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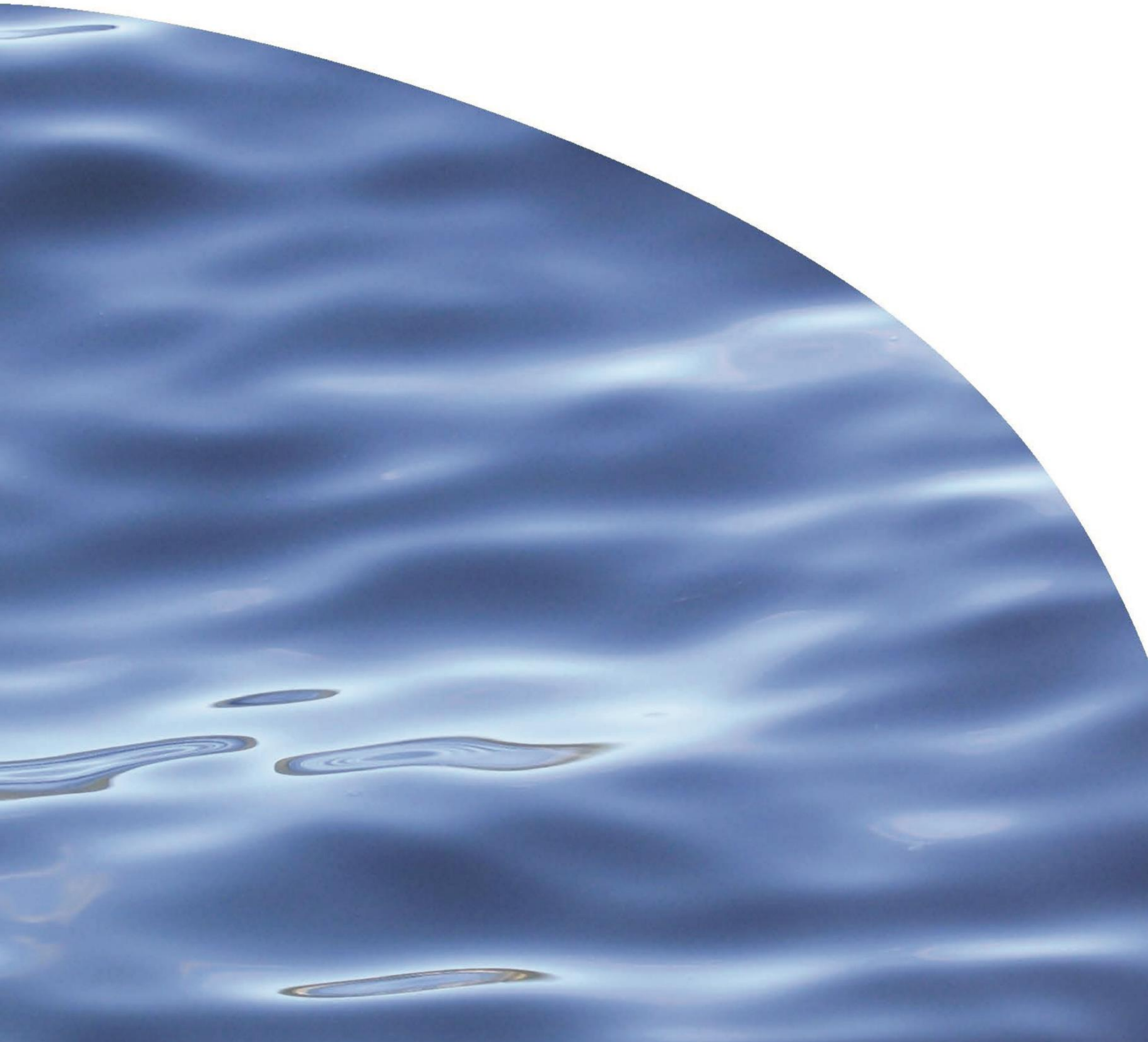
EFFECTS OF VARYING RIPARIAN MANAGEMENT PRACTICES ON INSTREAM HABITAT IN WAITUNA CREEK–IMPLICATIONS FOR MANAGEMENT



EFFECTS OF VARYING RIPARIAN MANAGEMENT PRACTICES ON INSTREAM HABITAT IN WAITUNA CREEK–IMPLICATIONS FOR MANAGEMENT

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Prepared for Department of Conservation / Fonterra Wetland Restoration Partnership

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EXECUTIVE SUMMARY

The general principles of 'good' riparian management are well established. However, in reality, managers and landowners are left with the onerous task of interpreting high-level generalised riparian management principles with respect to waterway-specific circumstances. For Waituna Creek (Southland) we addressed this issue by providing science-backed riparian management options for reducing fine sediment pollution and enhancing fish habitat. We investigated the response of structural instream habitat to different riparian management practices by using catchment-scale stream habitat data. Results were interpreted in relation to relevant stream habitat literature and the key characteristics of the Waituna catchment. Based on our findings we provide the following recommendations for the following ecological goals.

Reduction of fine sediment pollution:

1. Complete the network of stock exclusion fencing in Waituna Creek. This should be a priority for managing fine sediment pollution in the catchment — this action could result in reducing the total sediment load of Waituna Creek in the order of 50% (based on the length of stock exclusion fencing in 2014). However, increasing the fencing setback width beyond that necessary to exclude stock from the stream channel and protect riparian vegetation is unlikely to result in a detectable reduction in deposited instream fine sediment cover. Waituna Creek is characterised by a steeply entrenched channel and extensive under-field drainage rendering the riparian area ineffective at filtering fine sediment from overland flow.
2. Further planting of at least 1–2 m wide native grass riparian strips in 100 m (or longer) reaches in the upper catchment. Native grass strips (*e.g*. flax and *Carex*) along the bank edges were associated with reduced instream deposited fine sediment. The most ecological gains could be achieved through plantings around stream reaches which currently exceed 20% deposited fine sediment by less than 15% (i.e. reaches with less than 35% total fine sediment cover).

The protection / enhancement of fish habitat:

3. In the lower Waituna Creek, allow for 10 m fencing set banks (at least). Fence setbacks of 10 m or more (on both banks on average) were associated with improvements in residual pool depth and mesohabitat diversity (key fish habitat quality indicators). Taking the width of the entrenched channel into account, a 10 m setback equates to a fence setback of approximately 5 m from the bank / full channel edge. The space created by this set back would be wide enough to establish shrubs and trees in the riparian zone—see recommendation 4.
4. In the lower catchment, establishing shrubs and trees in riparian areas is likely to improve fish habitat. Areas of riparian shrubs and trees were associated with improvements in the following fish habitat quality indicators: residual pool depth, instream woody debris, undercut banks and overhanging vegetation.

Before implementing these recommendations careful consideration of how they will impact upon landowners and drainage management in the catchment is essential.

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1. INTRODUCTION

1.1. Background and aims

Working towards the environmental sustainability of New Zealand's agricultural industry, local communities are looking to develop effective riparian management plans for rivers and streams. However, an underlying theme of the riparian management literature is that management plans need to be catchment-specific, and furthermore, tailored to individual segments or reaches of streams. It is a resource-intensive exercise to develop bespoke riparian management plans that pay due diligence to all the factors that can influence the effectiveness of management options. A broad suite of structural, physico-chemical, biological and social variables need consideration (*e.g*. geomorphology, flow regimes, fish communities, drainage requirements, community values, *etc*.). Furthermore, habitat data are often not collected at the appropriate scale to inform riparian management plans. Consequently, despite voluminous reviews on the general principles of 'good' riparian management (*e.g*. Collier *et al*. 1995; Broadmeadow & Nisbet 2004; Quinn 2009) for the most part, managers and landowners are left with the onerous task of interpreting high-level generalised recommendations with respect to the specific circumstances of a waterway of interest.

In this report we address this problem by developing data-based riparian management recommendations for Waituna Creek.

The specific aims of this report are to:

- Identify how different riparian management practices affect adjacent and downstream structural instream habitat.

Use the outcomes from the above aim to:

- make recommendations regarding practical fencing setback widths and riparian management strategies to reduce deposited fine sediment cover,
- make recommendations regarding practical fencing setback widths and riparian management strategies to improve fish habitat.

In 2014, as part of the DOC / Fonterra Living Waters Programme, a community group[1] was assembled to collect the riparian and instream habitat data from streams draining the Waituna Catchment (Holmes *et al*. 2015). Stream habitat data were gathered using the Broad-scale Stream Habitat Mapping Protocol (BSHMP). This exercise generated 15 kilometres of riparian habitat data and 3.6 kilometres of instream

[1] Representatives from the following groups were included in the field mapping team: DOC, DairyNZ, Waituna farmers, Environment Southland, Fonterra, Te Ao Marama, Waituna Land Care Group, Southland Fish and Game.

structural habitat data. Habitat data were interpreted using indices of riparian and tuna (eel) habitat quality.

It was evident from the riparian habitat quality index scores that landowners in the Waituna catchment (primarily sheep and dairy farmers) have invested varying degrees of effort into managing the riparian area on their properties—thereby providing a gradient of riparian habitat quality within the catchment. In this report we investigated this gradient to identify potential links between riparian management practices and instream habitat quality. We then interpreted our findings in relation to the key catchment characteristics of Waituna Creek, and relevant stream habitat literature, to inform riparian management recommendations for the catchment.

Two broadly-framed hypotheses were tested when analysing the Waituna Creek habitat data. These hypotheses are based on the typical response of instream habitat to riparian management practices documented in the scientific literature (see Section 1.2 for a review):

Hypothesis (H_0) 1: Instream habitat in reaches within, or immediately downstream of, fenced and relatively wide riparian management areas (> 10 m on each bank) and / or areas with well-established riparian vegetation will have greater mesohabitat (run, riffle and pool) diversity, more stable banks, decreased widths, reduced deposited fine sediment levels, greater depths and increased amounts of instream fish cover relative to reaches with small or 'poorly' maintained riparian management areas (*i.e*. unfenced sections of stream with no riparian vegetation except pasture grasses);

H_0 2: the positive relationships between well-maintained riparian areas and instream habitat quality indicators will become stronger as the length of well-maintained fenced riparian area increases upstream of an instream survey reach (response variable).

To set the scene for this work, in the next two sections we briefly review the effects of agriculture on stream habitat structure, then provide a summary of the key catchment characteristics of Waituna Creek (that must be considered when interpreting our analysis of habitat data).

1.2. Agriculture, riparian management and structural stream habitat – a brief background

Agricultural development has resulted in degraded water quality and macroinvertebrate communities in the majority of New Zealand's lowland streams (Quinn *et al*. 1997; Quinn 2000; Larned *et al*. 2004). In addition, agriculture can cause conspicuous and ongoing changes to the structural habitat of streams through channelisation, the removal of riparian vegetation and macrophyte clearing (Quinn *et al.* 1992).

A key structural habitat change in streams within agricultural catchments is an increase in the amount of deposited fine sediment in the streambed (Allan 2004; Matthaei *et al*. 2006). This is caused by run-off from agricultural land and reduced bank stability as a result of vegetation clearance and livestock activity within a stream network (Trimble & Mendel 1995; Wood & Armitage 1999; Lyons *et al*. 2000).

Fine sediment homogenises stream habitat by reducing pool depth and smothering the stream bed. In turn, this reduces fish refuge areas during periods of low flow and the production of stream invertebrates—a key food source for fish (Duncan & Ward 1985; Wood & Armitage 1997; Allouche 2002; Sutherland *et al.* 2002). These changes can ultimately reduce the carrying capacity of a stream for fish (Waters 1995; Bjornn *et al.* 1977). Furthermore, fine sediment fills spaces within the stream bed substrate, spaces which provide cover for juvenile eels and other small fish (Raleigh *et al*. 1986; Glova *et al*. 1998; Glova 2002; Jowett & Richardson 2008).

In New Zealand, excluding livestock from the stream edge and re-establishing riparian vegetation underpins most rehabilitation projects (Parkyn *et al*. 2003; Dodd *et al*. 2009; Greenwood *et al*. 2012; Wahl *et al*. 2013). The potential benefits of establishing ungrazed riparian marginal strips are considerable (Quinn *et al*. 1997; Parkyn *et al.* 2003; Niyogi *et al*. 2007; Yuan *et al*. 2009; Wahl *et al*. 2013) and include:

- establishment of dense ground cover vegetation and more porous soils that filter fine sediment and particulate-bound contaminants from overland water flow,
- reduced nitrogen and phosphorus loading through degassing and assimilation into plant matter,
- reduced stream bank erosion through the establishment of protective vegetative ground cover and soil-binding root masses,
- reductions in stream temperatures and nuisance algal and macrophyte growths through shading,
- increased supply of terrestrial insects and leaf matter, and
- increased cover for fish through draping vegetation and the supply of debris to streams.

