an intermediate disturbance land use. The relative level of disturbance amongst the land use classes was based on a combination of existing information (mean stocking rate from AgriBase™) and professional judgement. The objective of the stratified random sampling strategy was to reduce the potential variation resulting from comparing sites of differing land use and allow for comparisons of riparian characteristics amongst land use categories.

The survey was field-based, involving a surveyor walking the sample stream and recording the condition of the riparian characteristics of interest (fencing, vegetation and erosion). Whilst this approach is time consuming, alternative methods of collecting the information remotely, such as aerial photography or satellite imagery, were limited in their ability to accurately record these riparian characteristics in a similar study (Environment Waikato, 2001; 2002).

3.2 Scoping

Initially it was planned to undertake a study of riparian characteristics based on the sampling methodology used in a similar study by Environment Waikato (2001; 2002). Environment Waikato's sampling design was based on robust analysis of data from a pilot study and involved sampling 42 stream sites of 1000 m length within each land use category. This sample size was based on the survey having sufficient statistical power to detect at least a 30% change from the mean over a ten year interval.

It was intended to utilize this existing knowledge of the statistical aspects of the sampling design and replicate this study in the Auckland region. However, initial GIS-based analysis of the Auckland stream resource indicated that there were insufficient sample units of 1000 m of stream length within the rural residential land use category. Environment Waikato didn't encounter this problem in their study as they didn't investigate a rural residential land use category. Furthermore, there is a large difference in the land area and stream resource between the two regions. Auckland (land area 5193 km^2 (MfE, 2003b)) has 6663 km of running waters recorded in the River

Environment Classification (REC) (Snelder *et al.*, 2004) database, whereas Waikato (land area 24973 km^2 (MfE, 2003b)) has 37760 km.

As a result of the difference in stream resource between the two regions, it was considered that a shorter length of stream may be more appropriate as a sample unit in an Auckland based study. Therefore, it was proposed that 500 m stream lengths were used in this study and the statistical implications of using a shorter stream length were investigated. These are reported below.

3.3 Statistical Assessment

To investigate the statistical aspects of the sampling design, an analysis of preliminary field data from an Environment Waikato pilot study was undertaken on ARC's behalf. The analysis was carried out by Brian McArdle at the University of Auckland. The full analysis is presented in Appendix 1 and summarised below.

It was determined that the mean, and measures of variance, of fencing extent using 500m stream sample units compared with 1000m were similar; the small reduction in variance achieved using 1000m was not considered important. Furthermore, the achievable precision for a given distance of stream sampled was higher for a 500m sample length. Taken together, it was concluded that a 500m stream length sample unit is considerably more efficient than a 1000m length.

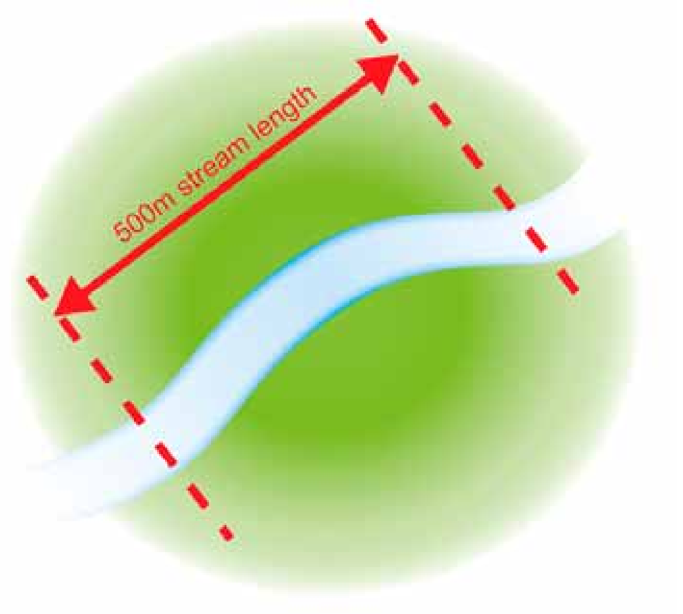
To determine the appropriate number of sample units, a power analysis was carried out examining the ability of differing sample sizes to identify temporal changes in fencing extent. Reducing the stream sample length to 500 m from 1000 m reduced the power to detect change when 40 sites were used. However, it was identified that 60 sites of 500 m provided a similar degree of power to detect change as 40 sites of 1000 m. The smaller sample units are more efficient (more statistical power for unit effort). Therefore the preferred sample design for this study was 60 sites of 500m stream length in each land use category. Each sample unit represented 500m of stream length and, because a stream obviously has two banks, 1000m of bank length (Figure 1).

3.4 Site Selection

In order to select sample units, the ARC GIS team was tasked with identifying all potential sample units of 500m of permanently flowing stream length, derived from the REC, that were located solely within each of the three land use types. The full details of this GIS site selection process are given in Appendix 2. This analysis provided the total “population” of sample units within each land use that could potentially be used in this study. This resulted in 647 sample units in the dairy land use category, 641 in drystock and 219 in rural residential. Within each of these “populations”, sample units were randomly selected to be used as study sites. Landowners of the randomly selected sites were contacted and the first 60 sites for which permission was forthcoming were used in the study.

The location of the study sites is not documented in this report to fulfil the anonymity offered to landowners in return for their participation in the study.

Figure 1:
A schematic diagram of a 500m sample unit within a stream reach.



3.5 Field Measurements

The sample units selected as study sites were surveyed and variables particular to fencing, vegetation and erosion recorded electronically on a handheld personal computer. The surveyor was an ARC staff member who attended training sessions prior to the surveys in order to reduce surveyor related variation. The surveyor walked along the stream bank and recorded changes in riparian fencing, vegetation and stream bank erosion. The nature of the change together with the distance from the start of the sample unit (measured with a surveyor's wheel) and on which bank (true left or true right) the change occurred was recorded. At the start of the survey and at 100m intervals, a photograph (5 in total) was taken showing the stream channel and its riparian margin.

The information required for each of the riparian characteristics was hierarchical, with the potential recording options on the handheld personal computer determined by the previous response. All information relating to riparian characteristics was selected from pre-set options to minimise data collection errors. The characteristics and options are described below.

3.5.1 General Site Information

Information recorded prior to survey start:

- Site identification code
- Grid reference
- Sampling date
- Surveyors
- Photograph numbers

3.5.2 Fencing

There were three potential levels of information required for the fencing characteristic. The first tier of information required was whether there was a fence present or not. If there was no fence, no further information was required.

If a fence was present, then two further characteristics were recorded. The second tier of information required the fence to be recorded as effective or ineffective. A fence was considered as effective if it restricted livestock access to the stream channel. Ineffective fences were typically those with broken wires or posts or were poorly located, and therefore did not restrict livestock access to the stream channel.

The third tier of information recorded whether the fence was permanent or temporary. A permanent fence was typically constructed from wood or masonry posts fixed into the ground. A temporary fence typically consisted of a portable electric fence or similar (see Figure 2).

Figure 2:
An example of the fencing characteristics; Permanent fence (far bank) and temporary fence in the form of a portable electric fence (near bank).

3.5.3 Erosion

Only one level of information was recorded for the erosion characteristic, with three options at the first tier; no erosion, inactive erosion and active erosion. No erosion was recorded if there was no evidence of erosion present. Active erosion was recorded if there was evidence of current erosion, such as bare eroding soil on the banks from scouring, bank slumping or slippage (Figure 3). Inactive erosion was recorded if there was evidence of previous erosion, such as areas of bare ground with some re-colonisation of vegetation (Figure 4). If in doubt as to whether to record an area as active or inactive erosion the following criterion was applied. If the area was currently contributing sediment to the stream it was recorded as active erosion, is there was bare ground which has the potential to contribute erosion in higher flows it was recorded as inactive erosion.

Figure 3:
An example of active erosion; bare soil as a result of a bank slump.

Figure 4:
An example of inactive erosion; previous bank slump with partial re-vegetation.

3.5.4 Vegetation

Three levels of information were required for this characteristic. The first level required the recording of the dominant vegetation type adjacent to the stream channel. There were four options for vegetation type; pastureland, wetland, native woodland and exotic woodland. The second and third tiers of information recorded the height and width of the vegetation; the options available were as follows:

- Pastureland: when selected the second tier (height) defaulted to <1m. The third tier required the selection of the width of the vegetation (as measured perpendicular from the stream bank) from four categories; <2m, 2-5m, 5-10m or >10m.
- Wetland: when selected the second tier (height) defaulted to <1m. The third tier required the selection of the width of the vegetation (as measured perpendicular from the stream bank) from four categories; <2m, 2-5m, 5-10m or >10m.
- Native Woodland: when selected the second tier (height) offered three options with no default. The options were 1-3m, 3-10m or >10m. The third tier required the selection of the width of the vegetation (as measured perpendicular from the stream bank) from four categories; <2m, 2-5m, 5-10m or >10m.
- Exotic Woodland: when selected the second tier (height) offered three options with no default. The options were 1-3m, 3-10m or >10m. The third tier required the selection of the width of the vegetation (as measured perpendicular from the stream bank) from four categories; <2m, 2-5m, 5-10m or >10m.

3.6 Sampling Timetable

The study sites were surveyed between September and December 2007. Each survey was undertaken by a team of two ARC personnel, at least one of which was a trained surveyor who led the survey.

3.7 Electronic data capture and processing

After each survey day, the data collected on the hand held personal computer was downloaded and stored in preparation for subsequent analysis.

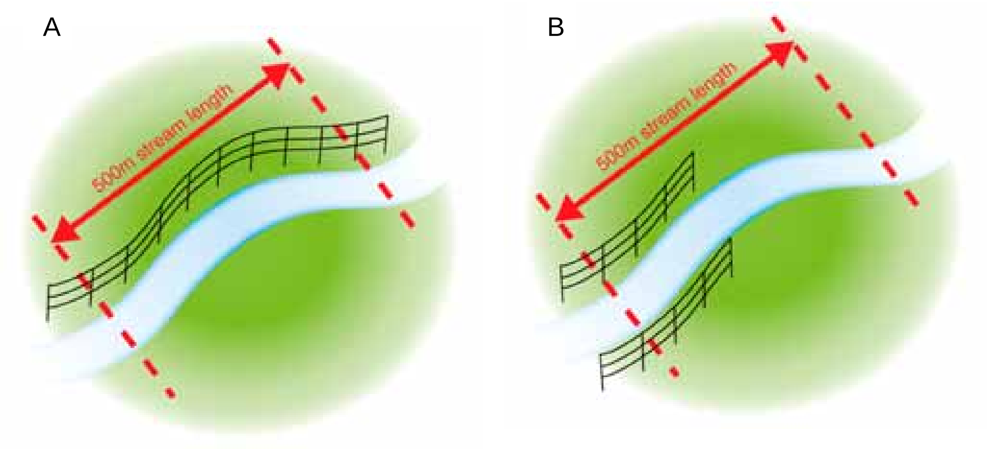
3.8 Data analysis

The fencing data was analysed in two ways;

- Firstly, fencing extent was investigated by stream length, where the length of stream (expressed as a percentage) with no fence, effective fence on one bank, and effective fence on both banks was analysed. This provided a concise assessment of the extent of fencing on the Region's streams and an indicator of the proportion of streams with stock exclusion.
- Secondly, fencing extent and type was investigated by bank length, where the length of the stream bank (expressed as a percentage) with each of the fencing types described in Section 3.5.2 was analysed; thus each sample unit had a single percentage figure for each fencing characteristic. This provided a detailed assessment of the extent and type of fencing on the Region's streams. In addition, this analysis indicated the extent of stream bank that remains to be fenced.

The difference between these two measures of fencing extent is subtle, but nevertheless important. For a given stream bank fenced, the stream length fencing characteristics can vary. For example, both sample units in Figure 5 have 50% bank length fenced. However, the stream length fencing statistics for sample unit 'A' are very different from sample unit 'B'. Therefore, to fully describe the fencing extent we have analysed the fencing data using both measures.

Figure 5
A schematic diagram of two different fencing regimes and associated fencing statistics.



Sample unit	A	B
Bank length fenced	50%	50%
Stream length with;		
No fence	0%	50%
Fenced one side	100%	0%
Fenced both sides	0%	50%

To enable comparison of the results collected in this study with the extent of fencing reported by Ministry for the Environment (2008) for streams covered by the Clean Streams Accord, non-accord streams were removed from the dataset and the fencing statistics were re-calculated. Streams that were considered not to meet the qualifying criteria of deeper than a "red band" and "wider than a stride" were not included in the analysis presented in section 4.1.1.2. This analysis was restricted to the extent of stream with effective fence on both banks (as described in the first bullet point above) as this was considered to be the fencing characteristic recorded in this study that most closely aligned to the "stock exclusion" measurement of the Accord.

The data for erosion and vegetation were investigated by bank length, in the same manner as the second fencing analysis described above. For the purposes of this report, only the first level of the vegetation information was analysed (i.e. pastureland, wetland, native wood and exotic wood).

As the REC was used in the site selection process, some of the environmental characteristics held in the database for each of the sample units were used in the data analysis. Specifically, the REC information for stream order, geology, network position and valley landform for each sample unit was used to explore their relationships with erosion recorded during this study. Soil information was determined from digitised soil maps of Auckland produced for the ARC by Landcare Research (McLeod, 2000).

All statistical analyses were performed within the R environment for statistical computing (R Development Core Team, 2006) by Brian McArdle.