1.3. Catchment characteristics of Waituna Creek

The receiving environment of Waituna Creek is Waituna Lagoon. Waituna Lagoon is part of the wider Awarua Wetlands, which form one of New Zealand's few remaining (relatively) unmodified shallow coastal wetland systems. It has been afforded special conservation status as an internationally significant wetland under the Ramsar Convention (Stevens & Robertson 2007). Waituna Lagoon is a designated Scientific Reserve and is managed as such by DOC. Furthermore, the area is also culturally significant to Ngāi Tahu — a fact recognised under the Statutory Acknowledgment within the Ngāi Tahu Claims Settlement Act 1998.

1.3.1. Land use

The Waituna Lagoon has a catchment area of approximately 20,000 ha; the majority of which is intensively farmed. Land use includes arable, forestry, sheep / beef and dairy. Dairy farming in the catchment has doubled over the past 15 years. There are now in excess of 30,000 cows present in the catchment (McDowell *et al.* 2013).

1.3.2. Geology

Lignite underlies much of the Waituna catchment. The upper catchment geology, above the ‘upper and lower catchment split’ shown in Figure 1, is predominantly quartz gravels. The lower catchment is a mixture of quartz gravels and highly erodible mudstone or peat. Predominant soil types differ at roughly the same boundary with the upper catchment dominated by relatively well draining ‘brown’ soil and the lower catchment predominantly poorly draining ‘gley and podzol’ - based on the New Zealand Genetic Soil Classification classes (Appendices 1 and 2).

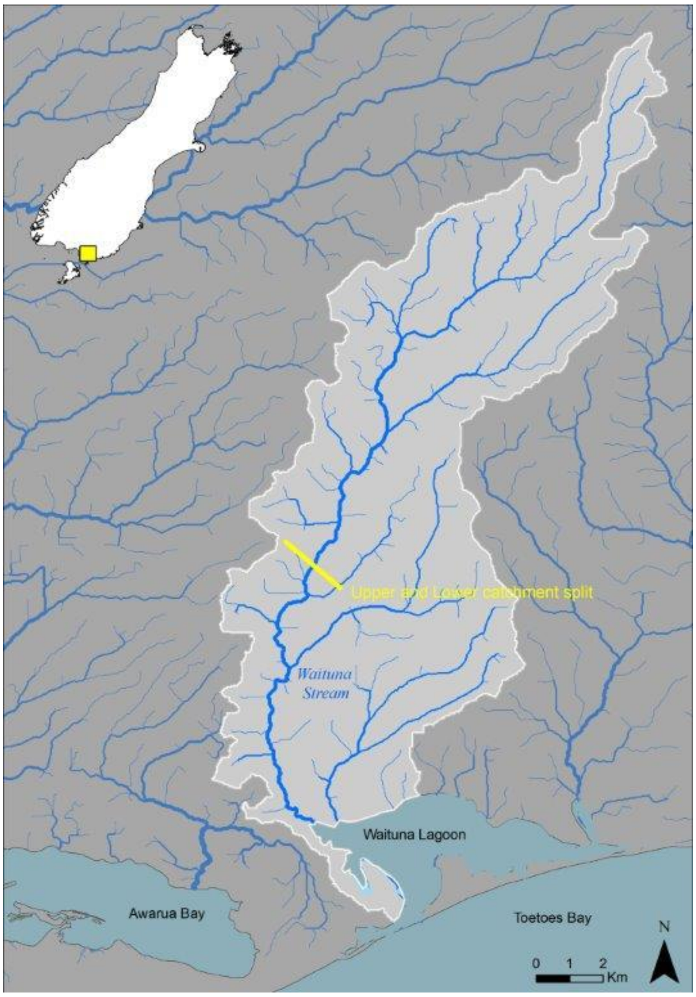

Figure 1. The Waituna Lagoon catchment (Southland, New Zealand). The Waituna Creek drainage area (our study stream) is highlighted in light grey. The yellow bar (centre) indicates an approximate boundary in the catchment where geology, average slope and channel engineering methods differ.

1.3.3. Stream flow and morphology

Three main streams drain the Waituna Lagoon catchment—Waituna, Carran and Moffat creeks. Waituna Creek contributes the majority of flow to the lagoon with a median discharge of 1.22 m^3/s. (The median discharges of Moffat Creek and Carran Creek are 0.196 and 0.385 m^3/s respectively). Waituna Creek has a low gradient, the average slope of the river segments in the upper catchment is 0.16 (rise / length), compared with the average slope of river segments in the lower catchment being 0.07.

Waituna Creek is generally shallow (99% of the creek is less than 1 m deep) and sluggish with steep, deeply incised banks (up to 3 m in places). ‘Slow run’ is the dominant mesohabitat type in the catchment (80%) with minor amounts of ‘fast run’ (11%) and ‘pool’ (8%). ‘Riffle’ habitat is rare, comprising just 1% of the wetted area of the stream (Holmes *et al*. 2015). The Waituna Lagoon tributaries contain a relatively diverse fish assemblage (12 species), with notable populations of tuna (eels) and giant kōkopu (*Galaxias argenteus*). Shortfin eels (*Anguilla australis*) are the more numerous species of tuna in the lagoon, whereas, longfins (*Anguilla dieffenbachii*) are dominant in the tributaries (Atkinson 2008).

1.3.4. Channel engineering and maintenance for drainage

Over the past century all the catchment's streams have been straightened and lowered throughout much of their length to facilitate drainage. In addition, mechanical clearing is undertaken routinely to remove deposited sediment and macrophytes (such as sweet-grass (*Glyceria fluitans*) and pondweed (*Potomogeton* spp)). Mechanical clearing is considered necessary to maintain the efficiency of under-field (mole and tile) farm drainage systems (Riddell *et al.* 1988). These management activities have resulted in a typical channel form shown in Figure 2. The highly modified deeply entrenched channel has resulted in extensive ongoing bank erosion (Figure 3).

Reducing sediment (and nutrient) loading in Waituna Creek is recognised as a key strategy to improve the state of the Waituna Lagoon (Robertson *et al.* 2011). A recent sediment source-tracking study in the lagoon's tributaries determined that the majority of the sediment budget in the catchment (between 64% and 94%) originates from eroding banks in Waituna Creek (McDowell *et al.* 2013). This result is in keeping with results from the 2014 Broadscale Stream Habitat Mapping Protocol (BSHMP) survey results which document extensive bank erosion, especially in unfenced areas of the mid-lower catchment (Holmes *et al*. 2015).

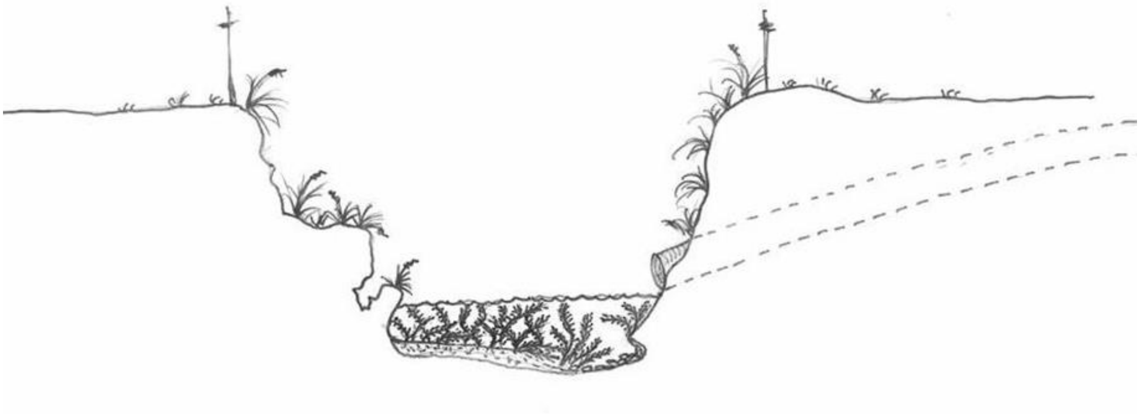

Figure 2. Schematic of a typical channel cross-section from the lower Waituna Creek. The stream has been lowered to facilitate the under-field pipe drainage (mole and tile) of the adjacent paddocks (not drawn to scale).

Figure 3. Waituna Creek (mid catchment) looking downstream. On the true left, mass failure of the bank (bank slumping), leading to fine sediment entering the stream, can be seen.

In contrast to the conspicuous bank erosion in the catchment, estimated specific sediment yields of the three main tributaries of Waituna Lagoon are among the lowest recorded for all New Zealand streams. The sediment yield of Waituna Creek is similar to low gradient native bush catchments (Meijer 2011). Waituna, Moffat and Carran Creek contribute 111, 122 and 71 kilograms of sediment per hectare per year to the specific yield in the catchment respectively (Meijer 2011). A report by Diffuse Sources Ltd and NIWA (2012) highlights that preliminary sediment load estimates for the catchment are 40 times less than that needed to explain the observed sediment deposition rates in Waituna Lagoon. Predicted sediment deposition rates from tributary inputs are 0.075 mm/yr, which is at odds with the observed Lagoon deposition rate of 2.8 mm/yr. It is possible that the significance of coastal sediment sources have been overlooked (Diffuse Sources Ltd & NIWA 2012). Alternatively, episodic sediment pulses may be occurring after drain-cleaning events that disturb the stream bed (Greer *et al*. unpublished data). These events may not have been captured in the monitoring data used to inform the sediment load model.

Despite the apparently low sediment yields of the Lagoon tributaries, eroding banks in Waituna Creek are still perceived to contribute to deposited sediment and sediment-bound contaminant loading in the Waituna Lagoon. To address this issue Environment Southland (ES), with funding from the Ministry for the Environment's 'Fresh Start for Fresh Water Clean-up Fund', has undertaken extensive bank reconstruction works (reshaping) in Waituna Creek (Draft Waituna Plan 2015). Reshaping reduces the angle of the stream bank to decrease the occurrence of bank slumping and scour erosion (Figure 4).

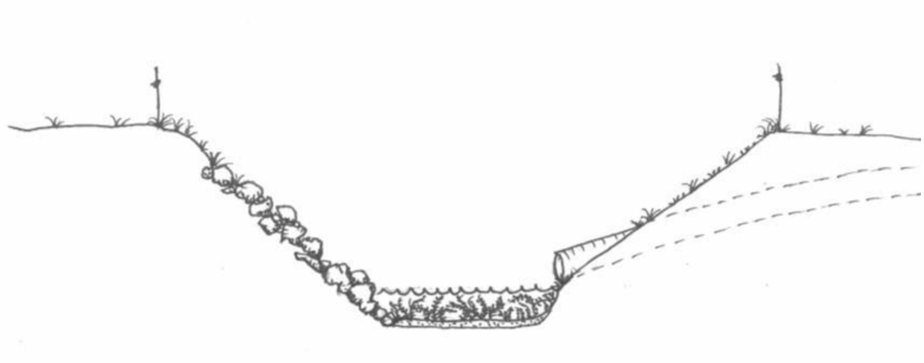

Figure 4. Schematic of a channel cross-section from Waituna Creek in an area that has been subjected to bank reshaping. Schematic shows rock rip-rap (left bank) which has been put in place at selected inside bends of the stream to prevent scour erosion (not drawn to scale).

The bank re-shaping work is scheduled to be completed along approximately 13 kilometres of Waituna Creek before 2016 (Draft Waituna Plan 2015). Some of the re-shaping work in the mid–lower Waituna Creek was recently completed prior to obtaining the survey data used in the analysis of this report (at segments 3A, 3B and 3H, see Figure 6 in Section 2.1).

Work to assess the ecological impact of the bank reshaping in Waituna Creek is ongoing. Preliminary results show that bank edge cover is significantly reduced immediately after the bank reshaping work. In addition, the biomass of longfin eels was reduced in the reshaped reaches in the following year, possibly as a result of the reduction of bank edge cover (unpublished quantitative fish population data collected by the lead author). One of the three impact and three control sites used in this on-going study are shown in Figure 5 (left and right respectively).

Figure 5. Fish population survey sites (from an annual survey initiated in March 2014) showing a recently re-shaped channel (impact site - left) and an area of stream that has not been subjected to channel engineering for at least 5 years (control site—right).

1.3.5. Key catchment characteristics summary

The key catchment characteristics of Waituna Creek, that need to be taken into account when interpreting the effects of riparian management practices are listed below.

- The creek drains intensive dairy and sheep / beef farmland into a high-value coastal lagoon / wetland complex that is vulnerable to sediment and nutrient loading

The creek has

- A very low gradient with low flood power
- A low sediment yield
- Banks that are highly prone to erosion (bank slumping)
- An entrenched channel (up to 3 m in places)
- Low mesohabitat diversity - predominantly slow run
- A high proportion of shallow water (99% of the stream is < 1 m deep)
- Poorly draining peat and quartz gravel geology in the lower catchment
- Mostly quartz gravels in the upper catchment
- An intensively engineered channel shape throughout much of the streams length - especially in the lower catchment
- An extensive network of under-field (mole and tile) drains
- A tendency to develop excessive macrophyte growths that required removing to ensure the efficiency of under-field drains
- A diverse fish community with notable populations of giant kōkopu and longfin eel which are classified as 'at risk in decline' (Goodman *et al.* 2013)
- A relatively low amount of bank edge fish cover as a result of bank reshaping.