Testing of differences in the fencing, erosion and vegetation characteristics between the three land use types were performed by one-way Analysis of Variance (ANOVA). Where pairwise comparisons between the characteristic means were required they were performed using Tukey's Honestly Significant Difference (HSD) tests.

For assessing the relationship with erosion, if the variable was continuous a Spearman's Rank Correlation was used. If the variable was categorical then one way ANOVA was used because Spearman's Rank Correlation can not be used with categorical variables. When modelling the relationship with erosion, General Linear Modelling (an extension of multiple regression) was used. This GLM analysis enables the relative importance of a number of "predictor" variables (i.e. the measured environmental variables) in determing the magnitude of a single "effect" variable (i.e. the extent of erosion). The final model was selected by manual backwards selection, thus the analysis started with all available environmental variables and those that did not make a statistically significant contribution to the prediction of the dependent variable were removed.

For the statistical tests described above, a p value provides a measure of the evidence that an observed result arises from a real difference rather than random or sampling variability. A p value is the probability that an observed result could occur by chance if there were no real difference between populations. For example, a p value of 0.05 indicates there is a 5% chance of observing a difference even if the two populations are identical. In other words, random sampling from identical populations would lead to a difference smaller that that observed in 95% or surveys and larger than that observed in 5% of surveys.

In ecology, a p value of 0.05 is conventionally used as a threshold indicating evidence of a real difference (Chalmers & Parker, 1986). P values of 0.01 and 0.001 are often used as thresholds to indicate when the probability of the observed result is less than 0.05. A p value of 0.01 indicates that there is a 1% chance of observing a difference as large as observed and a p value of 0.001 indicates a 0.1% chance. These conventions are followed in this report; where the p value for a test is less than 0.05 it is considered to be evidence of a statistically significant difference and the p values for these tests are reported as <0.05, <0.01 or <0.001. Where a p value is greater than 0.05, then any difference is not considered to be statistically significant and the actual p value is reported if appropriate.

4 Results

4.1 Fencing

4.1.1 Stream length analysis

4.1.1.1 All sites

The summary statistics for the fencing characteristic at all study sites (Figure 6 and Table 1) shows that 46.9% of the Region's pastoral stream length is not protected by what was considered by the surveying teams to be effective fencing (no fence). Of the streams with effective fencing, 28.3% have an effective fence on one bank, whilst 24.8% of streams have an effective fence on both banks.

Figure 6:
Mean and 95% confidence intervals for stream length fencing characteristics at all study sites.

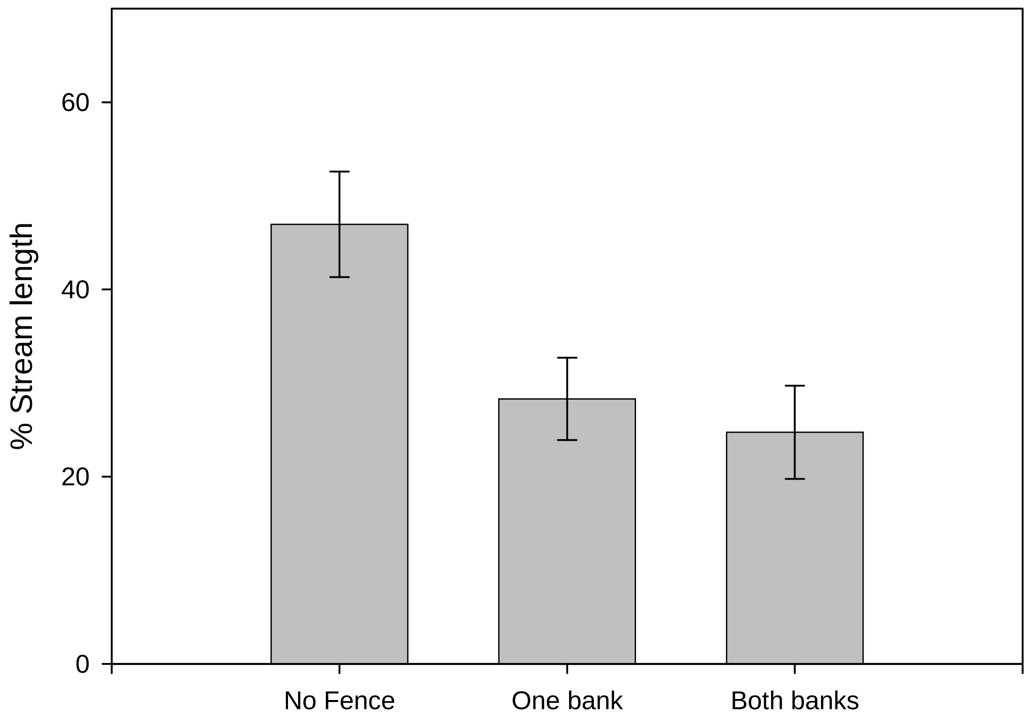


Table 1.

Summary statistics for the fencing characteristics at all study sites (mean with 95% upper and lower confidence limits).

	Mean %	Lower CL	Upper CL
No fence	46.9	41.3	52.5
Effective fence on one bank	28.3	23.9	32.7
Effective fence on both banks	24.8	19.8	29.8

4.1.1.2 Fencing characteristics by land use type

The fencing characteristics for the study sites in each of the land use types are summarised in Table 2. The variation of each of these fencing characteristics with land use is described in more detail below.

Table 2.

Stream length fencing characteristics by land use type (stream length mean % with 95% upper and lower confidence limits in parentheses). * indicates a statistically significant difference between the land use types for a particular fencing characteristic.

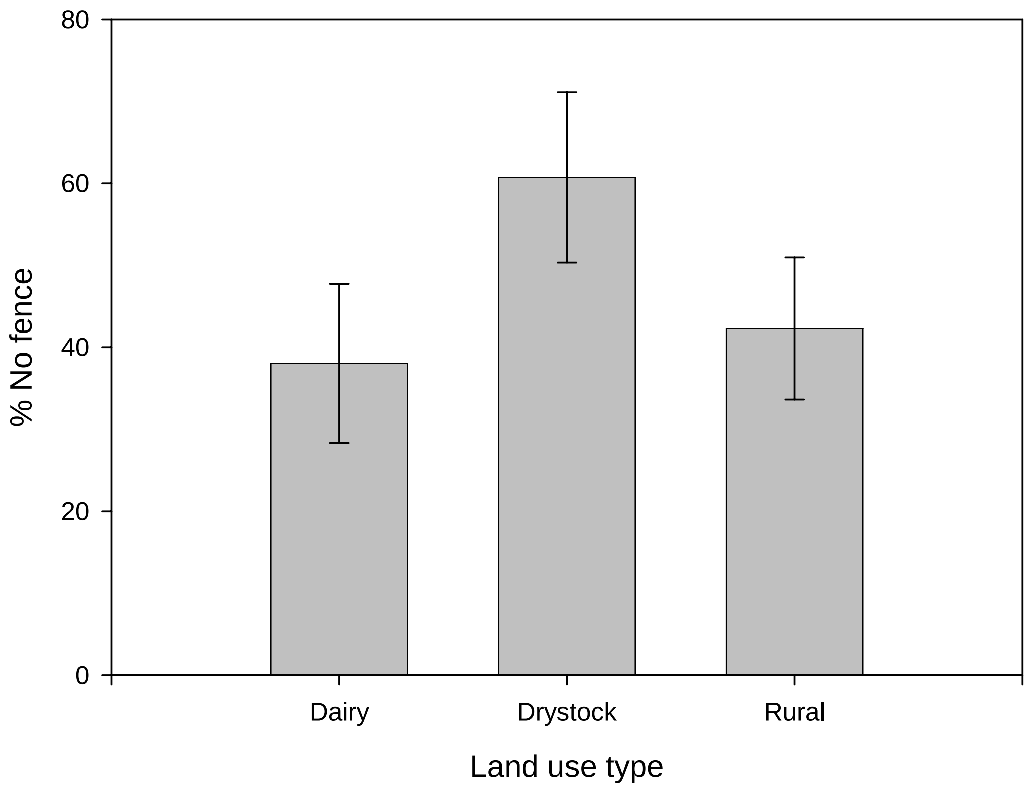
Fence type	Dairy	Drystock	Rural residential
No Fence *****	38.0 (28.3 – 47.7)	60.7 (50.3 – 71.1)	42.3 (33.6 – 51.0)
Effective fence on one bank *	36.8 (28.1 – 45.4)	18.3 (11.5 – 25.1)	29.7 (22.7 – 36.6)
Effective fence on both banks	25.2 (15.8 – 34.6)	20.9 (12.0 – 29.9)	28.0 (20.2 – 35.9)

No Fence

The absence of an effective fence on both banks is the most common situation in all land use types. However, the difference in the extent of stream length not fenced is significantly different (ANOVA p=<0.001) amongst the land use types (Figure 7). This difference is primarily a result of the lack of effective fencing on drystock streams (60.7% unfenced).

Dairy streams have the lowest extent of stream unfenced (38.0%), or in other words have the greatest percentage of stream length with some degree of fencing, although the difference between dairy and rural residential (42.3%) is not statistically significant.

Figure 7:
The mean and 95% confidence intervals for the extent of stream without effective fencing in each of the land use types.

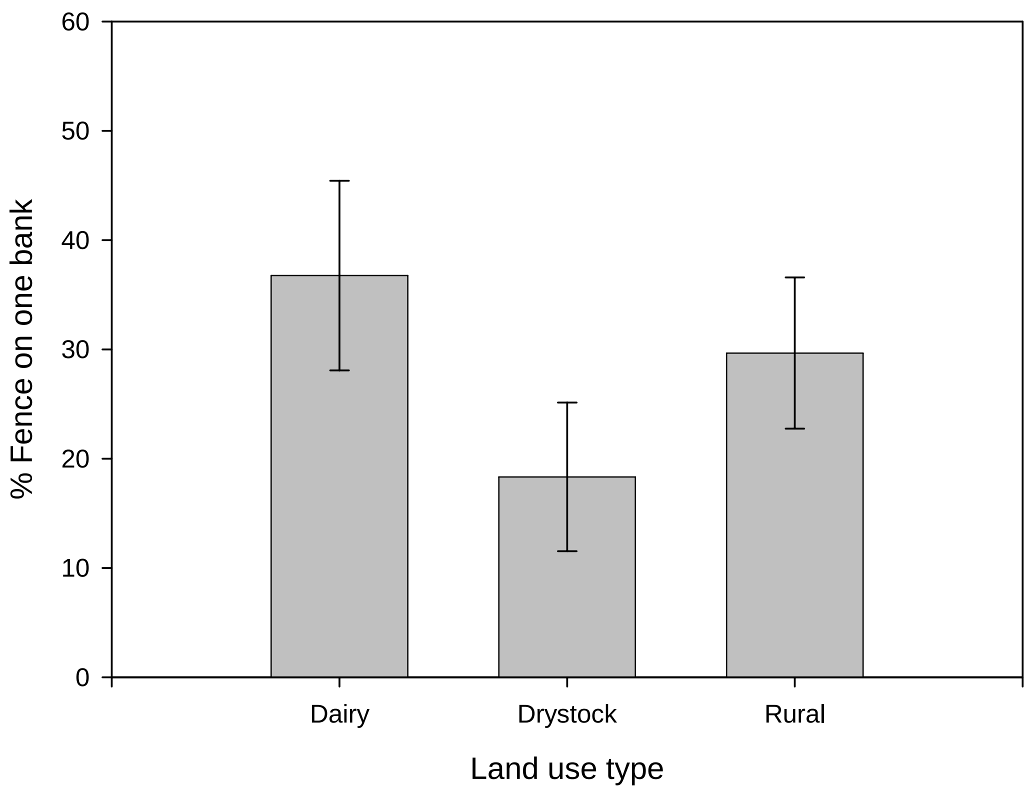


Fence on one bank

The extent of stream with effective fencing on one bank is significantly different (ANOVA p=<0.01) amongst the land use types (Figure 8). This difference is primarily a result of the difference between dairy and drystock stream banks with fence on one side (Tukey's HSD p= <0.01)

Dairy streams have the greatest extent of stream with a fence on one bank (36.8%), although the difference between dairy and rural residential (29.7%) is not statistically significant (Tukey's HSD p= 0.376). Similarly, the difference between rural residential and drystock (18.3%) is not significantly different (Tukey's HSD p= 0.087).