2. METHODS

2.1. Stream habitat data collection

The Broad-scale Stream Habitat Mapping Protocol (BSHMP) methodology (Holmes & Hayes 2011) was used to collect catchment-scale instream and riparian habitat data from the Waituna Lagoon tributaries: Waituna Creek, Moffat Creek and Carrans Creek. The survey was undertaken from 26 to 30 March 2014 during summer low-flow (base-flow) conditions. This survey method focuses solely on gathering structural stream habitat information. It is intended to complement analyses of flow and physicochemical data from a catchment. For a description of the application of this survey to the Waituna Lagoon tributaries and interpretation of the data using riparian and longfin tuna habitat quality indices see Holmes *et al*. (2015). For background on the BSHMP methodology see proof-of-concept reports: Holmes & Hayes 2011, Holmes *et al.* 2012 and Holmes *et al.* 2013.

In brief, representative survey segments (1,000 m long) are picked at random from catchment strata identified during the desktop analysis. The BSHMP is split into two stages at each survey segment:

- Stage 1: Riparian features and potential contaminant sources are surveyed over the entire 1,000 m segment
- Stage 2: In-stream habitat features are surveyed in three 100 m reaches that are nested within each 1,000 m segment—each 100 m reach is split into five continuous 20 m sub-reaches for ease of data collection.

Figure 6 shows an aerial photograph mosaic of the Waituna Lagoon catchment and the locations of the various BSHMP survey sites.

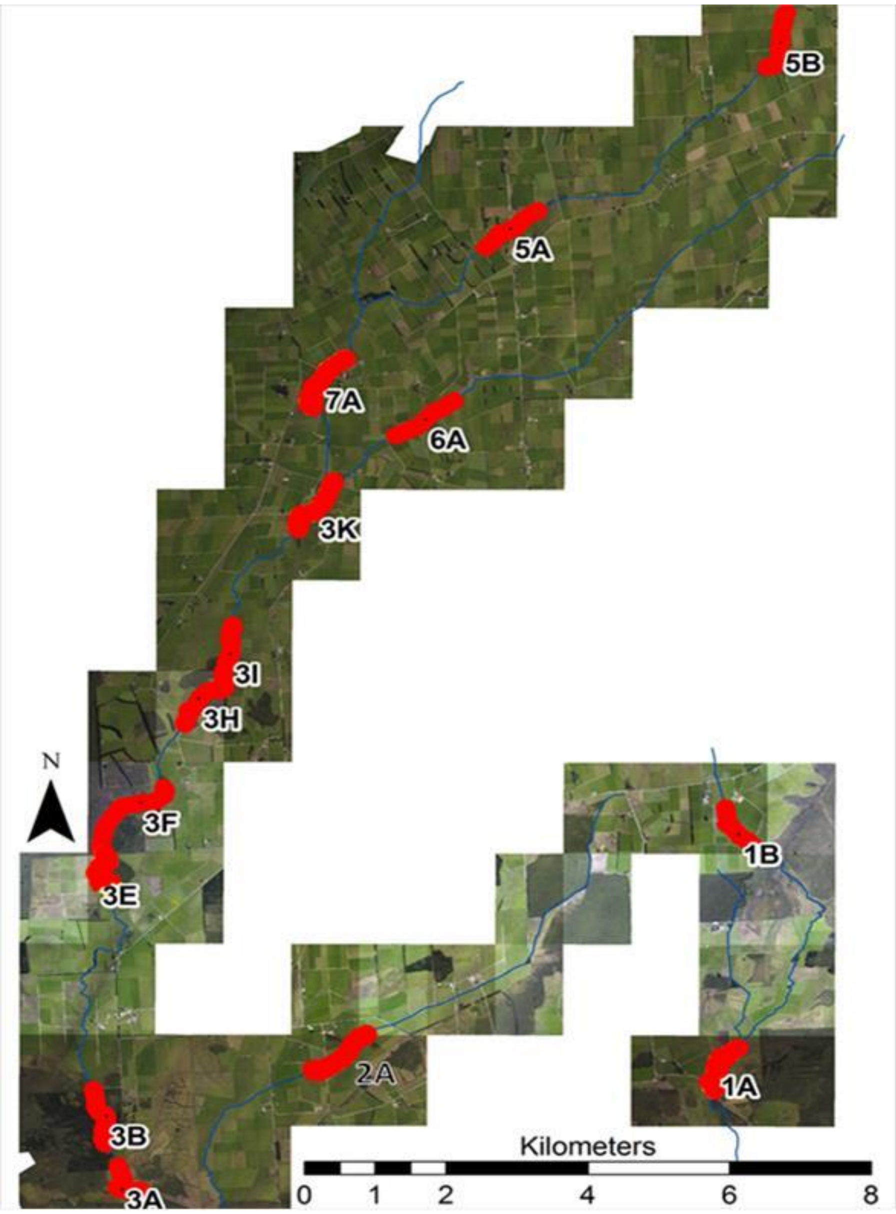

Figure 6. Waituna Lagoon catchment showing the locations of the broad-scale habitat mapping survey sites (red bars) in Waituna Creek (left), Moffatt Creek (middle) and Carran Creek (right). Streams flow from north to south.

2.1.1. Riparian survey component

Information recorded in the riparian survey included:

- Extent of the fenced riparian management areas
- Degree of stock access to the stream edge
- Broad category types of riparian vegetation (*e.g*. exotic grass, mixed native and exotic grasses and shrubs)
- Locations / areas of trees

- Land-use management features (such as stock crossing)
- Potential contaminant sources (*e.g.* bank slumping and stock pugging).

2.1.2. Instream survey component

Information recorded during the instream survey included:

- Percentage cover of meso-habitat types (*e.g.* riffle, run, pool)
- Percentage cover of depth categories (0–0.3 m, 0.3–0.5 m, 0.5–1 m and > 1 m)
- Percentage cover of nuisance algae (> 3 mm thick) and sediment particle size categories (according to the Wentworth (1922) sediment classification scale)
- The area (m^2) of various fish cover features (*e.g*. undercut banks, overhanging vegetation, woody debris).

An example of the field instructions for the riparian component of the survey and an instream data collection sheet are shown in Appendices 3 and 4 respectively.

2.2. Statistical analyses

Only habitat data from Waituna Creek were analysed (because of lack of sample size in the other two tributaries). There are substantial differences in flow, geology and soil types between the upper and lower catchment. These variables have the potential to affect how the riparian environment influences stream condition. Therefore, habitat data were split into upper and lower catchment areas before analysis. Downstream of site 3F (inclusive) was termed lower catchment and upstream of site 3F termed upper catchment (Figure 6).

Riparian habitat data were digitised by scanning and ortho-rectifying the ground-truthed aerial photographs within ArcView GIS version 10.1. All habitat information was then transferred to GIS by creating shape files of the hand-drawn information. Information about each habitat feature was transferred to attribute tables for each shape file. The twelve (1000 m) survey segments were divided into 100-m longitudinal 'GIS-Defined Riparian Zones' (GDZ), each with a 30-m-wide area either side of the stream to encompass all riparian habitat features. All GDZ had small differences in length and area depending on the sinuosity of the channel (*i.e*. a GDZ would be slightly smaller if it included tight bends in the stream channel, or larger if it included areas at the extreme end of a survey segment and thus gained extra length).

The areas of riparian features were calculated in GIS, to be used as inputs for regression modelling against instream habitat variables. All instream habitat data were converted to total areas or mean percentage area cover of the wetted area for each 100 m reach to standardise the measurements before being used as a response variable. An area-weighted riparian vegetation quality index (vegetation quality index) was calculated by weighting vegetation category types, defined in the BSHMP. Broadly, this index weighted riparian vegetation according to its successional stage from ungrazed rank-pasture grass to swampy vegetation or mature multi-storied canopies. Category weightings were as follows: mixed exotic grass (*1), mixed native and exotic grasses (*2), mixed native and/or exotic shrubs and grasses (*3), swampy and/or emergent mixed native and exotic grasses and herbs (*4), mature trees with understory vegetation (*5).

Statistical analysis was undertaken using R statistical software. Variables were transformed as appropriate for statistical modelling – logit transform (where logit(p) = log(p/(1-p)) for percentage (proportion) data, and log transform for count and other right-skewed data. Kendall Tau correlation allowed for any remaining non-linearity, such as threshold responses, to be tolerated in the relationships being investigated.

After matching instream habitat survey reaches with their corresponding GDZ, exploratory analyses were undertaken by constructing linear regressions for all measured riparian predictor variables (transformed if appropriate) against each instream variable. First the mean of all data available for a given riparian variable at each survey segment was regressed against the combined mean for an instream habitat variable from all three instream survey reaches within the survey segment. In this analysis, we assumed that the three instream survey reaches, which were randomly nested within each riparian survey segment, were representative of the instream habitat within the entire segment.

To investigate the effect of scale on potential relationships between riparian and instream habitat we repeated the riparian vs. instream regression analysis including only the mean values for the riparian variables for 500 m upstream of each of the instream reaches (*i.e*. the values from five continuous GDZ). For this analysis our sample size was reduced because some instream habitat reaches were positioned less than 500 m downstream of the upstream end of a riparian survey segment. These reaches were excluded from the analysis. A third ‘reach scale’ regression analysis was undertaken comparing the instream habitat variables with riparian variables in the immediately adjacent GDZ.

For the following variables: residual pool depth, woody debris, undercut banks, overhanging vegetation, bank slumping, fine sediment and shuffle test score,[2] we conducted a series of 10 linear regression analyses that incrementally included the fenced riparian area (or vegetation quality, mixed exotic grass or mixed grass and shrubs) of incrementally more upstream GDZ. Starting at 100 m (reach scale), the

[2] The shuffle test provides an indication of how much fine sediment is present in the gravel matrix of the stream substrate

fenced riparian area from the adjacent GDZ is used as the predictor value. For each subsequent regression, the mean fenced riparian areas of continuous GDZ were incrementally included (*i.e*. ≤ 200 m upstream, ≤ 300 m upstream *etc*.). The instream habitat reaches were located randomly within the riparian survey segments. Sample size was reduced as more GDZ were incrementally included in subsequent regressions—if an instream habitat reach was near the top of a segment, riparian data would not be available beyond a certain distance.

In a separate analysis, we used a general linear model to investigate the relationship between metres of bank slumping and metres stock fencing using all available data in the catchment (excluding the recently reshaped reaches).

3. RESULTS AND DISCUSSION

In this section we present results from our exploratory regression analysis at three different spatial scales (reach: 100 m; sub-segment: 500 m; and stream segment: 1000 m). We also discuss the incremental regressions of selected significant relationships. Results are presented for the upper and lower catchment separately. Because we performed a large number of individual regressions at the various different spatial scales (*i.e*. > 400 regression in total) only relationships of interest are shown (*i.e*. those that relate to our first hypothesis— see Section 1.1).

An important caveat of our regression results is that they are based on correlative analysis. This means that we cannot confirm causation between the variables assessed. However, the results are interpreted in relation to our first hypothesis, which is based on established riparian and instream habitat relationships demonstrated in the scientific literature.

3.1. Upper catchment

3.1.1. The effect of the area of stock exclusion fencing

In the upper catchment, the category 'fenced area' was negatively correlated with bank slumping at the sub-segment scale (Table 1). Sequential regressions revealed significant negative correlations between these variables when the riparian area of the adjacent reach (*c.*100 m) through to *c.* 700 m upstream were included in the regressions (Appendix 5). In all regressions, the relationship shape shows a sudden decline in the amount of bank slumping with a minimal increase in fenced area (Figure 7, Appendix 5). This indicates that most of the bank stabilisation benefit occurs with the first metre (width) of stock exclusion fencing.

Table 1. Selected correlations from an exploratory regression analysis of all riparian and instream habitat variables from the upper catchment. Regressions were undertaken at three scales: 100 m reach scale—where instream variables were regressed against riparian variables from the adjacent 100 m GIS-defined riparian zone (GDZ) (n = 21); 500 m sub-segment scale—where instream variables were regressed against mean riparian variables over five 100 m continuous GDZ upstream (n = 9); and 1000 m segment scale - where mean instream variables from all three 100-m instream habitat reaches within a 1000 m riparian survey segment were regressed against mean riparian variables from all of the GDZ in that riparian survey segment (n = 7). The 1000 m scale regressions assume that habitat in the three instream reaches were representative of a 1000 m segment. Only results that relate to our hypotheses, and were significant (*P* = < 0.05) at least one of the scales investigated, are shown.

Upper catchment	Area of stock exclusion fencing					
Upstream area of response variable	100m	100m	500m	500m	1k	1k
P-value and relationship direction	*P*	+/-	*P*	+/-	*P*	+/-
Mesohabitat diversity	-	-	0.02	Positive	-	-
Residual pool depth	-	-	0.01	Positive	0.03	Positive
Undercut bank length (0.3-0.5 m)	-	-	-	-	-	-
Overhanging vegetation	-	-	-	-	-	-
Bank slumping	-	-	0.01	Negative	-	-
Fine sediment	-	-	-	-	-	-
Shuffle test score	-	-	-	-	-	-
	Area of exotic grass					
Mesohabitat diversity	-	-	-	-	-	-
Residual pool depth	0.00	Positive	0.00	Positive	-	-
Undercut bank length (0.3-0.5 m)	-	-	-	-	-	-
Overhanging vegetation	-	-	-	-	-	-
Bank slumping	-	-	0.00	Negative	-	-
Fine sediment	-	-	-	-	-	-
Shuffle test score	-	-	-	-	-	-
	Area of grasses and shrubs					
Mesohabitat diversity	-	-	0.03	Positive	-	-
Residual pool depth	-	-	-	-	-	-
Undercut bank length (0.3-0.5 m)	-	-	-	-	-	-
Overhanging vegetation	-	-	-	-	-	-
Bank slumping	-	-	-	-	-	-
Fine sediment	-	-	-	-	-	-
Shuffle test score	-	-	-	-	-	-
	Area of mixed native and exotic grasses					
Mesohabitat diversity	-	-	-	-	-	-
Residual pool depth	-	-	-	-	-	-
Undercut bank length (0.3-0.5 m)	-	-	0.04	negative	-	-
Overhanging vegetation	-	-	-	-	-	-
Bank slumping	-	-	-	-	-	-
Fine sediment	-	-	0.00	Negative	0.04	Negative
Shuffle test score	0.03	Negative	0.01	Negative	-	-

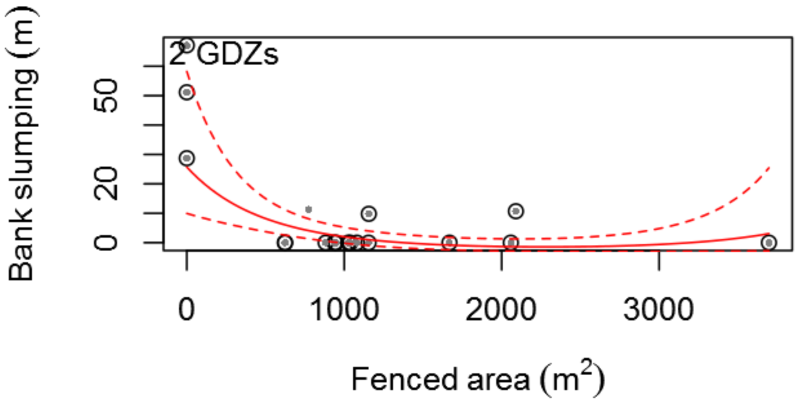

Figure 7. Significant negative correlation (Kendall Tau $P < 0.05$) between the amount of bank slumping (m) and the area of stock exclusion fencing (m^2) in the upper catchment. Plot shows the second regression in a sequence of 10 based on averages from upstream areas in *c.* 100 m increments (full set of 10 plots are shown in Appendix 5).

Contrary to our first hypothesis, the amount of deposited fine sediment and shuffle test score (an indication of how much fine sediment is present in the gravel matrix of the stream substrate) was not significantly correlated with fenced area. This indicates that fenced area does not have a strong effect on instream deposited fine sediment levels in adjacent or downstream reaches (*i.e*. up to 1,000 m downstream). In addition, our analysis suggests that riparian area in the upper catchment does not have a strong positive effect on mesohabitat diversity or residual pool depth (two key fish habitat quality indicators). Although there were positive relationships between fence area and these instream variables (Table 1), incremental regression analysis revealed that these relationships were not consistent (relationships not shown).

3.1.2. The effect of riparian vegetation type

The area of exotic (ungrazed) grass was positively correlated with residual pool depth at the reach and sub-segment scale (Table 1). Incremental regressions revealed the relationship between these two variables was significant, or close to significant, when the riparian area of the adjacent reach (*c.* 100 m) through to *c.* 800 m upstream was included in the regression analysis (Appendix 6).

The vegetation quality index was not significantly correlated with any instream habitat variables in the upper catchment. However, the area of mixed native and exotic grasses was negatively correlated with undercut banks at the sub-segment scale. In addition, mixed native and exotic grasses were also negatively correlated with fine sediment and shuffle test score (Table 1, Figures 8 and 9), incremental regressions of these relationships are shown in Appendices 7 and 8 respectively.

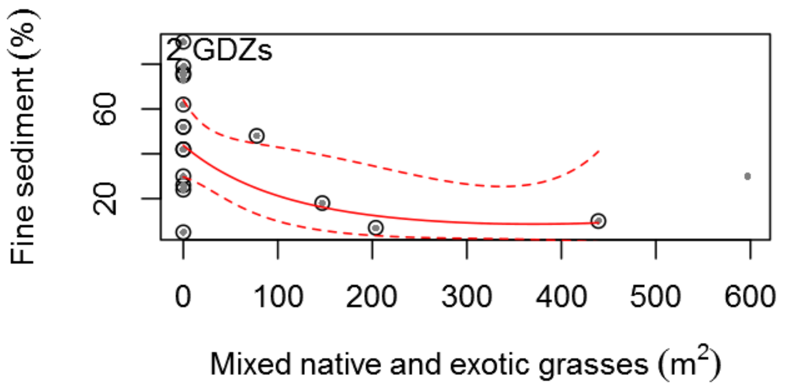

Figure 8. Significant negative correlation (Kendall Tau $P < 0.05$) between the % fine sediment cover of the stream bed (< 2 mm partial size) and the area of mixed native and exotic grasses (m^2) in the upper catchment. Plot shows the second regression in a sequence of 10 based on averages from upstream areas in *c.* 100 m increments (full set of 10 plots are shown in Appendix 7).

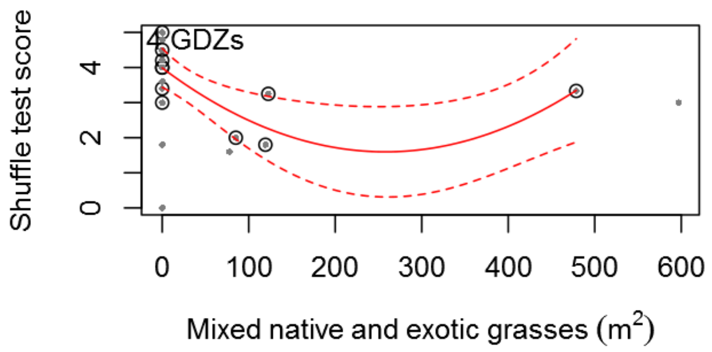

Figure 9. Significant negative correlation (Kendall Tau $P < 0.05$) between the average shuffle test score (on a 1–5 scale) and the area of mixed native and exotic grasses (m^2) in the upper catchment. Plot shows the fourth regression in a sequence of 10 based on averages from upstream areas in *c.* 100 m increments (full set of 10 are shown in Appendix 8).

These results show that, in the upper catchment, there were relatively low levels of deposited fine sediment in reaches where areas of native grasses were present (*e.g. Carex* and flax). Native grasses such as flax may be narrowing the channel and increasing the flushing power of the stream (Greenwood *et al*. 2012). Alternatively, the relatively large root masses of native grasses may stabilise the banks in the upper catchment. This would result in lower sediment inputs into the stream through reduced bank erosion. All the highest fine sediment values and shuffle test scores occurred in areas where no native grasses were present (Figures 8 and 9). If the relationship is causal, then even small areas of native grasses (*i.e*. in the order of 100 m^2 / 100 m of stream length) may have a positive influence on the instream habitat (Figures 8 and 9).

3.2. Lower catchment

3.2.1. The effect of the area of stock exclusion fencing

In support of our first hypothesis, the fenced area was positively correlated with residual pool depth at the sub-segment scale (Table 2, Appendix 9). Contrary to our hypothesis, there was no detectable influence of fenced area on fine sediment or shuffle index score (Table 2). The disturbance regimes in the lower catchment, as a result of floods and / or channel engineering, have the potential to obscure any influence of the riparian zone on deposited fine sediment dynamics in this part of the stream (at least up to the segment scale).

Table 2. Selected correlations from an exploratory regression analysis of all riparian and instream habitat variables from the lower catchment. Regressions were undertaken at three scales: 100 m reach scale - where instream variables were regressed against riparian variables from the adjacent 100 m GIS defined riparian zone (GDZ) (n = 15); 500-m sub-segment scale—where instream variables were regressed against mean riparian variables over five 100 m continuous GDZ upstream (n = 9); and 1000-m segment scale—where mean instream variables from all three 100 m instream habitat reaches within a 1000 m riparian survey segment were regressed against mean riparian variables from all of the GDZ in that riparian survey segment (n = 5). The 1000 m scale regressions assume that habitat in the three instream reaches were representative of a 1000 m segment. Only results that relate to our hypotheses, and were significant or close to significant (*P* = < 0.06) at least one of the scales investigated, are shown.

Lower catchment	Area-weighted vegetation quality index					
Upstream area of response variable	100m	100m	500m	500m	1k	1k
P-value and relationship direction	*P*	+/-	*P*	+/-	*P*	+/-
Mesohabitat diversity	-	-	-	-	-	-
Residual pool depth	0.02	Positive	0.00	Positive	-	-
Woody debris	0.00	Positive	0.00	Positive	-	-
Undercut bank length (0.3-0.5 m)	0.06	Positive	0.06	Positive	-	-
Overhanging vegetation	0.02	Positive	0.02	Positive	-	-
Bank slumping	-	-	-	-	-	-
Fine sediment	-	-	-	-	-	-
Shuffle test score	-	-	-	-	-	-
	Area of stock exclusion fencing					
Mesohabitat diversity	-	-	-	-	-	-
Residual pool depth	-	-	0.00	Positive	-	-
Woody debris	0.03	Positive	0.01	Positive	-	-
Undercut bank length (0.3-0.5 m)	-	-	-	-	-	-
Overhanging vegetation	-	-	0.05	Positive	-	-
Bank slumping	-	-	-	-	-	-
Fine sediment	-	-	-	-	-	-
Shuffle test score	-	-	-	-	-	-
	Area of exotic grass					
Bank slumping	-	-	-	-	0.05	Negative
Fine sediment	-	-	-	-	-	-
Shuffle test score	-	-	-	-	-	-
	Area of grasses and shrubs					
Bank slumping	-	-	0.01	Positive	-	-
Fine sediment	-	-	-	-	-	-
Shuffle test score	-	-	-	-	-	-

3.2.2. The effect of riparian vegetation type

The area-weighted vegetation index (vegetation quality index) was positively correlated with the following key fish habitat quality indicators: residual pool depth, instream woody debris (Table 2, Appendices 11 and 12 respectively), undercut banks and overhanging vegetation (Table 2). Individual relationships from the sequenced regressions for residual pool depth and woody debris regressed against the vegetation quality index are shown in Figures 10 and 11 below (respectively).

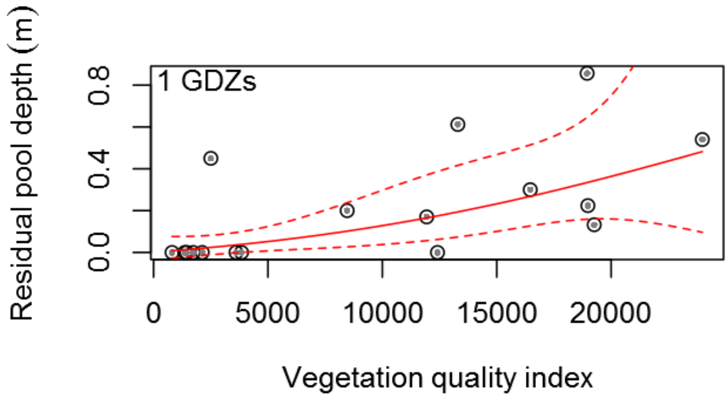

Figure 10. Significant positive correlation (Kendall Tau $P < 0.05$) between residual pool depth (m) and the area-weighted riparian vegetation quality index in the lower catchment. Plot shows the first regression in a sequence of 10 based on averages from upstream areas in *c.* 100 m increments (full set of 10 are shown in Appendix 10).

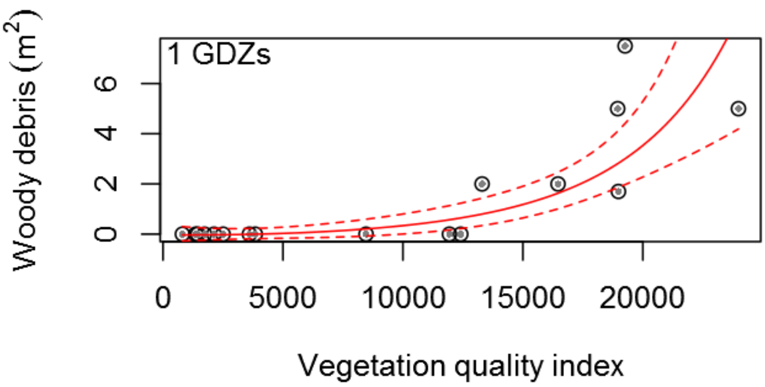

Figure 11. Significant positive correlation (Kendall Tau $P < 0.05$) between woody debris (m^2) and the area-weighted riparian vegetation quality index in the lower catchment. Plot shows the first regression in a sequence of 10 based on averages from upstream areas in *c.* 100 m increments (full set of 10 are shown in Appendix 11).