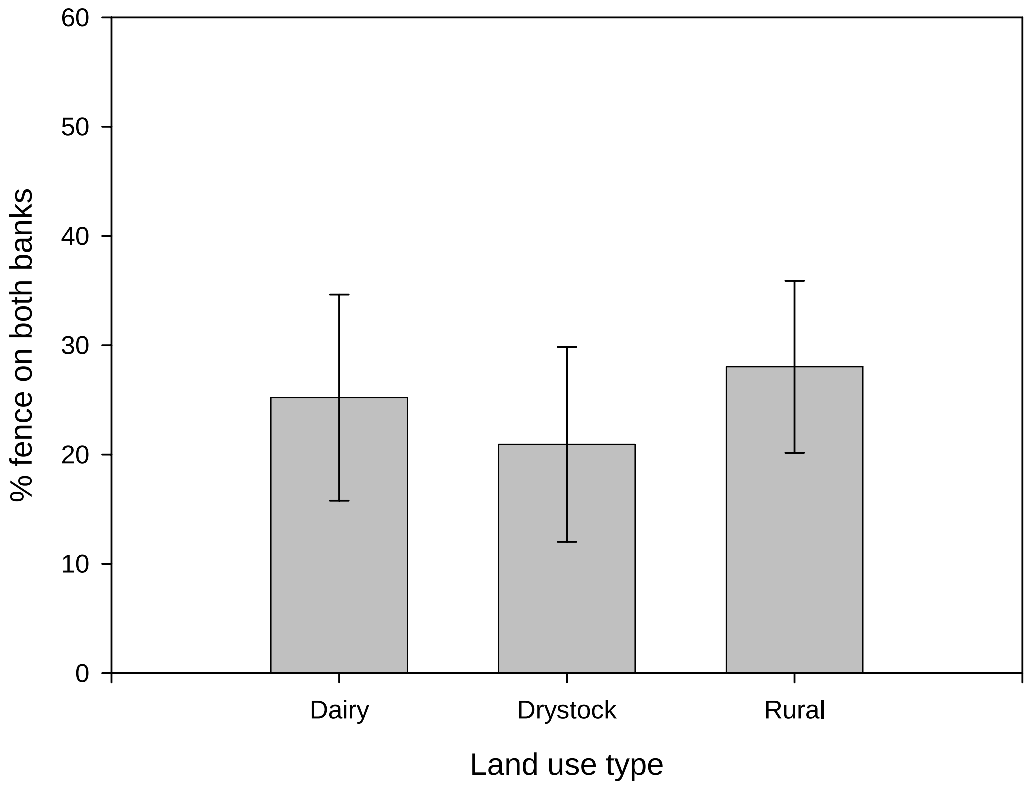
Figure 8:
The mean and 95% confidence intervals for the extent of stream with effective fencing on one bank in each of the land use types.



Fence on both banks

The extent of stream with effective fencing on both banks is not significantly different (ANOVA p=0.516) amongst the land use types (Figure 9).

Figure 9:
The mean and 95% confidence intervals for the extent of stream with effective fencing on both banks in each of the land use types.



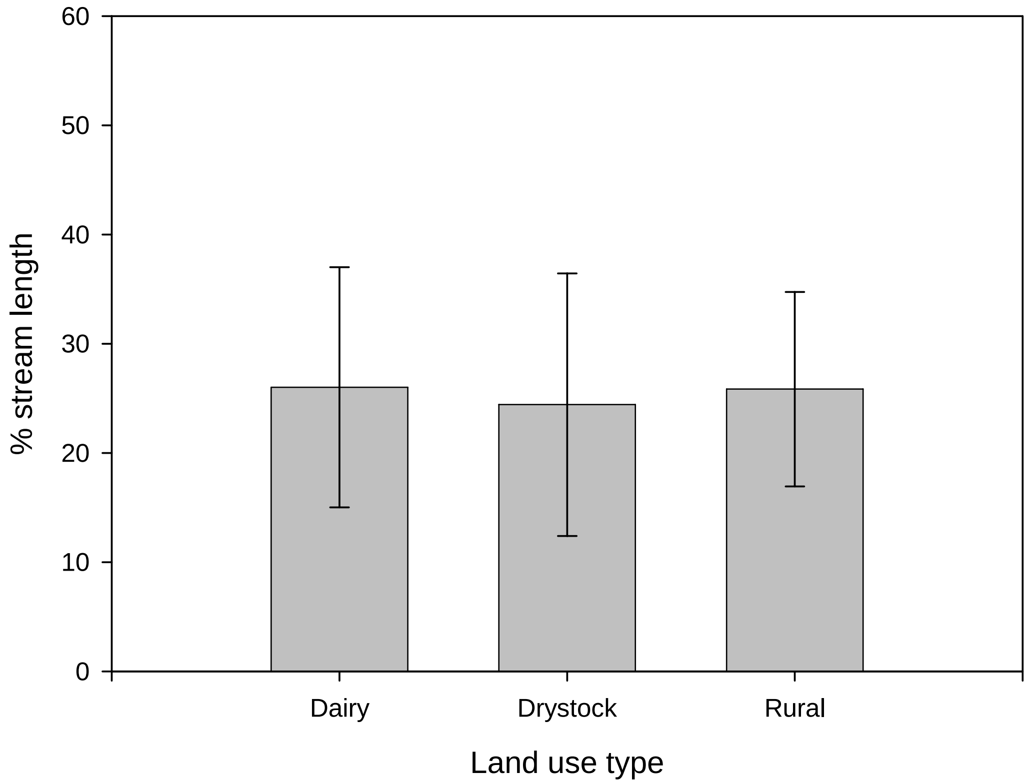
4.1.1.3 Clean streams accord streams

Removing the samples that were considered to not qualify as Accord streams from our dataset resulted in sample sizes for each land use type of 46 (dairy), 40 (drystock) and 41 (rural) sites.

The extent of effective fence on both banks of Accord streams is 26.0% for dairy streams, 25.8% for rural residential streams and 24.4% in drystock streams (Figure 10). Removing non-Accord streams did affect the relative ranking in the extent of effective fence amongst the three land use types, with dairy streams having the greatest extent of effective fencing on both banks of Accord streams.

The figure presented here for the percentage of Accord streams with effective fencing on both banks in dairy land use in Auckland (26.0%) is less than the 70% of Auckland waterways reported to have excluded livestock access in the Dairying and Clean Streams Accord progress report 2007/2008 (MAF, 2009).

Figure 10:
The mean and 95% confidence intervals for the extent of Clean Stream Accord streams with effective fencing on both banks in each of the land use types



4.1.2 Bank length analysis

4.1.2.1 All sites

The summary statistics for the fencing characteristic at all study sites (Figure 11 and Table 3) shows that 51.0% of the Region's pastoral stream banks are unfenced. Of the fenced banks, the majority are protected by permanent effective fences (35.6%). Permanent ineffective fences account for 9.5% of the fenced banks, with temporary fences occurring on less than 4% of banks.

Figure 11:
The mean and 95% confidence intervals for bank length fencing characteristics at all study sites (see Table 3 for the full text of the x-axis label abbreviations)

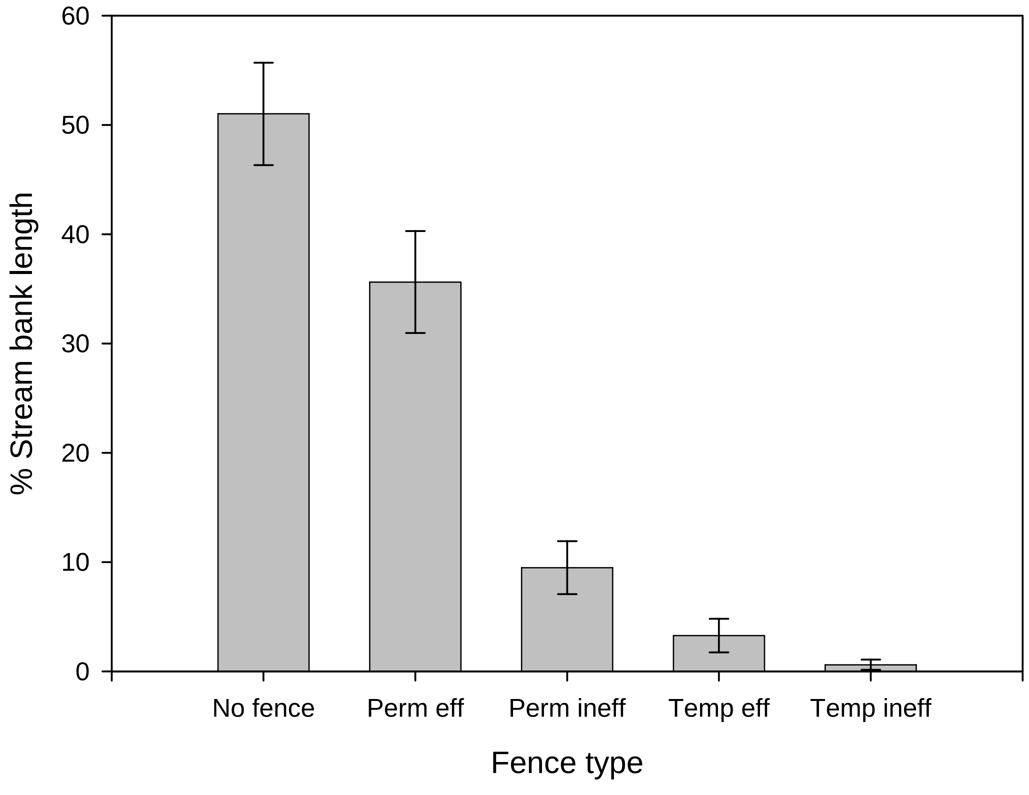


Table 3.

Summary statistics for the bank length fencing characteristics at all study sites (mean with 95% confidence limits).

	Mean %	Lower CL	Upper CL
No fence	51.0	46.3	55.7
Permanent effective	35.6	31.0	40.3
Permanent ineffective	9.5	7.1	11.9
Temporary effective	3.3	1.7	4.8
Temporary ineffective	0.6	0.1	1.1

4.1.2.2 Fencing characteristics by land use type

The fencing characteristics for each of the land use types are summarised in Table 4.

There are differences in the fencing characteristics amongst the land use types, however the differences in permanent effective (ANOVA p=0.067), permanent ineffective (ANOVA p=0.464), temporary effective (ANOVA p=0.061) and temporary ineffective (ANOVA p=0.393) were not statistically significant.

There are statistically significant differences in the no fence and effective fence characteristics; these are presented in more detail below.

Table 4.

Bank length fencing characteristics by land use type (mean % with 95% upper and lower confidence limits in parentheses). * indicates a statistically significant difference between the land use types for a particular fencing characteristic.

Fence type	Dairy	Drystock	Rural residential
No Fence *****	45.0 (37.6 – 52.5)	59.4 (50.1 – 68.7)	48.7 (41.2 – 56.1)
Permanent effective	41.5 (33.0 – 50.0)	28.3 (19.6 – 37.0)	37.0 (29.9 – 44.2)
Permanent ineffective	11.0 (6.3 – 15.6)	10.1 (5.3 – 14.9)	7.4 (4.2 – 10.6)
Temporary effective	2.1 (0.0 – 4.83)	1.8 (0.0 – 3.81)	5.8 (2.7 – 9.0)
Temporary ineffective	0.4 (0.0 – 0.1)	0.4 (0.0 – 1.1)	1.1 (0.0 – 2.1)
Effective * (permanent & temporary)	43.6 (35.1 – 52.1)	30.1 (21.1 – 39.2)	42.9 (35.3 – 50.39)

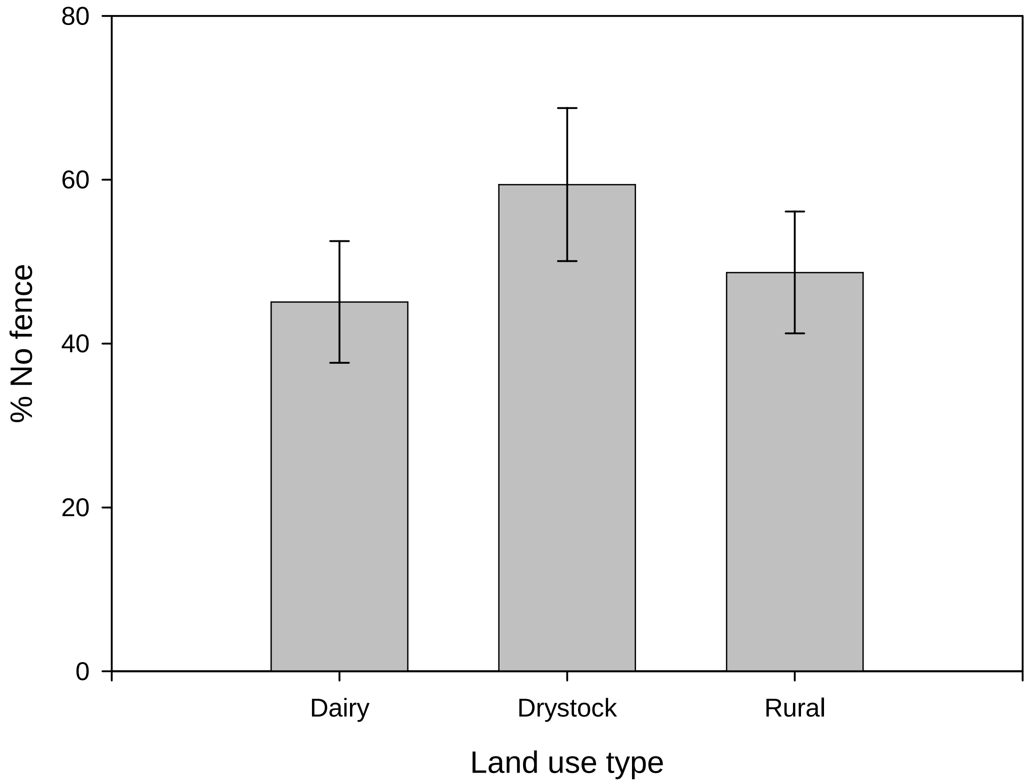
No fence

The absence of a fence is the most common situation in all land uses; the difference in the extent of stream banks not fenced is significantly different (ANOVA $p=<0.05$) amongst the land use types (Figure 12). This difference is primarily a result of the lack of fencing on drystock stream banks (59.4% un-fenced).

Dairy streams have the lowest extent of stream bank unfenced (45.0%), or in other words have the greatest percentage of stream banks with a fence, although the difference between dairy and rural residential (48.7%) is not statistically significant.

Figure 12:

The mean and 95% confidence intervals for the extent of no fencing on stream banks in each of the land use types.

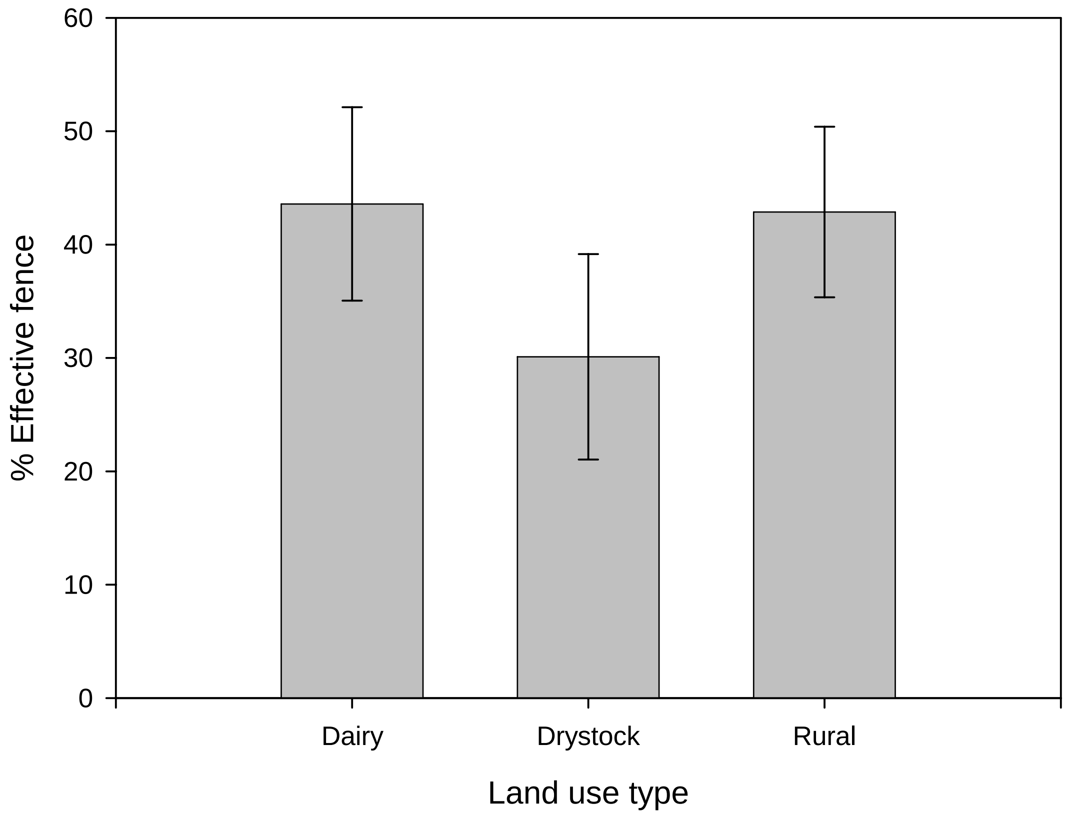


Effective fence

The extent of effective fence (permanent and temporary combined) is significantly different (ANOVA p=<0.05) amongst the land use types (Figure 13). This difference is primarily a result of the lack of effective fencing on drystock streams (30.1%).

Dairy stream banks have the greatest extent of effective fencing (43.6%), although the difference between dairy and rural residential (42.9%) is not statistically significant.

Figure 13:
The mean and 95% confidence intervals for the extent of effective fencing on stream banks in each of the land use types.



4.2 Erosion

4.2.1 All sites

The summary statistics for the Erosion characteristics at all study sites (Figure 14 and Table 5) show that 54.5% of the Region's pastoral stream banks are unaffected by erosion. Of the stream banks that are affected by erosion, the majority are subject to inactive erosion (40.1%). Active erosion is less common, affecting 5.4% of the Region's pastoral stream banks.

Figure 14:
The mean and 95% confidence intervals for erosion characteristics at all study sites.

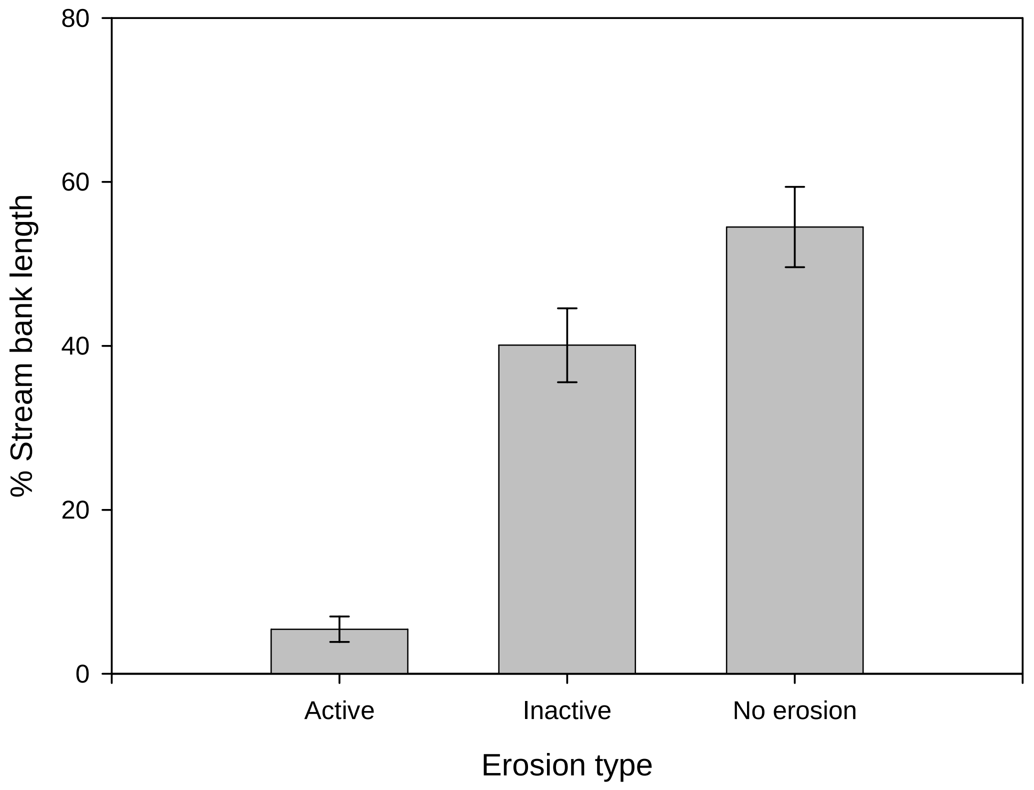


Table 5.

Summary statistics for the erosion characteristics at all study sites (mean with 95% confidence limits).

	Mean %	Lower CL	Upper CL
Active erosion	5.4	3.9	7.0
Inactive erosion	40.1	35.6	44.6
Total erosion (active & inactive)	45.5	40.6	50.4
No erosion	54.5	49.6	59.4

4.2.2 Erosion characteristics by land use type

The erosion characteristics for each of the land use types are summarised in Table 6. There are statistically significant differences in all of the erosion characteristics amongst the land use types; these are presented in more detail below.

Table 6.

Erosion characteristics by land use type (mean % with 95% upper and lower confidence limits in parentheses). * indicates a statistically significant difference between the land use types for a particular erosion characteristic.

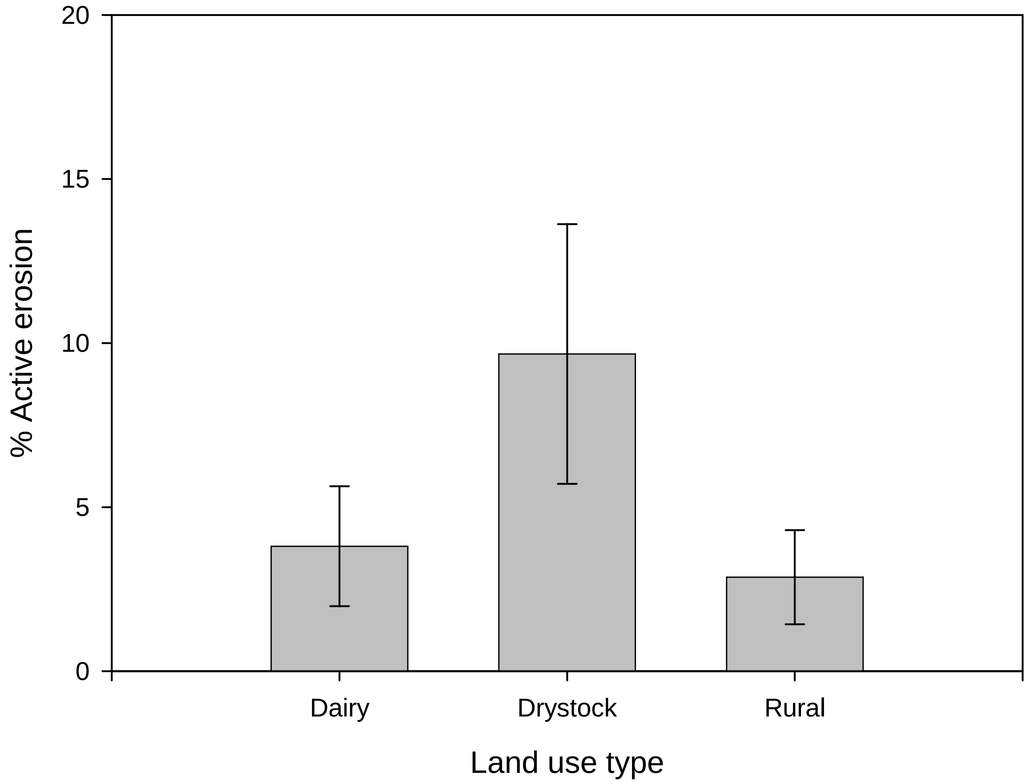
Erosion type	Dairy	Drystock	Rural residential
Active erosion *	3.8 (2.0 – 5.6)	9.6 (5.7 – 13.6)	2.9 (1.4 – 4.3)
Inactive erosion *	46.4 (38.2 – 54.7)	45.0 (36.7 – 53.3)	28.9 (22.5 – 35.3)
Total erosion * (active & inactive)	50.2 (41.7 – 58.8)	54.6 (45.7 – 63.6)	31.8 (24.6 – 40.0)
No erosion *	49.8 (41.2 – 58.3)	45.4 (36.4 – 54.3)	68.2 (61.0 – 75.4)

4.2.2.1 Active erosion

Active erosion was the least commonly recorded state for the erosion characteristics. The difference in the extent of stream banks affected by active erosion amongst the land use types (Figure 15) is highly significant (ANOVA p=<0.001). The difference is primarily a result of the extent of active erosion on drystock stream banks (9.7%).

Rural residential stream banks have the lowest extent of active erosion (2.9%), although the difference between rural residential and dairy (3.8%) is not statistically significant.

Figure 15:
The mean and 95% confidence intervals for the extent of active erosion on stream banks in each of the land use types.

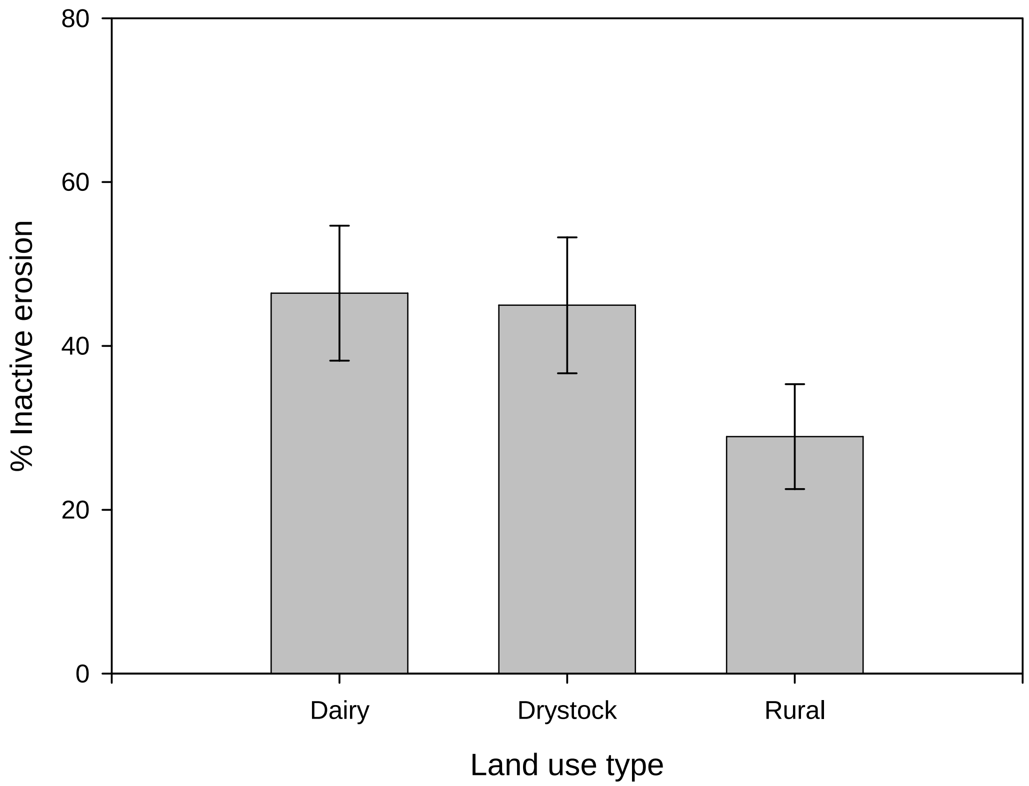


4.2.2.2 Inactive erosion

The extent of inactive erosion is significantly different (ANOVA P=<0.01) amongst the land use types (Figure 16). This difference is primarily a result of the lesser extent of inactive erosion on rural residential stream banks (28.9%).