Shrubs and trees and their displaced root-wads and branches would create hydraulic diversity within the largely entrenched channel of the lower river (especially during high flow events). This may encourage channel meandering in Waituna Creek leading to bank undercutting and scouring. This in turn would lead to deepening of pools and ultimately pool-riffle sequence formation. Mesohabitat diversity showed a positive trend with increasing vegetation quality (at the reach scale) lending some support to this interpretation of the results (Appendix 12). Alternatively, the observed relationships may be the result of natural channel evolution since the last channel engineering event—irrespective of any effect of riparian vegetation. If straightened streams are not subjected to channel engineering they have a natural tendency to form meanders over time (Rosgen 1994).

We could not include ‘time since channel re-shaping’ as a predictor in the regression modelling because this information was not available. Riparian vegetation would be more developed in reaches that have not been subjected to channel engineering for a longer period of time. With the available data we cannot determine which of the above potential mechanisms caused the observed relationships. Nevertheless, it is clear that not reshaping the banks for long enough to allow shrubs and trees to develop has potential to improve key fish habitat quality indicators.

3.3. Spatial scale of significant responses

In both the upper or lower catchment we found little support for our second hypothesis: that any relationships between ‘well-maintained’ riparian areas and instream habitat quality will become stronger as the length of well-maintained riparian area upstream of ‘response’ reach increases. Relationships were generally strongest between the riparian predictor variable and the instream response variable in the adjacent reach (*i.e*. 100 m). This indicates that the response of the instream environment to any riparian management actions, based on the relationships found in this study, should be strongest at the reach scale (*i.e*. 100 m).

3.4. Summary of results

Overall, the results from our regression analyses suggest that:

1. A minimal area of stock exclusion fencing corresponds to a large reduction in bank slumping (this relationship is explored further in Section 3.4.1).
2. In the upper catchment, relatively small areas of native grasses within the riparian zone were associated with reduced deposited and intra-gravel fine sediment in adjacent and downstream reaches.
3. In the lower catchment, shrubs and trees in the riparian zone were significantly positively correlated with a range of fish habitat quality indicators, including residual pool depth, woody debris, undercut banks and overhanging vegetation.
4. In both the upper and lower catchment, relatively large fenced areas were not correlated with deposited fine sediment or shuffle test score.

5. Relationships were generally strongest between the riparian predictor variable and the instream response variable in the adjacent reach (*i.e*. 100 m).

The elements of our first hypothesis that were supported by the regression analyses are shown in Table 3.

Table 3. Summary of the elements of our first hypothesis which were supported by the regression analysis of riparian and instream habitat data. Ticks indicate variables present within or immediately downstream of fenced and/or wide riparian management areas.

Instream habitat variable	Upper Waituna Creek	Lower Waituna Creek
Greater mesohabitat diversity	—	—
Reduced deposited fine sediment	✓	—
Greater depths	✓	✓
More fish cover	✓	✓
More stable banks	✓	—
Decreased widths	—	—

4. RIPARIAN MANAGEMENT RECOMMENDATIONS

Regional councils and the dairy industry are now encouraging riparian planting in addition to fencing as part of farm management plans. The challenge for scientists and managers is to provide practical recommendations that can direct how wide fenced areas should be—and what should be planted within them. Without these recommendations, fencing and planting projects risk devoting too little land to the riparian area and thus failing to protect instream values, or ‘sacrificing’ too much land at a cost to on-farm production. However, there are a variety of factors that can influence the effectiveness of fencing and riparian planting as a mitigation strategy. In the following sections we interpret our regression analyses in relation to riparian management literature and the key characteristics of the Waituna Catchment (identified in Section 1.3.5) to develop fencing and riparian planting management recommendations.

4.1. The effect of fencing on one bank only

Of the survey segments within dairy farms, 100% had stock exclusion fencing on both banks. This fencing effort has significantly reduced bank erosion in the catchment (Holmes *et al*. 2015). However, there are still substantial stretches of stream (*i.e*. kilometres) where stock can access the stream edge in areas with stock exclusion fencing on one bank only (Figure 12).

Figure 12. Waituna Creek (mid catchment) looking downstream. On the true left, mass failure of the bank (bank slumping) can be seen on the inside bend of the stream that is accessible to stock (*i.e*. no stock exclusion fencing). The riparian area of the inside bend (right) has been fenced from stock for at least 5 years.

Discussions with individual farmers revealed that, historically, areas of Waituna Creek were not fenced on one bank to provide machine access for mechanical clearing of sediment and macrophytes from the stream bed. Since undertaking the BSHMP survey in 2014 (from which the analysis in this report is based on), much of the riparian area in the mid-lower river has since been fenced as part of the bank reshaping process. In addition, Environment Southland has recently led an initiative to subsidise fencing (of both banks) in the Waituna Catchment (pers. comm. Katrina Robinson, Environment Southland).

In a study of riparian characteristics for the Waikato region, Storey (2010) noted that riparian (stock exclusion) fencing was strongly negatively correlated with stream bank erosion. However, he also noted that fencing on only one bank was not significantly negatively correlated with bank erosion, suggesting that fencing both sides of a stream is important for bank stabilisation, probably because stock can cross streams. We did not find this effect in Waituna Creek. There was no significant relationship between the metres of fencing on the left bank and bank erosion on the right bank and vice versa (results not shown). This indicates that erosion caused by stock accessing the riparian zone is limited to the side of the stream that can be accessed. The entrenched channel and / or the creek itself appear to act as a barrier to stock accessing the opposite bank (stock accessing the riparian areas are predominantly sheep because all dairy farms were fenced).

The relationship between the metres of bank slumping (per metre of stream) and the metres of stock fencing (per metre of stream) is shown in Figure 13. This variable, but highly significant relationship ($P < 0.001$) is driven primarily by a large amount of stream reaches with 'zero' bank slumping in areas where there is 100% stock exclusion fencing. There appears to be a disproportionally high reduction in bank slumping when the entire length of stream within a 100 m reach is fenced. This is likely because stock can cause erosion along a reach as they travel up and downstream of an access point (although not across the channel in the case of Waituna Creek).

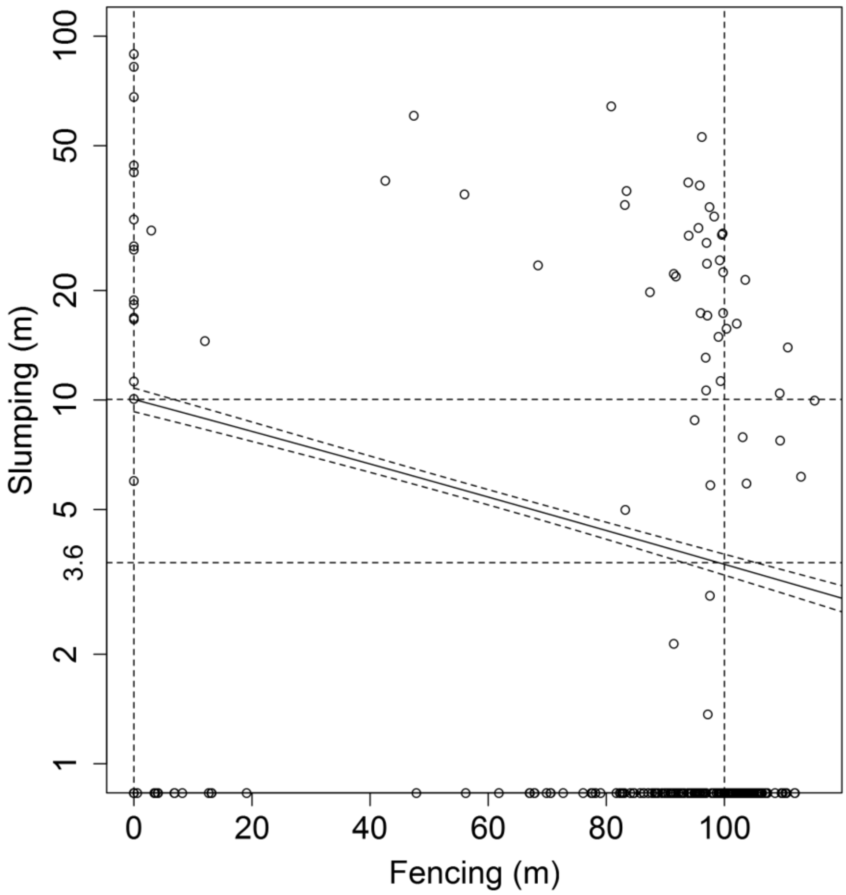

Figure 13. General linear model of the relationship between the average length of stock exclusion fencing (m) and the average length of bank slumping (m) shown with 95% confidence intervals. ($P < 0.001$, R = 0.01). Vertical and horizontal dotted lines show the amount of bank slumping predicted to occur at 100 m per GIS-Defined riparian Zone (GDZ) (equivalent to full stock exclusion) = 3.6 m and at 0 m of stocked exclusion fencing per 100 m = 10 m. Y axis is displayed on a log scale for ease of interpretation. Note: the large number of zero slumping values (210) at high levels of fencing (greater than 80 m).

By interrogating the bank slumping and stock access model we can estimate the potential benefit to bank stabilisation from completing the network of stock exclusion fencing in the catchment. It is apparent that without stock fencing, on average 10% of a stream bank (10 m per 100 m) can be expected to have eroding banks, compared with just 3.6% of a fully-fenced stream reach (Figure 13). That is, all other things being equal, you can expect to see about a threefold reduction in bank slumping by fully fencing the stream.

Prior to the bank reshaping in Waituna Creek, McDowell *et al*. (2013) undertook a sediment-source tracking study to determine the proportions of various sediment sources in the catchment. He estimated that between 64% and 94% of the catchment sediment load (from the upper and lower catchment respectively) was derived from bank erosion. We can use these values, in combination with our bank slumping / stock access model to estimate the percentage reduction in *total sediment load* from completing stock exclusion fencing in the catchment. If we take the average of the two percentage values for bank-derived sediment (*i.e.* 79%) and multiply this by the proportional reduction in bank slumping derived from the model from full fencing (*i.e*. 0.36), then add the residual percentage of the sediment load from other undefined sources (21%) – we calculate that completing the stock exclusion network in the catchment would result in a 50% reduction in the total sediment load (79% * 0.36 + 21% = 50%).

This is a crude estimate, based (in part), on a correlative analysis. However, it demonstrates that substantial reductions in sediment load can be achieved by fencing alone. The distance covered by stock exclusion fencing has increased since undertaking the BSHMP survey in 2014 (*i.e*. all reshaped reaches have now been fenced). Nevertheless, our results demonstrate that further investment in fencing should be a priority for any management initiative aimed at reducing the sediment load of Waituna Creek.

Putting aside the potential ecological gains of reducing sediment loads in Waituna Creek and the Lagoon downstream, our results demonstrate that it is in the interest of catchment managers and landowners to ensure the entire catchment is fenced. Under-field drains become less effective as the stream bed level rises from sediment deposition. Reduced sediment loading rates, through more metres of stock exclusion fencing, will reduce the sediment load. This in turn may reduce the required frequency of resource intensive mechanical clearing operations.

In principle, these results should be applicable to other low gradient entrenched streams with under-field drainage throughout New Zealand. Fencing recommendations for farms have been in place for decades based on qualitative data. Our analysis adds further weight to these recommendations by providing a catchment-scale performance based measure of stream fencing. We demonstrate that fencing can substantially reduce total sediment load—in the order of 50% for an entrenched low gradient stream.

4.2. Potential for reducing deposited sediment levels below 20% in Waituna Creek

Reducing or maintaining the amount of fine sediment covering the stream bed to below 20% is emerging as an appropriate national target to protect the life-supporting capacity of stony-bottomed streams (Olsson & Persson 1988; Clapcott *et al.* 2011; Burdon *et al*. 2013). For example, Burdon *et al*. (2013) showed that as deposited fine sediment approaches 20% cover in small Canterbury drains and streams, there is a precipitous decline in the relative abundance of mayfly, caddisfly and stonefly taxa (known collectively as EPT taxa). A reduction in the abundance of these taxa can be expected to reduce growth potential and feeding opportunities for fish, particularly drift-feeding fish such as giant kōkopu and trout. This is because EPT taxa are generally larger and more likely to be entrained in the water column than other stream invertebrates. However, caution must be used when applying this 20% deposited sediment target value in a management context because some stream types have naturally high levels of deposited fine sediment. For example, in parts of the Auckland region, streams are characterised by a naturally sandy substrate.