Dairy stream banks have the greatest extent of inactive erosion (46.4%), although the difference between dairy and drystock (45.0%) is not statistically significant.

Figure 16:
The mean and 95% confidence intervals for the extent of inactive erosion on stream banks in each of the land use types.

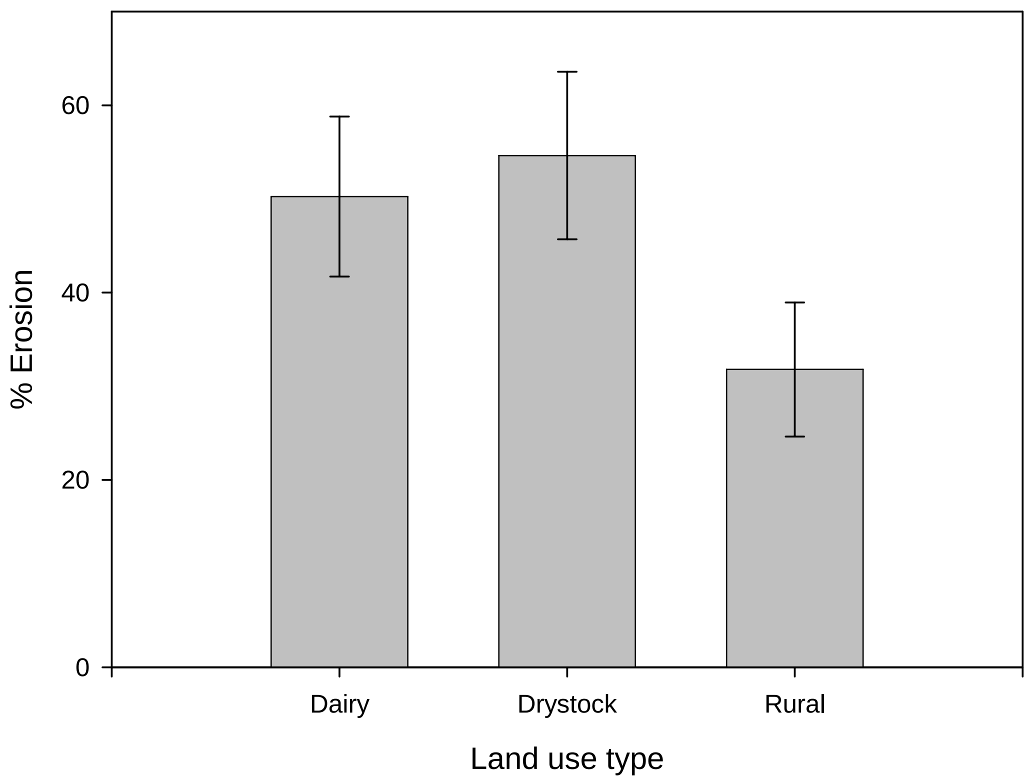


4.2.2.3 Total erosion

The extent of total erosion (active and inactive erosion combined) is significantly different (ANOVA P=<0.001) amongst the land use types (Figure 17). This difference is primarily a result of the lesser extent of total erosion on rural residential stream banks (31.8%).

Drystock stream banks have the greatest extent of total erosion (54.6%), although the difference between drystock and dairy (50.3%) is not statistically significant.

Figure 17:
The mean and 95% confidence intervals for the extent of total erosion on stream banks in each of the land use types.

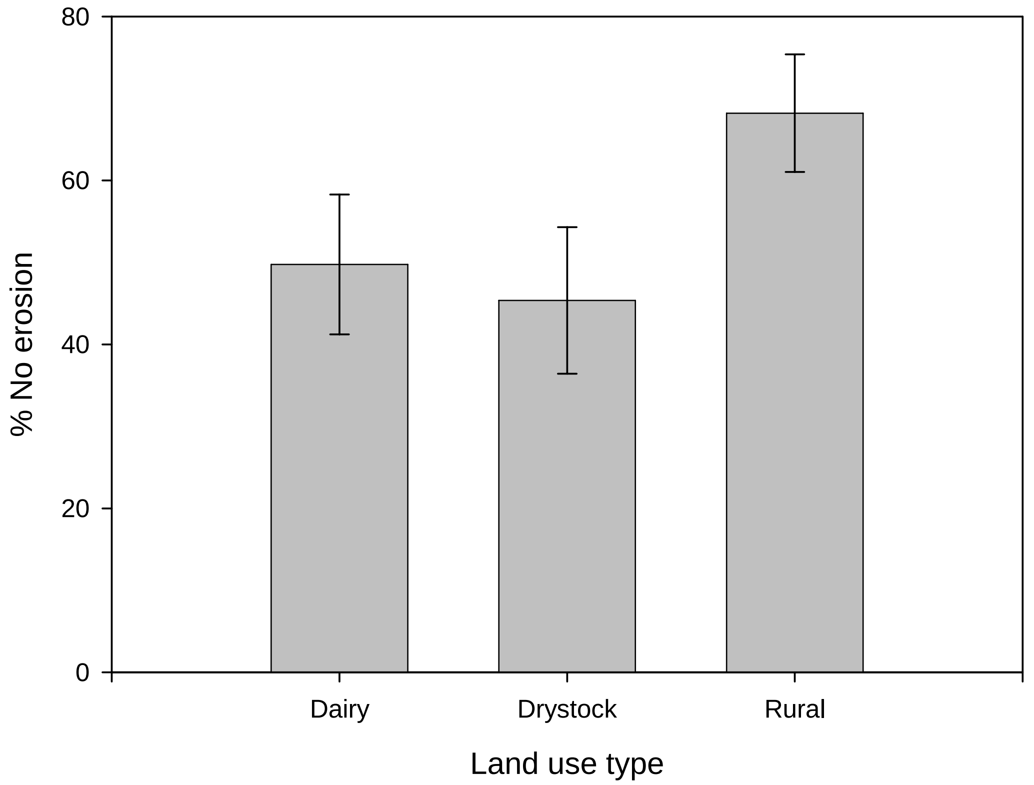


4.2.2.4 No erosion

The extent of no erosion is significantly different (ANOVA P=<0.001) amongst the land use types (Figure 18). This is to be expected because it is simply the inverse of the total erosion analysis presented above. This difference is primarily a result of the greater extent of no erosion on rural residential stream banks (68.2%).

Drystock stream banks have the smallest extent of no erosion (45.4%), although the difference between drystock and dairy (49.8%) is not statistically significant.

Figure 18:
The mean and 95% confidence intervals for the extent of no erosion on stream banks in each of the land use types.



4.3 Vegetation

4.3.1 All sites

The summary statistics for the vegetation characteristics at all study sites (Figure 19 and Table 7) shows that predictably pastureland (61.5%) is the most common vegetation type on the Region's rural stream banks. Exotic woody vegetation (19.8%) is the second most common vegetation type; native woody vegetation (13.2%) is the next most common whilst wetland vegetation is only present on 5.5% of the Regions pastoral stream banks.

Figure 19:
The mean and 95% confidence intervals for vegetation characteristics at all study sites.

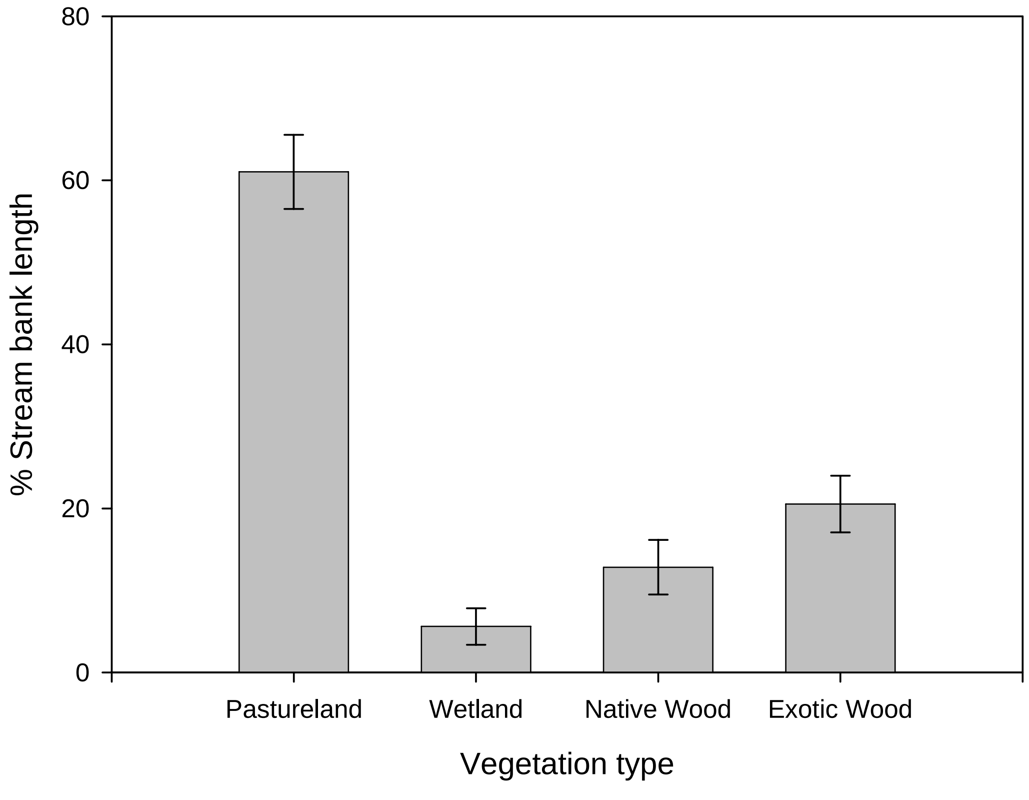


Table 7.

Summary statistics for the vegetation characteristics at all study sites (mean with 95% confidence limits).

	Mean %	Lower CL	Upper CL
Pastureland	61.5	57.5	65.6
Exotic woody vegetation	19.8	16.9	22.7
Native woody vegetation	13.2	10.3	16.1
Wetland vegetation	5.5	3.6	7.4

4.3.2 Vegetation characteristics by land use type

The vegetation characteristics for each of the land use types are summarised in Table 8. There are statistically significant differences in all of the vegetation characteristics amongst the land use types; these are presented in more detail below.

Table 8.

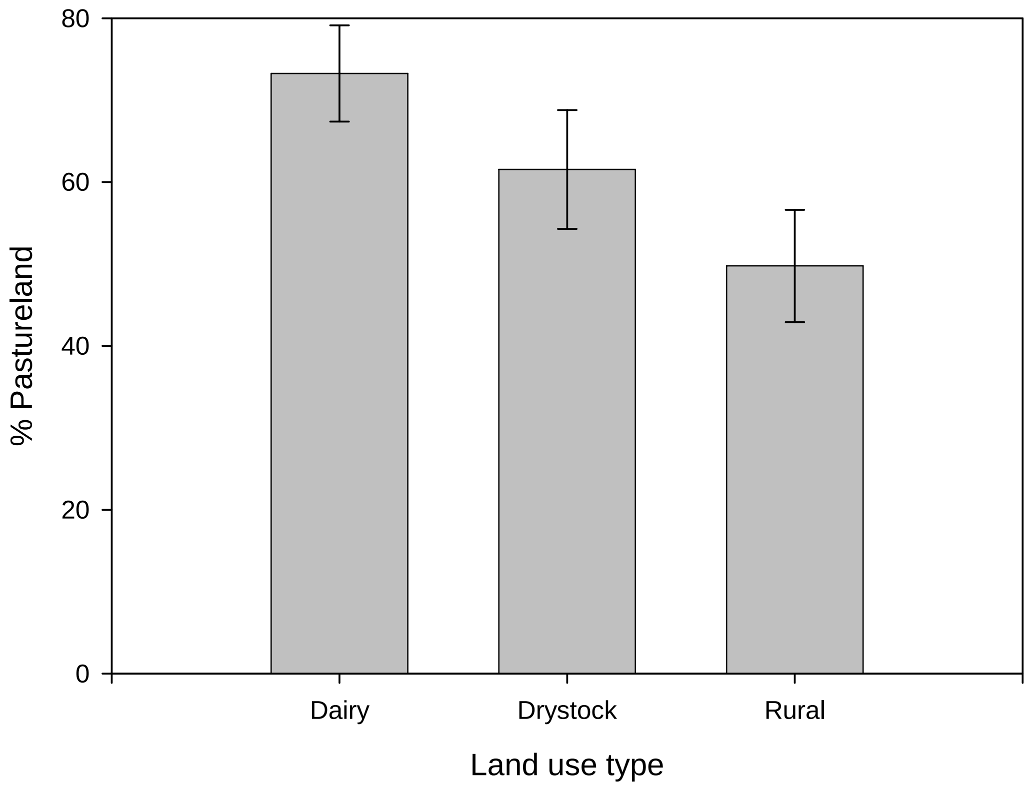
Vegetation characteristics by land use type (mean % with 95% upper and lower confidence limits in parentheses). * indicates a statistically significant difference between the land use types for a particular erosion characteristic.

Vegetation type	Dairy	Drystock	Rural residential
Pastureland *	**73.3 (67.4 – 79.1)**	**61.5 (54.3 – 68.8)**	**49.8 (42.9 – 56.6)**
Exotic woody vegetation *	**15.9 (11.5 – 20.2)**	**12.9 (8.8 – 16.9)**	**30.6 (25.2 – 26.0)**
Native woody vegetation *	**7.2 (3.5 – 10.9)**	**15.9 (10.7 – 21.2)**	**16.4 (10.7 – 22.1)**
Wetland vegetation *	**3.7 (1.1 – 6.2)**	**9.7 (5.4 – 13.9)**	**3.3 (0.6 – 5.9)**

4.3.2.1 Pastureland

Pastureland is the most common vegetation type in all land uses; the difference in the extent of stream banks with pasture vegetation is significantly different (ANOVA p=<0.001) amongst the land use types (Figure 20). The extent of pasture vegetation on dairy stream banks is significantly higher than both drystock (Tukey's HSD p=<0.05) and Rural residential (Tukey's HSD p=<0.001). Similarly, the extent of pasture on drystock stream banks is significantly higher than rural residential (Tukey's HSD p=<0.05).

Figure 20:
The mean and 95% confidence intervals for the extent of pastureland on stream banks in each of the land use types.

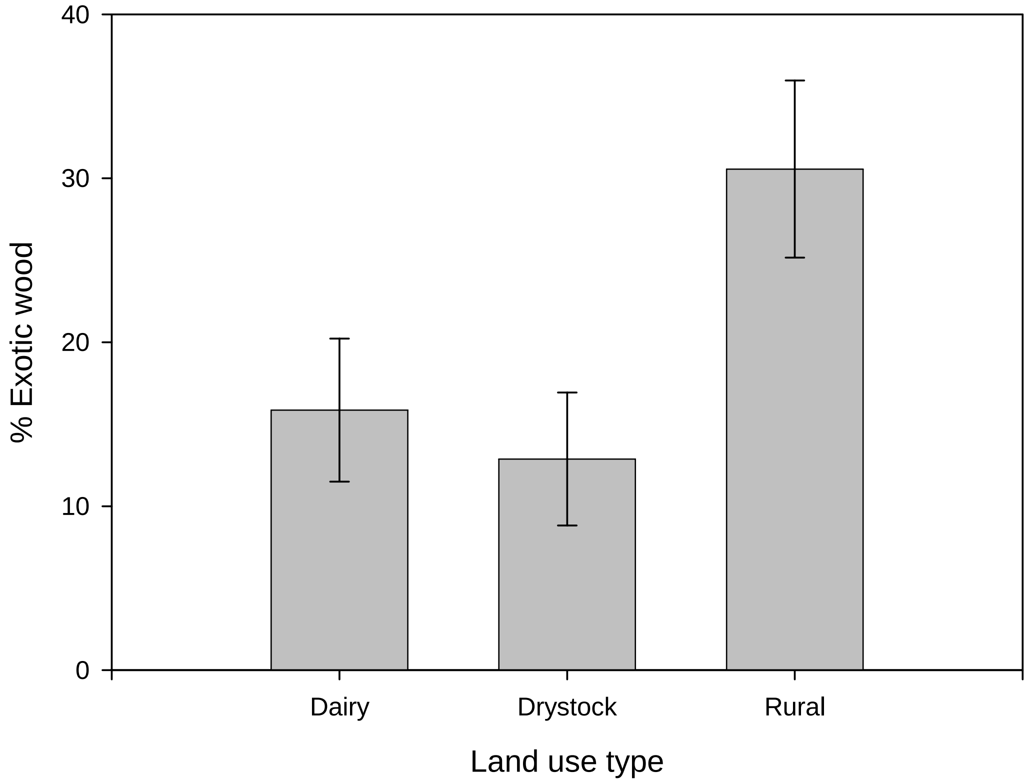


4.3.2.2 Exotic woody vegetation

The extent of exotic woody vegetation is significantly different (ANOVA p=<0.001) amongst the land use types (Figure 21). This difference is primarily a result of the greater extent of exotic woody vegetation on rural residential stream banks (30.6%).

Drystock stream banks have the lowest extent of exotic woody vegetation (12.9%), although the difference between drystock and dairy (15.9%) is not significantly different.

Figure 21:
The mean and 95% confidence intervals for the extent of exotic woody vegetation on stream banks in each of the land use types.

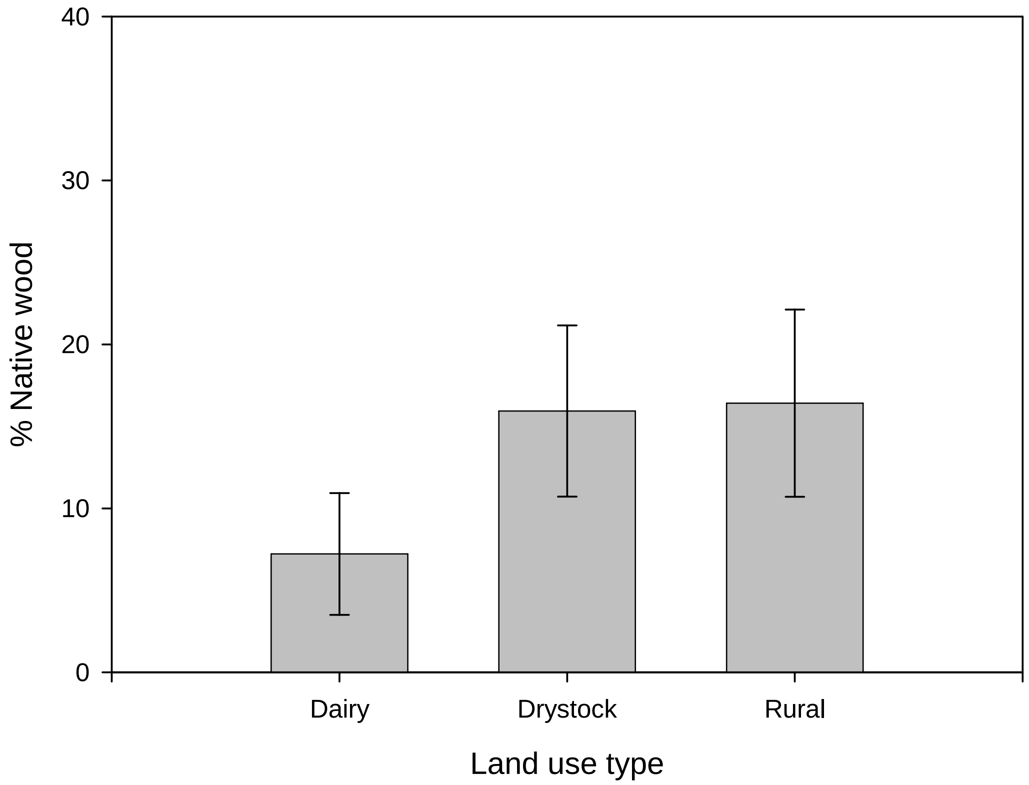


4.3.2.3 Native woody vegetation

The extent of native woody vegetation is significantly different (ANOVA p=<0.05) amongst the land use types (Figure 22). This difference is primarily a result of the lack of native woody vegetation on dairy stream banks (7.2%).

Rural residential stream banks have the greatest extent of native woody vegetation (16.4%), although the difference between rural residential and drystock (15.9%) is not significantly different.

Figure 22:
The mean and 95% confidence intervals for the extent of native woody vegetation on stream banks in each of the land use types.

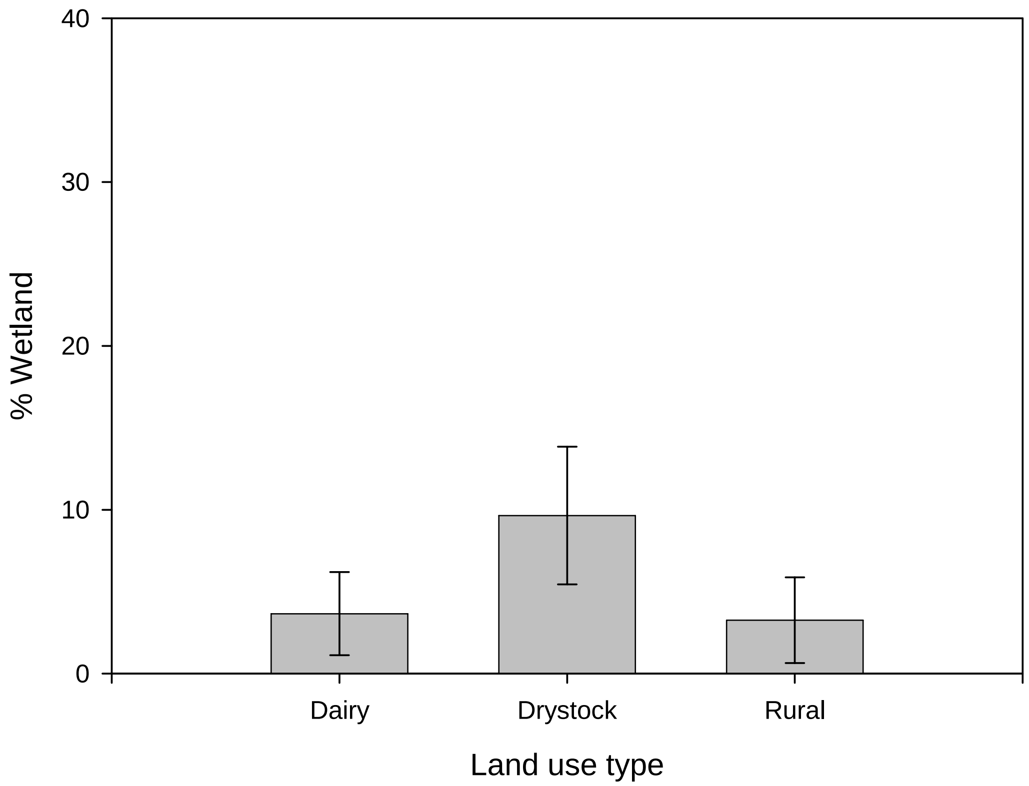


4.3.2.4 Wetland

The extent of wetland is significantly different (ANOVA p=<0.01) amongst the land use types (Figure 23). This difference is primarily a result of the greater extent of wetland on drystock stream banks (9.7%).

Rural residential stream banks have the lowest extent of wetland (3.3%), although the difference between rural residential and dairy (3.7%) is not significantly different.

Figure 23:
The mean and 95% confidence intervals for the extent of native woody vegetation on stream banks in each of the land use types.



4.4 Relationships with erosion

The fencing and vegetation characteristics collected during this study together with site specific environmental characteristics derived from the REC database were used to explore relationships between these environmental factors and the extent of erosion observed during the course of this study.

4.4.1 Simple relationships

Of the 12 environmental factors available for analysis, six were significantly associated with the extent of stream bank erosion. The relationships with continuous variables (Spearman Rank Correlations) are presented in Table 9; relationships with categorical variables (ANOVA) are presented in Table 10.

Land use is highly significantly related to erosion (ANOVA P=<0.001) as also identified in section 4.2.2.3. This is primarily a result of the lesser extent of erosion on rural residential stream banks.

There are highly significant (Spearman Rank P=<0.001) negative correlations between both extent effective fencing and woody vegetation with erosion (i.e. the more fencing or woody vegetation on a stream bank, the less erosion was recorded). Further negative correlations are identified between erosion and exotic and native woody vegetation.

There is a significant (Spearman Rank P=<0.001) positive correlation between erosion and pasture vegetation (i.e. the more pasture on a stream bank, the more erosion was recorded).

There were no significant relationships with erosion identified with the environmental variables soil type, stream order, geology, network position or valley landform (Table 9).

Table 9.

Spearman Rank correlations between the extent of erosion and the continuous environmental variables.

Environmental variable	Correlation	P value
Effective fence	-0.593	<0.001
Exotic woody vegetation	-0.269	<0.001
Native woody vegetation	-0.152	<0.05
Total woody vegetation (exotic and native)	-0.316	<0.001
Pastureland	0.292	<0.001
Wetland	0.087	0.247

Table 10.

ANOVA relationships between the extent of erosion and the categorical environmental variables.

Environmental variable	P value
Land use type	<0.001
Soil type	0.148
Stream order	0.624
Geology	0.258
Network position	0.329
Valley landform	0.117

4.4.2 General linear modelling

The general linear model identified that 50.6% (r^2 = 50.6) of erosion found on pastoral stream banks could be associated with fencing, vegetation and the land use type. The environmental "predictor" variables used in the model were effective fence, total woody vegetation and the land use type. The coefficient in Table 11 tells us about the relationship between erosion and each of the "predictor" environmental variables; for each one unit increase in the "predictor" variable, the extent of erosion changes by the value of the co-efficient given the other "predictor" variables are held constant.

Table 11.

General Linear Modelling for stream bank erosion and the "predictor" environmental variables.

	Coefficient	Standard error	t value	p value
(intercept)	94.36	5.02	18.79	<0.001
Effective fence	-0.89	0.09	-10.23	<0.001
Drystock	-3.62	4.44	-0.82	0.42
Rural	-14.32	4.68	-3.06	<0.01
Total woody vegetation	-0.68	0.11	-5.98	<0.001
Effective fence: Total woody vegetation	0.01	0.00	4.96	<0.001

From a management perspective, two of the key relationships with erosion are those with fencing and riparian vegetation because they are relatively easy to modify. The model coefficients (Table 11) show that a 1% increase in effective fencing reduces the extent of stream bank erosion by 0.89%, given the other "predictor" variables are held constant. Similarly, a 1% increase in woody vegetation reduces the extent of erosion by 0.68%.