In the upper Waituna catchment, the stream bed comprises a greater proportion of fine and coarse gravel in comparison with the lower catchment (50% *vs*. 24%). It is likely that a substantial proportion of the deposited fine sediment in the upper catchment is the result of inputs from the ongoing development and landuse intensification. According to the National Freshwater Ecosystems of New Zealand (FENZ) database, the modelled average deposited fine sediment cover 'reference condition' (*i.e*. before land use development) for all segments in the upper Waituna Creek is estimated to be just 2%. This contrasts with the observed deposited fine sediment cover of 45% (Holmes *et al.* 2015). The observed fine sediment cover in the upper catchment is in agreement with the modelled FENZ based predictions of deposited sediment levels that account for contemporary land use (47%).

Because of the non-linear 'threshold' impact of fine sediment on the life-supporting capacity of streams, the most ecological gain for a corresponding reduction in deposited fine sediment will be achieved in areas that currently exceed 20% cover by a small amount (*i.e*. by less than 15%). In these areas, a small reduction in fine sediment cover to below the 20% threshold will potentially cause a shift in invertebrate community composition to one that is better able to support fish production. Based on the catchment-scale habitat data from Holmes *et al.* (2015), these areas are 5A, 5B, 6A, 3K and 3I (refer to Figure 6). These areas could be appropriate priority sites for fine sediment reduction management initiatives.

Because of the shallow gradient in the lower Waituna Creek it is reasonable to assume that this part of the stream would naturally have had high fine sediment cover levels prior to land use development. In any case, irrespective of the possible reference condition of the lower Waituna Creek, currently most of the stream bed is covered with fine sediment (mean = 57%). Even if the supply of fine sediment was halted, the shallow gradient of the stream means that there would be limited potential for fine sediment to be removed from the bed through flushing events (freshes and floods). Therefore, with the exception of a few isolated areas, setting a target level of less than 20% will not be practically achievable in this part of the catchment.

An alternative strategy to improve invertebrate diversity and production (and fish habitat quality) would be to introduce measures that increase the amount of vegetative debris in the stream. Vegetative debris (*e.g*. logs or submerged branches) are hots-spots for invertebrate diversity and production in soft-bottomed streams like the lower Waituna Creek (as it is presently) (Stark *et a*l. 2001).

4.3. Fencing setback widths for fine sediment management

Our analysis of catchment-scale data in Waituna Creek indicates that there is an immediate benefit of more stable banks from stock exclusion fencing. However, in both the upper and lower catchment, there is no detectable effect of fenced area (which equates to average fenced set back width) on instream deposited fine sediment measures (Tables 1 and 2).

Overland flow, which can be a significant source of fine sediment to streams, largely bypasses the riparian zone in Waituna Creek through the under-field drainage network. This renders the sediment filtering function of the riparian zone less effective (even in the widest riparian areas). Furthermore, fences in Waituna Creek are mostly situated at the edge of the entrenched channel or at the 'bank full' boundary (fences within the entrenched channel would be washed away on the first high flow event). The slope of the bank from the stream edge to the bank full edge is steep (*i.e*. a 1 : 2 slope or greater). Therefore, contaminants such as fine sediment entrained within overland flow, passing through this steep riparian area, will largely remain in suspension and enter the creek (Collier *et al*.1995).

Environment Southland currently recommends that landowners place their fences

> 'at least three metres away from the water's edge. However, in cases where artificial drains need to be cleaned to maintain drainage outfall, fence lines should be placed close to the top of the bank or 10 m away from the edge to allow diggers access to the waterway' (Environment Southland 2014).

With respect to fine sediment management, we found that these existing recommendations are largely suitable for Waituna Creek. Our analysis suggests that after stock exclusion fencing is in place there will be little sediment reduction benefit to increasing the fencing setback widths beyond the bank full channel edge. However, there may be some benefit to ensuring that fences are setback at least 1–2 m from the bank full edge to ensure that grazing pressure is removed from vegetation around the change in slope. This area may be a point of weakness in unfenced areas. A large proportion of bank slumping appears to occur in the upper section of the channel (personal observation by the lead author—for examples see Figures 3 and 12).

At an individual farm scale, there will be some areas where paddock depressions near the stream edge will create localised pathways for overland flow. Ideally, from a fine sediment management perspective, these depressions should be fenced with generous buffers (*e.g*. > 5 m) and left to develop a thick matt of grasses to filter out fine sediments from overland flow. However, identifying such areas was not possible using the available BSHMP data.

4.4. Fencing setback widths for improved fish habitat quality

Riparian areas provide benefits to instream habitat that are unrelated to contaminant management (*e.g*. improved fish habitat, terrestrial biodiversity and aesthetic values). Given the apparent limited potential to influence deposited fine sediment levels by varying the fenced setback width in Waituna Creek, it is appropriate to consider managing setback widths for fish habitat.

We found no significant relationships between fenced area and instream habitat variables in the upper catchment. However, in the lower catchment, our analysis showed a significant positive correlation between fenced area and residual pool depth and an increasing trend with mesohabitat diversity. The shape of both of these relationships is relatively flat until the fenced area reaches about 2000 m^2 / 100 m (Appendices 9 and 10). This equates to an average fenced setback width of 10 m on each bank (2000 / 100 / 2 = 10). The implication from these results is that fences set back 10 m or more (on average) from the wetted edge will positively influence mesohabitat diversity and residual pool depth. Taking into account the width of the entrenched channel, this would equate to a fence set back roughly 5 m from the bank full edge. The space created by this set back would be wide enough to establish shrubs and trees in the riparian zone which as our results demonstrate will likely further improve fish habitat (see next section).

4.5. Riparian vegetation management

In keeping with our hypothesis, riparian segments in the upper catchment with areas of mixed native and exotic grasses (typically *Carex* sp. and flax) were associated with relatively low levels of deposited and inter-gravel fine sediment. These results suggest that further planting of flax and *Carex* sp. in the upper catchment will have a positive effect on stream habitat. Interestingly, the regression models show a reduction in fine sediment in reaches with relatively small areas of native and exotic grasses and little decrease in fine sediment levels with increasing areas of native and exotic grasses beyond 100 m^2 per 100 m of stream (or, 1 m width per m of stream on average) (Appendix 7). Given the limited resources available for riparian planting, in terms of fine sediment reduction, our results indicate that resources may be better allocated by creating longer narrow riparian strips of native grasses (*i.e*. 1–2 m wide on average), as opposed to wider planted areas.

In the lower catchment, later successional stages of riparian vegetation (*i.e*. shrubs and trees) were positively associated with fish habitat quality in adjacent and downstream reaches. From a fish habitat perspective, there is likely to be minor differences in the positive functional effects of different types of shrub and tree species on community assemblages of fish (beyond faster-growing plants having a better chance of establishment and providing the benefits sooner after planting). Therefore, it is appropriate to consider native biodiversity values when selecting appropriate species.

In terms of selecting appropriate species for planting in the riparian areas, there are numerous regionally-specific technical reports and riparian management guidelines produced by regional councils and DairyNZ. Furthermore, there is a range of well-researched information available on Environment Southland's website. This includes two technical reports on riparian management in the Southland region (Goldsmith *et al.* 2013, Goldsmith & Ryder 2013). A selection of potentially suitable riparian plant species is given in Table 4 and the following webpage links provide simple and well-presented Southland-specific guides to suitable riparian plant species for the Waituna catchment.

Riparian plants for Southland (Environment Southland):
http://www.es.govt.nz/media/48746/riparian_planting_species_booklet_-_web.pdf

Getting planting right in Southland (DairyNZ):
http://www.es.govt.nz/media/38904/riparian_management_southland_web.pdf

A spatial data base that provides appropriate species lists for various areas in New Zealand including Waituna Lagoon (Landcare Research):
http://natureservices.landcareresearch.co.nz/app/purpose/26/168.53941328644171/-46.54477962302653/

Table 4. A selection of grass, shrub and tree species suitable for establishing in in the riparian areas of Waituna Creek.

Upper bank	Lower bank
Cabbage tree (tī kōuka)	*Carex secta*
Cordyline australis	
Swamp flax (harakeke)	Red tussock grass
Phormium tenax	*Chionochloa rubra*
Broadleaf (kapuka)	Swamp sedge (pūrei)
Griselinia littoralis	*Carex virgata*

Although there is potential for fencing and planting to reduce the necessity of channel maintenance activities (through reducing sediment loads and shading macrophytes), in the medium term, these management activities can impinge on routine channel maintenance activities. Ideally, if taller-growing species are used, these should be planted on the north side of the channel to allow the maximum potential for shading of the stream. Low stature grasses and shrubs (< 0.8 m high *e.g*. *Carex secta*) can then be used on the south side of the channel to allow recreational access and / or drain maintenance activities to be carried out if necessary. Approval or resource consent is required from Environment Southland for revegetation work: 'If planting within 20 m of water body whose catchment extends over 200 hectares' - this applies to Waituna Creek.

4.6. Management recommendations summary

Based on our results we conclude the following:

1. Completing the catchment's network of stock exclusion fencing should be a priority management action to reduce fine sediment loading in the catchment.
2. Increasing the fencing setback width beyond that necessary to exclude stock from the stream channel and protect stream edge vegetation is unlikely to result in a detectable reduction in deposited instream fine sediment cover.
3. In the upper catchment, planting 1–2 m wide native grass strips along the bank edges is recommended to reduce instream fine sediment cover levels. The following sites should be prioritised: 5A, 5B, 6A, 3K and 3I (shown in Figure 6, see Section 2.1).
4. To maintain or improve fish habitat in the lower catchment we recommend 10 m set banks (at least) on both banks to allow the creek space to create reach-scale hydraulic diversity and depth variation. This equates to a fence set back of approximately 5 m from the bank full channel edge.

5. In the lower catchment, to maintain or improve a range of fish habitat quality indicators, we recommended encouraging shrubs and trees in the riparian areas within the *c.* 10 m fenced riparian area recommended in point (4).

Before implementing these recommendations careful consideration of how they will impact upon landowners and drainage management in the catchment is essential.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Allan DJ 2004. Landscapes and riverscapes: The influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics 35: 257-284.

Allouche S 2002. Nature and functions of cover for riverine fish. Bulletin Francais De La Peche et De La Pisciculture. 365-66: 297-324.

Atkinson E 2008. What's lurking in Waituna Wetlands? A freshwater fish survey – Arawai Kakariki project. Department of Conservation technical report. 34 p.

Bjornn TC, Brusven MA, Molnau MP, Milligan JH, Klamt RA, Chacho E, Schaye C 1977. Transport of granitic sediment in streams and its effects on insects and fish. Forest, Wildlife and Range Experiment Station bulletin. Prepared for University of Idaho. 43 p.

Broadmeadow S, Nisbet TR 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. Hydrology and Earth System Sciences 8: 286-305.

Burdon FJ, McIntosh AR, Harding JR 2013. Habitat loss drives threshold response of benthic invertebrate communities to deposited sediment in agricultural streams. Ecological Applications 23: 1036-1047.

Clapcott JE, Young RG, Harding JS, Matthaei CD, Quinn JM, Death RG 2011. Sediment assessment methods: Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values. Cawthron Institute, Nelson, New Zealand.

Collier KJ, Cooper AB, Davies-Colley RJ, Rutherford JC, Smith CM, Williamson RB 1995. Managing riparian zones: A contribution to protecting New Zealand's rivers and streams. Guidelines. Department of Conservation Vol 2, Wellington New Zealand.

Diffuse Sources and NIWA 2012. Waituna catchment load methods. Report for Environment Southland. 67 p.

Dodd M, Wilcock B, Parminter T 2009. Review of recent rural catchment-based research in New Zealand. AgResearch and National Institute of Water and Atmospheric Research Report, prepared for MAF policy. 121 p.

Draft strategy and action plan for Waituna 2015. Environment Southland working document. 23 p.

Duncan SH, Ward JW 1985. The influence of watershed geology and forest roads on the composition of salmon spawning gravel. Northwest Science 59: 204-212.

Environment Southland 2014. Drainage and channel maintenance – considerations when fencing and planting riparian zones. Water and Land 2020 and Beyond factsheet. 3 p.

Glova GJ 2002. Density effects on juvenile shortfinned eel (*Anguilla australis*) cover preferences in replicate channels. New Zealand Journal of Marine and Freshwater Research 36: 483-490.

Glova GJ, Jellyman DJ, Bonnett ML 1998. Factors associated with the distribution of habitat of eel (*Anguilla* spp.) in three New Zealand lowland streams. New Zealand Journal of Marine and Freshwater Research. 32: 255–269.

GNS Science 2003. Geology of the Murihiku area. Institute of Geological & Nuclear Sciences Limited (IM Turnbull and AH Allibone compliers), Lower Hutt, New Zealand. 74 p.

Goodman JM, Dunn NR, Ravenscroft PJ, Allibone RM, Boubee JAT, David BO, Griffiths M, Ling N, Hitchmough RA, Rolfe JR 2013. Conservation status of New Zealand freshwater fish, 2013. Department of Conservation report, New Zealand Threat Classification Series. 16 p.

Goldsmith R, Olsen D, Ryder G 2013. Environmental effects of activities within the riparian zone - technical review. Ryder Consulting technical report. Prepared for Environment Southland. 54 p.

Goldsmith R, Ryder G 2013 Factors affecting contaminant loss in overland flow - technical review. Ryder Consulting technical report. Prepared for Environment Southland. 49 p.

Greenwood MJ, Harding JS, Niyogi DK, McIntosh AR 2012. Improving the effectiveness of riparian management for aquatic invertebrates in a degraded agricultural landscape: stream size and land-use legacies. Journal of Applied Ecology 49: 213-222.

Holmes R, Goodwin E, Allen C 2015. Riparian and instream habitat quality in the tributaries of Waituna Lagoon, Southland. Prepared for Department of Conservation / Fonterra Wetland Restoration Partnership. Cawthron Report No. 2587. 40 p. plus appendices.

Holmes R, Goodwin E, Hayes JW 2013. Development of a GIS-based index to assess riparian habitat quality in a dairy best practice catchment. Cawthron Report No. 2350. 32 p. plus appendices.

Holmes R, Hayes JW 2011. Broad-scale trout habitat mapping for streams (using aerial photography and GIS). Cawthron Report No. 1979. 40 p.

Holmes R, Megan W, Hayes JW 2012 Broad-scale trout habitat mapping in a best practice dairy catchment. Cawthron Report. No 1979. 40 p.

Jowett IG, Richardson J 2008.Habitat use by New Zealand fish and habitat suitability models. NIWA science and technology series No. 55. 148 pp.

Larned ST, Scarsbrook MR, Snelder TH, Norton NJ, Biggs BJF 2004. Water quality in low elevation streams and rivers of New Zealand: recent state and trends in contrasting land cover classes. New Zealand Journal of Marine and Freshwater Research 38: 347-366.

Lyons J, Weigel BM, Paine LK, Undersander DJ 2000. Influence of intensive rotational grazing on bank erosion, fish habitat quality, and fish communities in south-western Wisconsin trout streams. Journal of Soil and Water Conservation 55: 271-276.

Matthaei CD, Weller F, Kelly DW, Townsend CR 2006. Impacts of fine sediment addition to tussock, pasture, dairy and deer farming streams in New Zealand. Freshwater Biology 51: 2154–2172.

McDowell RW, Norris M, Cox N 2013. Waituna sediment fingerprinting study. AgResearch Report No. RE500/2013/136. 30 p. plus appendices.

Meijer K 2011. Surface water quality - Waituna catchment. File Reference 701/13/07. Environment Southland. Invercargill, New Zealand.

Niyogi DK, Koren M, Arbuckle CJ, Townsend CR 2007. Longitudinal changes in biota along four New Zealand streams: declines and improvements in stream health related to land use. New Zealand Journal of Marine and Freshwater Research 41: 63-75.

Olsson TI, Persson BG 1988. Effects of deposited sand on ova survival and alevin emergence in brown trout (*Salmo trutta* L.). Archiv für Hydrobiologie 113: 621-627.

Parkyn SM, Davies-Colley RJ, Halliday NJ, Costley KJ, Croker GF 2003. Planted riparian buffer zones in New Zealand: do they live up to expectations? Restoration Ecology 11: 436-447.

Quinn JM, Cooper AB, Stroud MJ, Burrell GP 1997. Shade effects on stream periphyton and invertebrates: an experiment in stream channels. New Zealand Journal of Marine and Freshwater Research 31 (5): 665-683.

Quinn JM 2000. Effects of pastoral development. In: Collier KJ, Winterbourn MJ. (eds) New Zealand stream invertebrates: ecology and implications for management. (New Zealand Limnological Society, Christchurch.) 415 p.

Quinn JM 2009. Riparian management classification reference manual. NIWA client report prepared for Environment Canterbury. NIWA Report No. HAM2009-072. 60p.

Quinn JM, Williamson RB, Smith RK, Vickers ML 1992. Effects of riparian grazing and channelisation on streams in Southland, New Zealand. 2. benthic invertebrates. New Zealand Journal of Marine and Freshwater Research. 26: 259-273.

Raleigh RF, Zuckerman LD, Nelson PC. 1986. Habitat suitability index models and instream flow suitability curves: brown trout, revised (Modified in RYHABSIM). Prepared for U.S. Fish and Wildlife Service.

Riddell JM, Watson NRN, Davis SF 1988. Fisheries investigations of the Ashers-Waituna, Benhar and Hawkdun lignite deposit areas. New Zealand Freshwater Fisheries Report. No. 94. 20 p. plus appendices.

Robertson B, Stevens L, Schallenberg M, Robertson H, Hamill K, Hicks A, Hayward S, Kitson J, Larkin G, Meijer K, Jenkins C, Whaanga D 2011. Interim recommendations to reduce the risk of the Waituna Lagoon flipping to an algal dominated state. Report prepared for Environment Southland by the Lagoon Technical Group (LTG). 19 p. plus appendices.

Rosgen DL 1994. A classification of natural rivers. Catena 22: 169-199.

Stark JD, Boothroyd IKG, Harding JS, Maxted JR, Scarsbrook MR 2001. Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report No. 1. Prepared for the Ministry for the Environment. Sustainable Management Fund Project No. 5103. 57 p.

Stevens L, Robertson B 2007. Waituna Lagoon 2007 Ecological vulnerability assessment and monitoring recommendations. Wriggle Limited Report, prepared for Environment Southland. 25 p. plus appendices.

Storey R 2010. Riparian characteristics of pastoral streams in the Waikato region, 2002 and 2007. NIWA technical report: HAM2010-022. Prepared for Environment Waikato. 68 p.

Sutherland AB, Meyer JL, Gardiner EP 2002. Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. Freshwater Biology 47 (9): 1791-1805.

Trimble SW, Mendel AC 1995. The cow as a geomorphic agent — A critical review. Geomorphology. 13: 233-253.

Wahl CM, Neils A, Hooper D 2013. Impacts of land use at the catchment-scale constrain the habitat benefits of stream riparian buffers. Freshwater Biology 58: 2310-2324.

Waters TF 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society: Monograph 7. 251p.

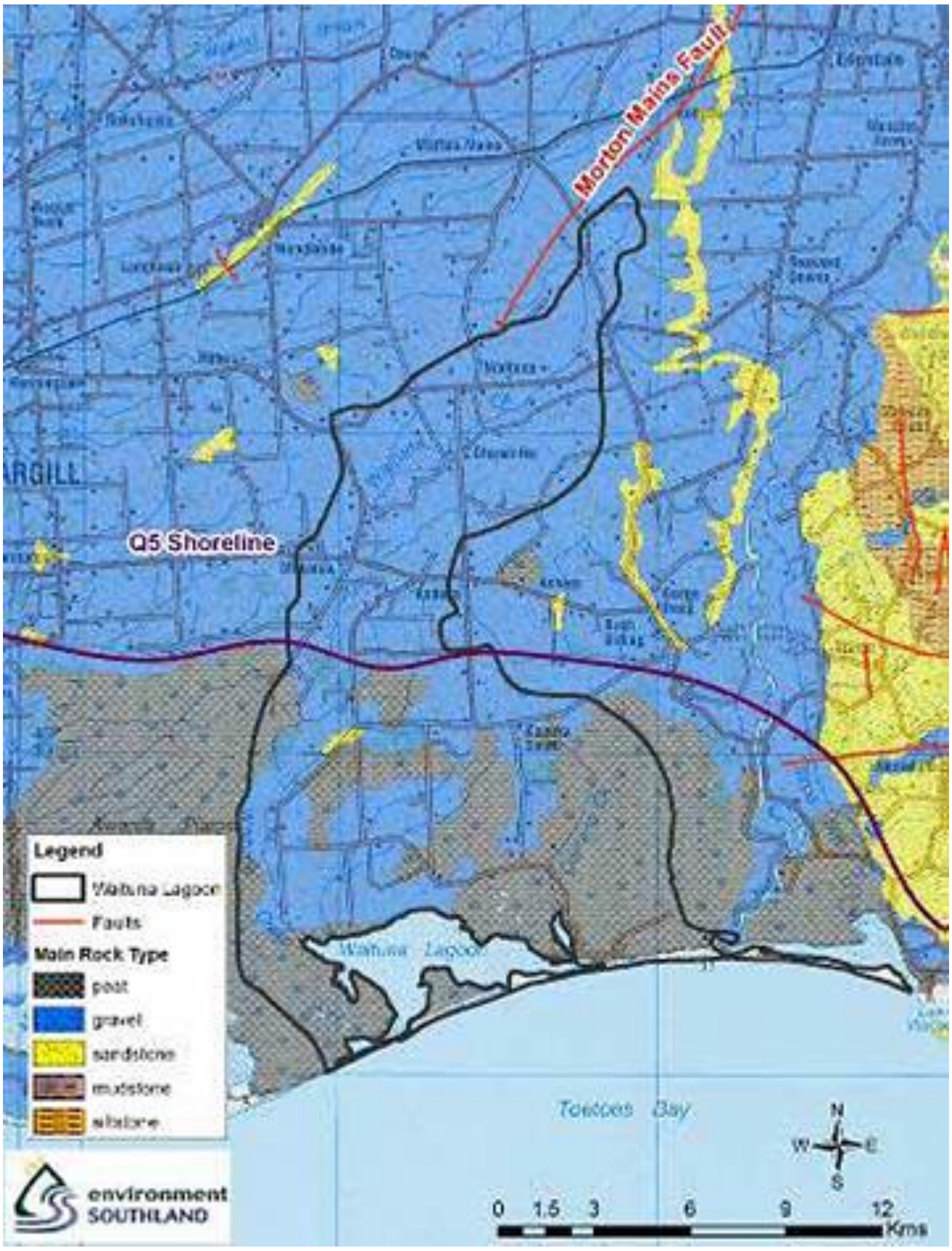
Wentworth CK 1922. A scale of grade and class terms for clastic sediments. Journal of Geology 30: 377-392.

Wood PJ, Armitage PD 1999. Sediment deposition in a small lowland stream – management implications. Regulated Rivers-Research and Management 15: 199–210.

Yuan YP, Bingner RL, Locke MA 2009. A review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. Ecohydrology 2: 321-336

7. APPENDICES

Appendix 1 Geology (left) map for the Waituna Lagoon catchment. Source: GNS Science (2003).



Appendix 2. Soil map for the Waituna Lagoon catchment. Source: GNS Science (2003).

Appendix 3. An instream survey sheet used to complete a 20 m sub-reach survey. Five continuous sub-reached are completed at each 100 m reach.

Stream:		**Site (20m sub-reach) number:**	**Date:**	**Assessor team:**
D/S Width (m):		**D/S gps** (true right)**:**		
		e		n
Midpoint width (m)				
U/S, Width (m):		**U/S gps** (true right):		
		e		n

% Mesohabitat types for 20m sub-reach:			
Riffle	Slow run	Fast run	Pool

% Area depths for 0m to 10m mark:			
0 – 0.3 m deep	0.3 – 0.5 m deep	0.5 – 1 m deep	1 m + deep

% Area depths for 10m to 20m mark:			
0 – 0.3 m deep	0.3 – 0.5 m deep	0.5 – 1 m deep	1 m + deep

% Substrate Type for 20m sub-reach:						
Fine sed (<2mm)	Gravel (2 – 32mm)	Large gravel (32-64mm)	Small cobble (64-128mm)	Large cobble (128-256mm)	Boulder (>256mm)	Bed rock (continuous)

% Weed/macrophyte cover	**% Algal cover** (include only filamentous or thick algal mat cover >3mm)	**Shuffle test score (1-5 scale):**(in run or pool-tail/glide only)

Fish cover:			
Undercut bank - True Right bank (linear m of bank edge length – *i.e.* maximum of 20m)			
0 – 0.3 m deep	0.3 – 0.5 m deep	0.5 – 1 m deep	1 m + deep
Undercut bank - True Left bank (linear m of bank edge length – *i.e.* maximum of 20m)			
0 – 0.3 m deep	0.3 – 0.5 m deep	0.5 – 1 m deep	1 m + deep
Overhanging veg - True Right bank (linear m of bank edge – *i.e.* maximum of 20m)			
0 – 0.3 m	0.3 – 0.5 m	0.5 – 1 m	1 m +
Overhanging veg - True Left bank (linear m of bank edge – *i.e.* maximum of 20m)			
0 – 0.3 m	0.3 – 0.5 m	0.5 – 1 m	1 m +
Woody debris (m^2) (include items >0.5m*0.3m)	**Submerged branches (m^2)** include items (>1m*0.3m)	**Turbulence (m^2)** (Include if the stream bed is obscured and depth is >0.3m.)	**Manmade cover (m^2)** (e.g. rip-rap, bridges, old tires)

Residual Pool depth (m):		**Comments**	**Photo taken?**	
Deepest point depth	D/S Hydraulic control depth		**All sheet fields completed?**	

Appendix 4. Riparian survey field instructions. Contact the lead author for a full set of instructions and protocol sheets.