It should be noted that the two land use variables in the model are contrasted with dairy as the baseline (Table 11). Hence, the model shows that the extent of erosion on drystock stream banks was not significantly different from dairy ($p = 0.416$), whereas rural residential streams were significantly different ($p = <0.01$) with 14.3% less erosion than dairy streams.

The interaction term (Effective fence x Total woody vegetation) adjusts for the fact that it is impossible to have more than 100% total fencing and woody vegetation and as such it has no useful interpretation.

5 Discussion

This study has met its primary objective of benchmarking the type and extent of fencing, riparian vegetation and erosion on stream banks in the Auckland Region. Meeting this objective has provided valuable information to inform riparian management objectives and policies and provided a baseline against which temporal changes in stream bank fencing, vegetation and erosion can be compared through future surveys; hence the full value of this information will not be fully realised until subsequent surveys are completed. In addition, the study has provided information of immediate value by meeting the secondary objectives of 1; investigating the relationships between stream bank erosion and environmental factors including riparian management practices, and 2; providing a comparison of stream fencing on dairy farms in Auckland with the stock exclusion data reported by the MfE on behalf of the Clean Streams Accord partners. The key objectives of the study are further discussed and evaluated below.

5.1 Objective 1: Current state of the resource

It is clear from the results of the study that, even given the widely recognised benefits of riparian fencing and vegetation, that many of the Region's pastoral streams have neither effective fencing (51% bank length unfenced) nor woody riparian vegetation (66% bank length without woody vegetation).

Fencing

The absence of an effective fence on both stream banks is the most common situation in all land use types (Figure 7). However, there is a significant difference between the land use types, with drystock land use having the most unfenced streams. The stream length analysis of the fencing data showed that only 24.8% of all pastoral streams (mean of all land use types) were effectively fenced on both banks; whilst there were small differences between the land use types, none of these were statistically significant (Figure 9).

The analysis of the extent of stream length with effective fence on one bank also showed a significant difference amongst the land use types (Figure 8). This was primarily a result of the lesser extent of drystock streams with effective fencing on one bank. Drystock streams had significantly less fencing on one bank than dairy streams, and whilst there were more rural residential streams with one bank fenced, the difference was not statistically significant. The bank length analysis of the fencing data allowed us to investigate these differences in more detail. Whilst there were differences identified amongst the land use types in the fencing measures using the bank length analysis, the only statistically significant differences were with the "no fence" and "effective fence" parameters. These findings mirrored the stream length analysis, in that drystock was found to have the least amount of effective fencing and the greatest amount of unfenced stream.

The consistent finding, whether the stream length or bank length analyis is used, is that drystock streams have the least stream bank fencing of the three land use types. This is likely a result of the current statutory and non-statutory policies which encourage stream bank fencing in rural residential and dairy land uses. For example, the Clean Streams Accord (MfE, 2003), places an expectation on dairy farmers to fence qualifying streams and some Territoral Local Authorities place an obligation upon land owners to fence streams when productive rural land is subdivided and converted to rural residential (for example, Rule 7.14.2.5 of the Rodney District Plan). This study offers evidence that these two policies have led to a greater extent of fencing on dairy and rural residential stream banks, when compared with drystock streams. This raises the issue of whether a similar policy is required to encourage or incentivise fencing on drystock streams.

Whilst the effects of the two policies have been recognised, it should be noted that around 50% of the region's rural waterways remain unfenced. The bank length analysis of fencing allows us to estimate the extent of pastoral stream bank that remains to be fenced in the Region. Section 4.1.2.1 states that 35.6% of the stream banks in this survey were fenced with a permanent effective fence; this leaves 64.4% of stream banks without an effective permanent fence. Given the current estimate of stream length for the Auckland Region (16650 km) and that 63% of the Region’s streams are in rural land use (ARC, 2005), it can be estimated that there are 10490 km of rural streams (bank length 20980 km) in the Auckland Region. Combining the results of this study with this estimate, it can be calculated there are 13511 km (64.4% of 20980 km) of rural stream banks without an effective fence in the Auckland Region.

Erosion

The study found that 45.5% of the Region’s pastoral streams were affected by erosion (mean of all land use types). However, active erosion was relatively rare (5.4%). Rural residential streams consistently had a lesser extent of erosion (active, inactive and total) than both dairy and drystock streams. Whilst the extent of inactive and total erosion were similar between dairy and drystock streams, active erosion was significantly more common on drystock streams (Figure 15). Potential explanatory relationships between the extent of stream bank erosion and environmental factors are discussed below.

Riparian vegetation

As would be expected in a study of pastoral streams, pasture (61.5%) was by far the most common vegetation type encountered on stream banks (Figure 19). Exotic (19.8%) and native (13.2%) woody vegetation were more common than wetland vegetation (5.5%).

The extent of exotic woody vegetation was significantly higher on rural residential stream banks and it is hypothesised that this is a result of the planting of ornamental trees and shelterbelts in rural subdivisions. The extent of native woody vegetation was significantly lower on dairy streams and may be a result of more intensive land use in these areas.

The relationship between erosion and riparian vegetation is explored below.

5.2 Objective 2: Relationships with erosion

The simple analysis of the relationship between erosion and the environmental variables available demonstrated that the key variables associated with erosion were the extent of effective fencing, woody vegetation (native and exotic) and pasture vegetation, together with the land use type. This analysis tells us there is a relationship between these variables and erosion, but it doesn't necessarily indicate a causal relationship.

This analysis indicated that the variables related to land management practices (i.e., land use and riparian fencing and vegetation) were significantly related to the extent of stream bank erosion. The absence of significant relationships between erosion and the large-scale physical variables (i.e. soil order, stream order, geology, network position and valley landform) is an important result. It suggests that stream bank erosion can be reduced through changes in land use and improvements in riparian management.

An interesting comparison resulting from this analysis is the relationship between erosion and native and exotic woody vegetation. The Spearman Rank correlation indicates that exotic woody vegetation is more strongly related to erosion than native woody vegetation. This finding suggests that exotic trees may be more effective at reducing stream bank erosion than native trees. When this finding is considered together with that of the State of the Environment rivers and streams ecology programme, where it was found that streams in exotic forestry plantations supported similar invertebrates communities to native forest catchments (ARC, 2008), it could be argued that exotic trees are as valuable to stream systems as native trees. The benefits of stream shading and bank stabilisation are common to both types of vegetation. However, one would expect greater terrestrial biodiversity benefits with native woody vegetation rather than with exotic woody vegetation.

The linear modelling exercise confirmed the results of the simple analysis discussed above where the land management related variables (effective fencing, land use and woody vegetation) explained over 50% of the variation in stream bank erosion. Inclusion of any of the large-scale physical variables did not improve the performance of the model. The model clearly reinforces the benefit of riparian fencing and woody vegetation on stream systems, and provides empirical evidence that increases in both variable would result in less stream bank erosion. Indeed, the relationship between effective fencing and erosion is nearly 1:1; the model predicting a 1% increase in effective fencing would result in a 0.9% reduction in erosion.

5.3 Objective 3: Clean Streams Accord comparison

Whilst it was not a primary objective of the study, the survey of stream bank fencing allowed a comparison of the stock exclusion measure reported by the MAF (2009) in relation to the Clean Stream Accord. For the purposes of this study it was considered that an effective fence on both stream banks constituted stock exclusion and this figure was compared with the MAF-reported measure. It is recognised that the extent of fence on both banks does not align exactly with the Clean Streams Accord measure of stock exclusion, but in our opinion they are sufficiently analogous to allow a comparison. The extent of effective fence on both stream banks was 26% for dairy streams; this is clearly less than the 70% stock exclusion measure reported by the MAF (2009).

The different data collection and interpretation processes may account for some of the differences between the two values. The MAF-reported value is based on farm-scale data derived from verbal assessments, whereas this study is based on land use-scale data derived from field surveys. Hence, direct comparison of the results of the surveys is hampered by the different methodologies and definitions employed.

5.4 Management implications

The results of the extent of fencing on pastoral streams suggest that drystock has significantly less stream bank fenced than that of dairy or rural residential streams. This is probably a result of the obligations and incentives for fencing in dairy and rural residential land use types. This raises the issue of whether such schemes should be initiated for drystock farmers, particularly given the relatively high occurrence of active erosion in this land use. This issue could be considered in a wider review of the ARC's current riparian management strategies and incentives in light of the findings of this study. This would allow the evaluation of the current ARC policies and inform the development of further methods to compliment and support existing Local Authority and industry initiatives.

This report has provided empirical evidence of the association between fencing and woody riparian vegetation and reducing stream bank erosion. Furthermore, The ARC's State of the Environment monitoring programmes have documented that rural streams with fencing and woody riparian vegetation support higher scoring invertebrate communities (ARC, 2005 & 2008) and have higher water quality (ARC, 2007) when compared with rural streams with no riparian fencing or vegetation. These multiple benefits of stream fencing and woody riparian vegetation provide support for having a robust policy framework that promotes riparian planting and fencing.

This study has provided an assessment of the scale of the stream fencing issue. It is estimated that there are 13511 km of rural stream banks that are unfenced in the Auckland Region. The financial cost of installing fencing on these unfenced stream banks is dependent on the type of fence installed; installing 7 wire post and batten fencing (approximate cost $15 per metre) would require in the region of $202 million, whilst installing 4 wire electric fencing (approximate cost $4 per metre) would require in the region of $54 million. It should be recognised that this is both a conservative estimate of not only the financial cost of fencing the Region's rural streams, but also the wider implications of riparian management as this estimate does not include the cost of planting, loss of productive land and ongoing management.

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8 Appendix 1

ARC Riparian sample design evaluation by Brian McArdle (University of Auckland).

For weighted scores (0-14) and proportion fenced:

1) From the pilot study test differences between catchments, years, and sites and estimate variances within a year across sites within a catchment (and over catchments). Check for differences in variance between catchments.

The data were analysed using PROC MIXED in SAS. This allowed the variance of the surveyed segments of stream edges to be estimated despite the dependency between measures on the same places in sequential years.

No evidence of differences between catchments in their mean scores, or mean proportion fenced. Nor any for differences between years.

This analysis allows unequal variances for each catchments to be tested for. No evidence of this was found using any of the measures.

Weighted scores: 1KM sampling units.

So: The overall mean was estimated at 6.503 with a Standard error (estimated using PROC MIXED to allow for the within-site dependencies) of SE 1.001 df. 25.

The variance estimate for sites (1km units) was 28.72 with Standard error 7.27, 18 d.f.

Weighted scores: 500m sampling units

The overall mean was estimated at 6.504, SE. 0.7394.

Variance 31.35, SE 5.55, df 37

Notice the variance of the 500m units is only slightly larger than the 1km units. This suggests that the 500m units might be more efficient.

Proportion fenced: 1km units

Mean 0.5387, SE 0.068. df 51

Variance. 0.1334, SE 0.034.

Proportion fenced: 500m units

Mean 0.5487, SE 0.0407, df 51.

Variance. 0.1466, SE 0.0264 df 37

Again, the variance is only slightly larger for the smaller unit. Again suggesting that the 500m could be more efficient..

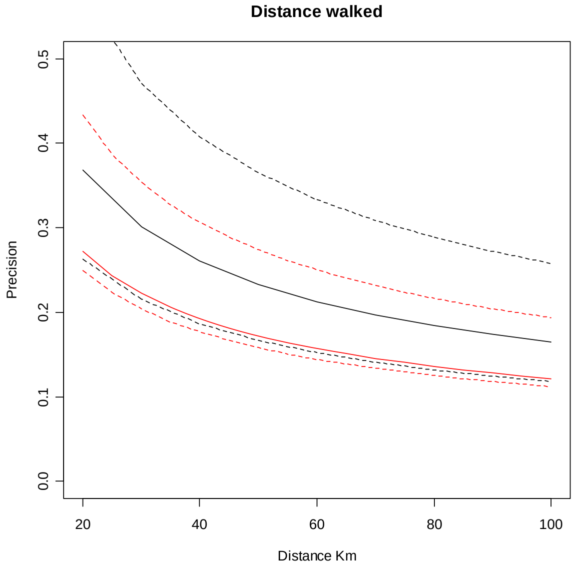
2) Calculate sample size versus precision relationships based on the pilot study error variance, and compare the 1km and the 500m sample units

Concerns with the Pilot study.

When calculating optimal/predicted sample sizes or power values we have to assume that the means and error variances are known. Sampling error in these estimates can be accommodated and the recommendations provided with some assessment of the risk of failing to achieve the desired precision or power. I have done this below by providing confidence limits on the predicted values. However there is no way to compensate for bias in the pilot study. If the samples taken in the pilot study do not represent the samples available for the main study, then it is unlikely that the estimated means and variances will be appropriate. Any recommendations based on them must be taken with a large pinch of salt. The data for the pilot study were collected in the dairy country of the Waikato; the main study on the 3 very different land use types of the Auckland Region. It must be born in mind the variation between samples in the Waikato could be very different from that in the main study. Some pilot samples from the main study area would have been of inestimable value. Without them the following calculations can only be regarded as rough guidelines as to what may happen in the main study.

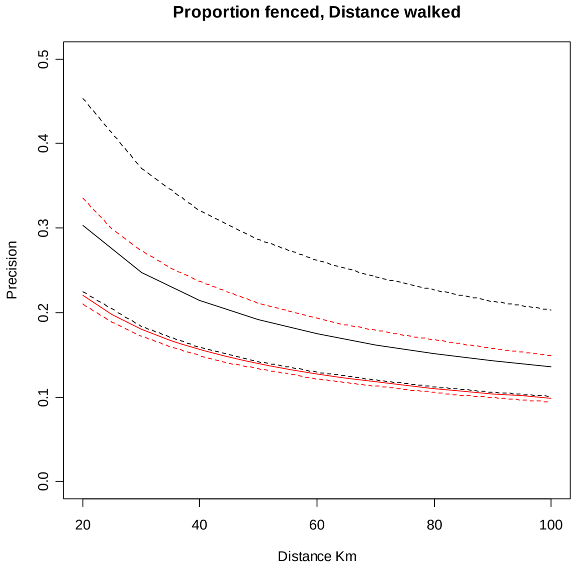
Sample size estimation for weighted scores.

The results are presented as the achievable precision for given distance walked. This allows the easy comparison of the efficiency of the 2 sample unit sizes (lkm and 500m). Precision is here defined as an inverse measure: the distance a 95% confidence interval extends from the mean as a proportion of the mean. Thus a value of 0.1 means that confidence intervals extend 10% of the mean on either side. So, the smaller the better. The dotted lines represent approximate 90% confidence intervals on the precision). The solid line represents the calculated value using the usual formula. Black is the 1km sample unit, red the 500m unit. Clearly for a given distance walked the 500m units are considerably more efficient. However the reliability of the precision estimates is poor. For example for a sample distance of 40km using 1km units we might expect confidence intervals that were about 22% of the mean on either side of the mean. However, the actual intervals that we got might plausibly be as big as 33% of the mean, or as small as 17%. The sampling error in the pilot study makes a more precise prediction impossible.



Proportion fenced

A similar analysis was performed for the proportion fenced. It is clearly easier to get a more precise estimate of this measure, and again the 500m unit is much more efficient.



3) Perform a power analysis for detecting change over 5 years.

Detecting change over 5 years

An experimental design based on 3 strata, 40 sample units per year per stratum, and 5 years was simulated. The starting means for the strata were identically the pilot study means, they were incremented linearly each year so as by the 5^{th} year they had increased by either 10%, 20%, 30% or 40%. The variances were from the analyses described above. Given the uncertainty in the means and variances, the sampling variation in those parameters was incorporated into the analysis so the result is a range of probabilities of detecting the given effect at the 5% level (the power) within which the actual power you achieve in your final study is likely to fall.

The Analysis

The analysis is assumed to be a two way ANOVA with the test of interest being a simple year effect. In the final analysis no doubt separate analyses will be performed on each stratum separately. Provided the assumptions of the two-way ANOVA are justified then these individual analyses should be performed as planned comparisons using the overall residual mean square as the error term. This will give considerable gains in power over performing individual one-way ANOVAs. If the assumptions of the two-way are not justified (e.g. there is considerable heterogeneity of variance) then the ANOVA should be performed using a Linear Mixed Model, e.g. using PROC MIXED in SAS, which adjusts for the unequal variances, and still allows the planned comparisons to be made.

Power Analyses

The power is calculated for the simple two-way ANOVA using the parameters reported above.

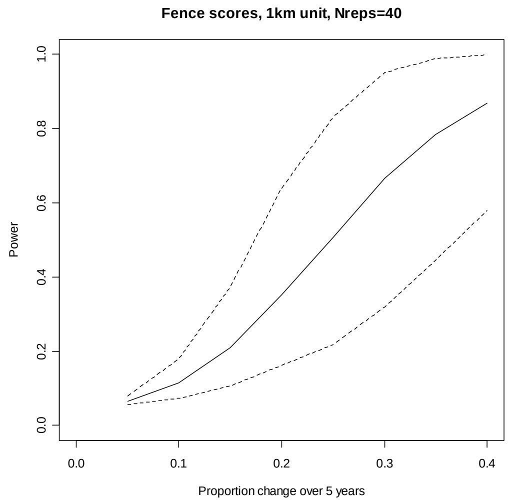
It is reported in the form of a graph indicating the power with which a given total increment in fencing (either as score or proportion) can be detected. For the 1 km units only a sample size of 40 per stratum per year is considered. For the smaller 500m unit sample sizes of 40, 60 and 80 are considered to show gains in efficiency over the larger unit.

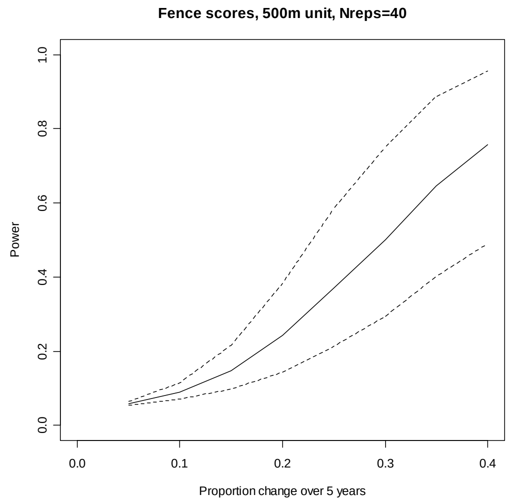
Fence Scores

Given that the 80 replicates of the 500m units is equivalent (at least in total distance if not in cost) it is interesting to see the gain in efficiency from using the smaller units. Roughly 60 (30km) of the smaller units are to be preferred over 40 (40km) of the larger. Depending on relocation costs and the problems associated with getting permissions to sample, and provided the sampling is genuinely random within each stratum within each year, then the smaller samples are clearly to be preferred.

Proportion fenced.

Once again, there is rough equivalence of the 40km of large units and the 30 km of 60 of the smaller ones


Fence scores, 1km unit, Nreps=40
Power
Proportion change over 5 years
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.1
0.2
0.3
0.4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Power
Proportion change over 5 years
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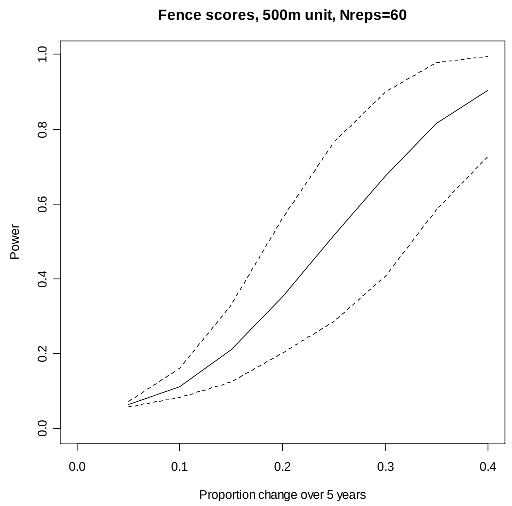
0.4
0.6
0.8
1.0
0.0
0.1
0.2
0.3
0.4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Power
Proportion change over 5 years
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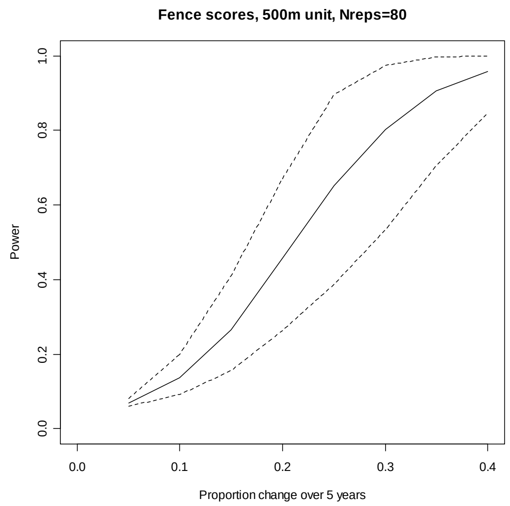
0.4
0.6
0.8
1.0
0.0
0.1
0.2
0.3
0.4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Power
Proportion change over 5 years
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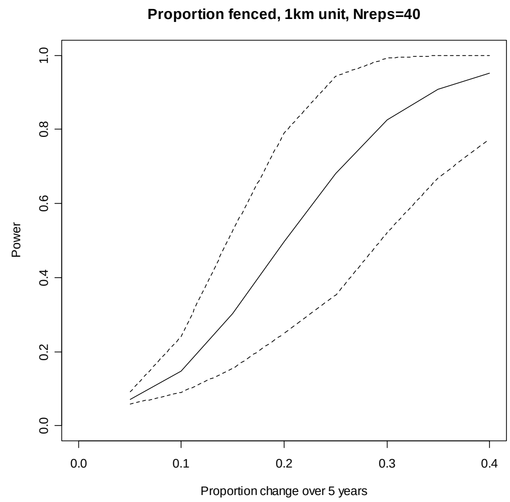
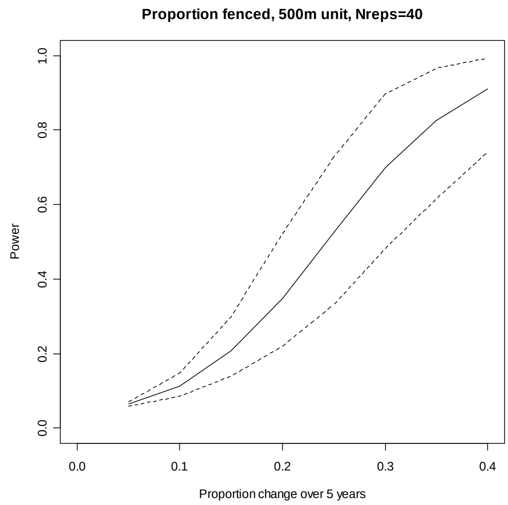
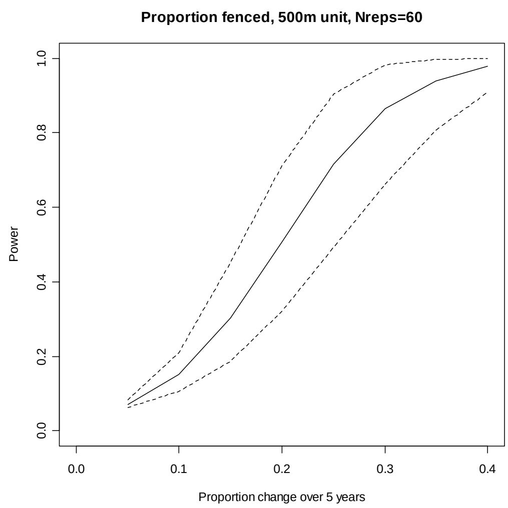
0.4
0.6
0.8
1.0
0.0
0.1
0.2
0.3
0.4


Proportion fenced, 1km unit, Nreps=40
Power
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.1
0.2
0.3
0.4
Proportion change over 5 years


Proportion fenced, 500m unit, Nreps=40
Power
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.1
0.2
0.3
0.4
Proportion change over 5 years


Proportion fenced, 500m unit, Nreps=60
Power
0.0
0.2
0.4
0.6
0.8
1.0
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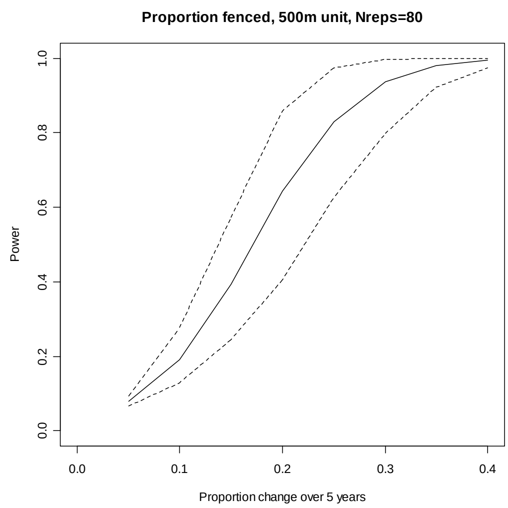
0.2
0.3
0.4
Proportion change over 5 years


Proportion fenced, 500m unit, Nreps=80
Power
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.1
0.2
0.3
0.4
Proportion change over 5 years

9 Appendix 2

9.1 GIS based site selection process

1. The REC streams and LCDB2 were overlayed using the ‘identity’ tool (similar to union) to attribute the REC lines with LCDB2 attributes.
2. REC streams from step 1 were cut to include only the pastoral LDCB2 classes 40 (high producing exotic grassland) and 41 (low producing grassland).
3. The pastoral REC streams identified from step 2 were then cut using a “soft geology” layer derived from the NZ Land Resource Inventory. This step effectively removed the hard geology Hunua (Greywacke) and Waitakere (Volcanic) areas from the dataset.
4. The product of step 3 was overlayed with layers derived from Agribase™ to identify streams in dairy and drystock land uses. Using the Agribase™ database farm types, DAI (dairy cattle farming) and DRY (dairy dry stock) were combined to form the dairy land use type and BEF (beef cattle farming), SHP (Sheep farming) and SNB (mixed sheep and beef farming) were combined to from the drystock land use type.
5. For drystock and dairy land use, all segments of REC streams greater than 500m that were inside a dissolved continuous area of dairy or drystock landuse were identified. This GIS layer was then exported to a table with attributes for each stream segment.
6. To identify rural residential land use type, the following rural zones used by the Territorial Local Authorities in Auckland were compiled into one GIS layer.
    a. General Rural
    b. Rural settlement
    c. Landscape Protection
    d. Countryside Living
7. Dairy or drystock areas identified in step 4 were excluded from the layer derived in step 6 to produce the rural residential land use type.
8. All segments of REC streams greater than 500m that were inside a dissolved continuous area of rural residential land use were identified using the layer from step 7. This GIS layer was then exported to a table with attributes for stream segment.
9. The required number of samples (60) for each land use type was then randomly determined from the GIS-derived tables.