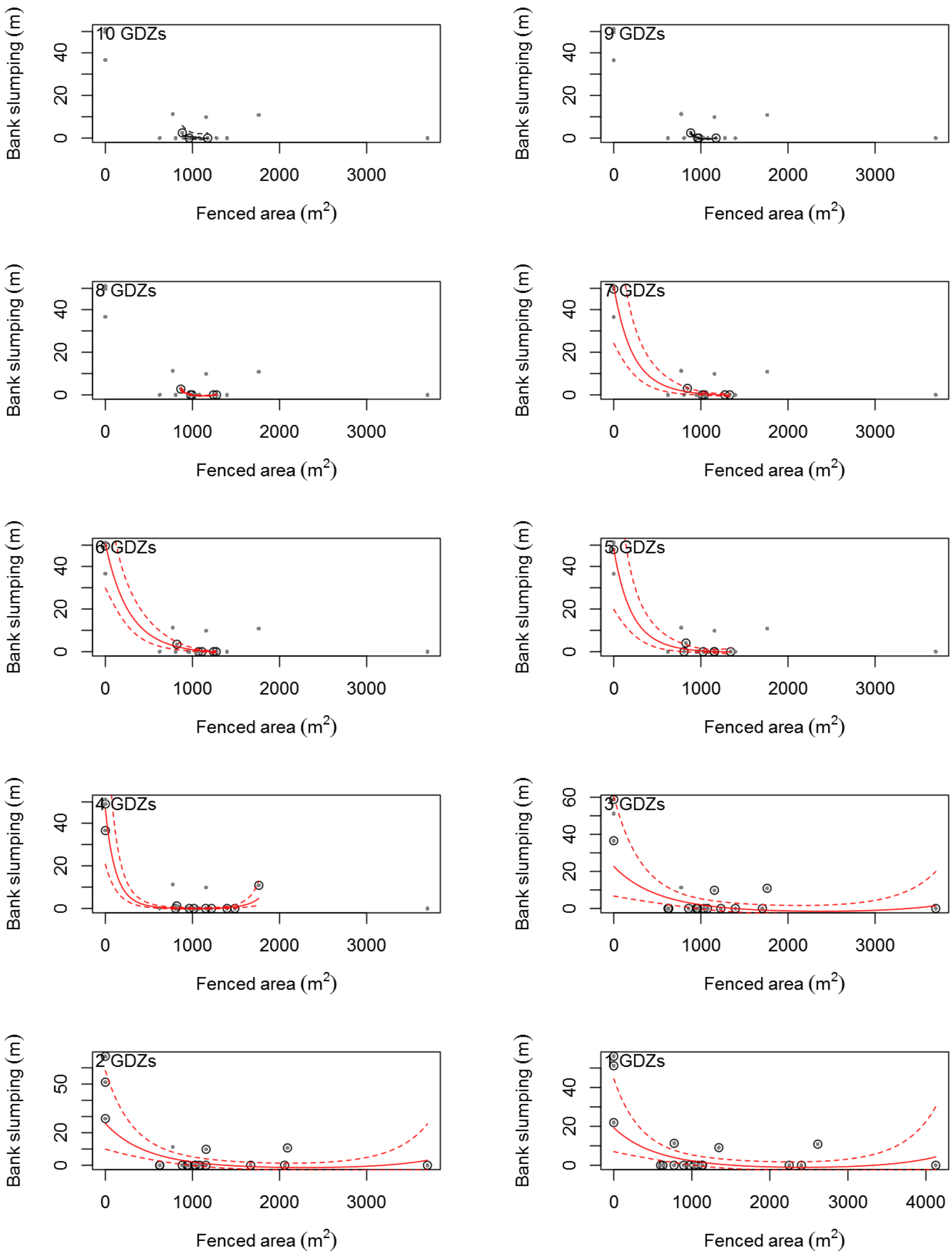
Stage one: riparian, land-use and contaminant source assessment field guide.

For hardcopy photographs, **when possible trace around the habitat feature if it can be seen on the photo** and attach the relevant code (see Tables 1 and 2). If the feature is too small to be seen on the photo, then place a point at its location and estimate its size (m^2) and/or length (m).

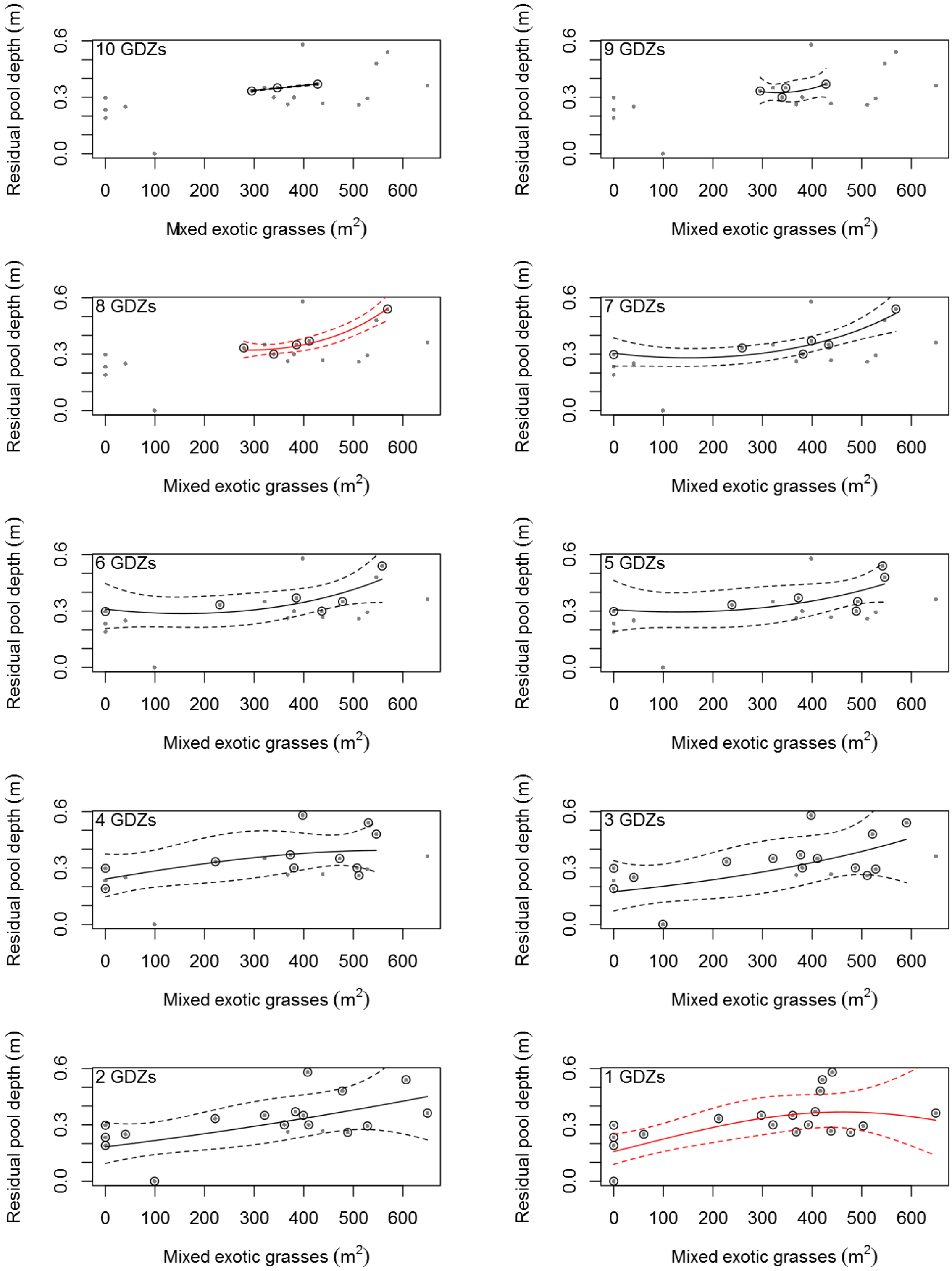
Note the land-use type: crop, sheep/beef cattle, dairy or other (specify) — record land-use type only at the start of the assessment or when it changes.
Follow steps 1–7.

1. Trace along the wetted edge of the stream
2. Trace around and/or estimate the average width of the (fenced) riparian management zone. Record the level of stock access within the riparian zone — no access, fenced with periodic/partial access, open access
3. Record the vegetation types within the riparian management zone (see veg. codes in Table 1)
4. Trace around or estimate the area (m^2) of vegetation within 30 m of the stream edge — record vegetation type (see veg. codes in Table 1) estimate height of any trees to the nearest 5 m.
5. Note, trace around or estimate the area (m^2) of any vegetation overhanging the stream edge (see Table 1)
6. Trace along the length, or estimate the area (if it is too small to be seen on the aerial photograph) of any significant potential sources of sediment (*i.e.* bank slumping or stock pugging (see Table 1)
7. Note any drains or tributaries and label type (*e.g*: small tributary, open drain, mole/tile). Record if the tributary/drain is fenced or not. Record other land-use features described in Table 2.

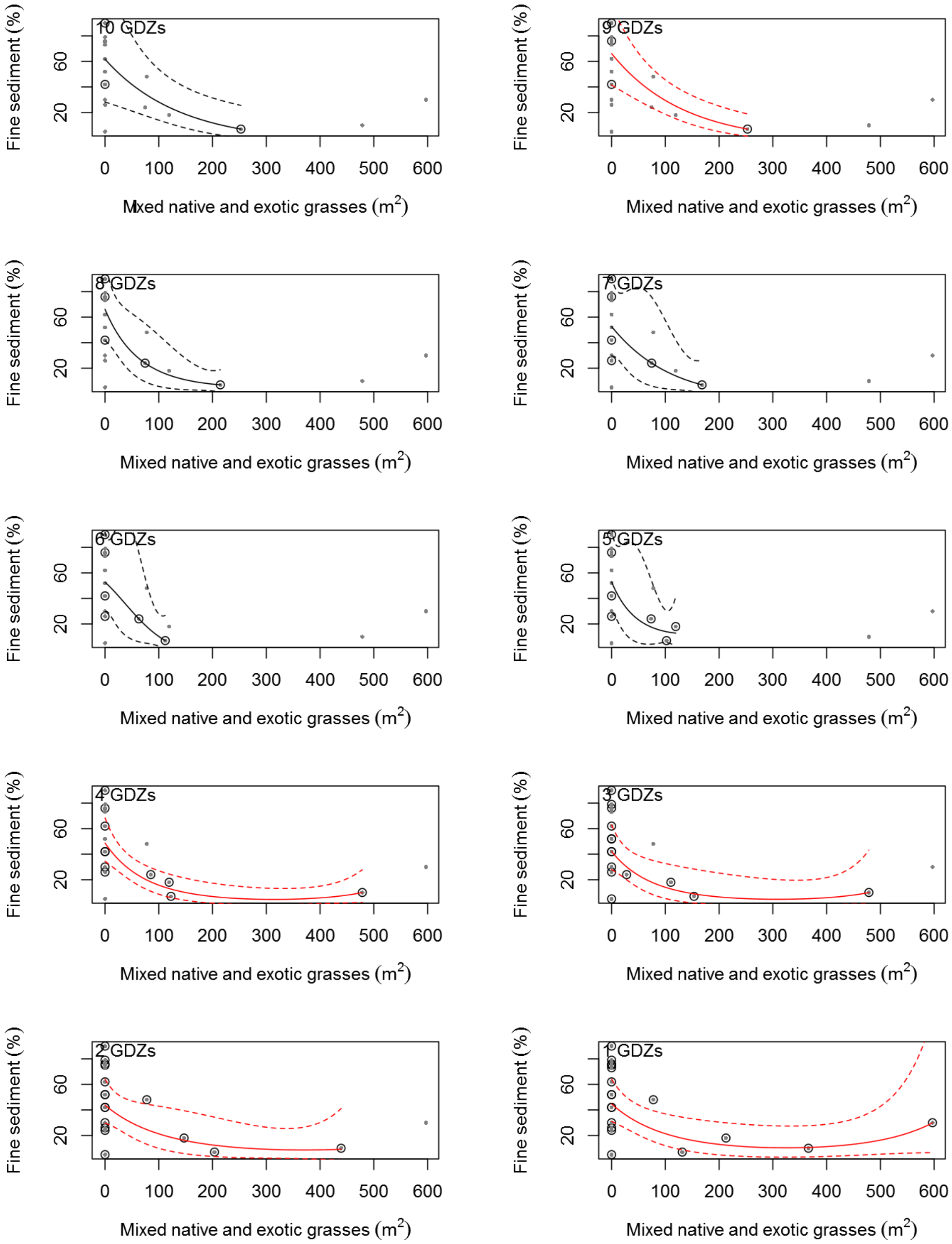
Appendix 5. Ten individual sequential regressions of mean bank slumping (m) against the mean area of riparian stock exclusion fencing (m^2) from the upper catchment. The first regression, at the 100 m reach scale, compares bank slumping to fenced riparian area from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the fenced riparian area is the mean from upstream GDZ incrementally included in the analysis.



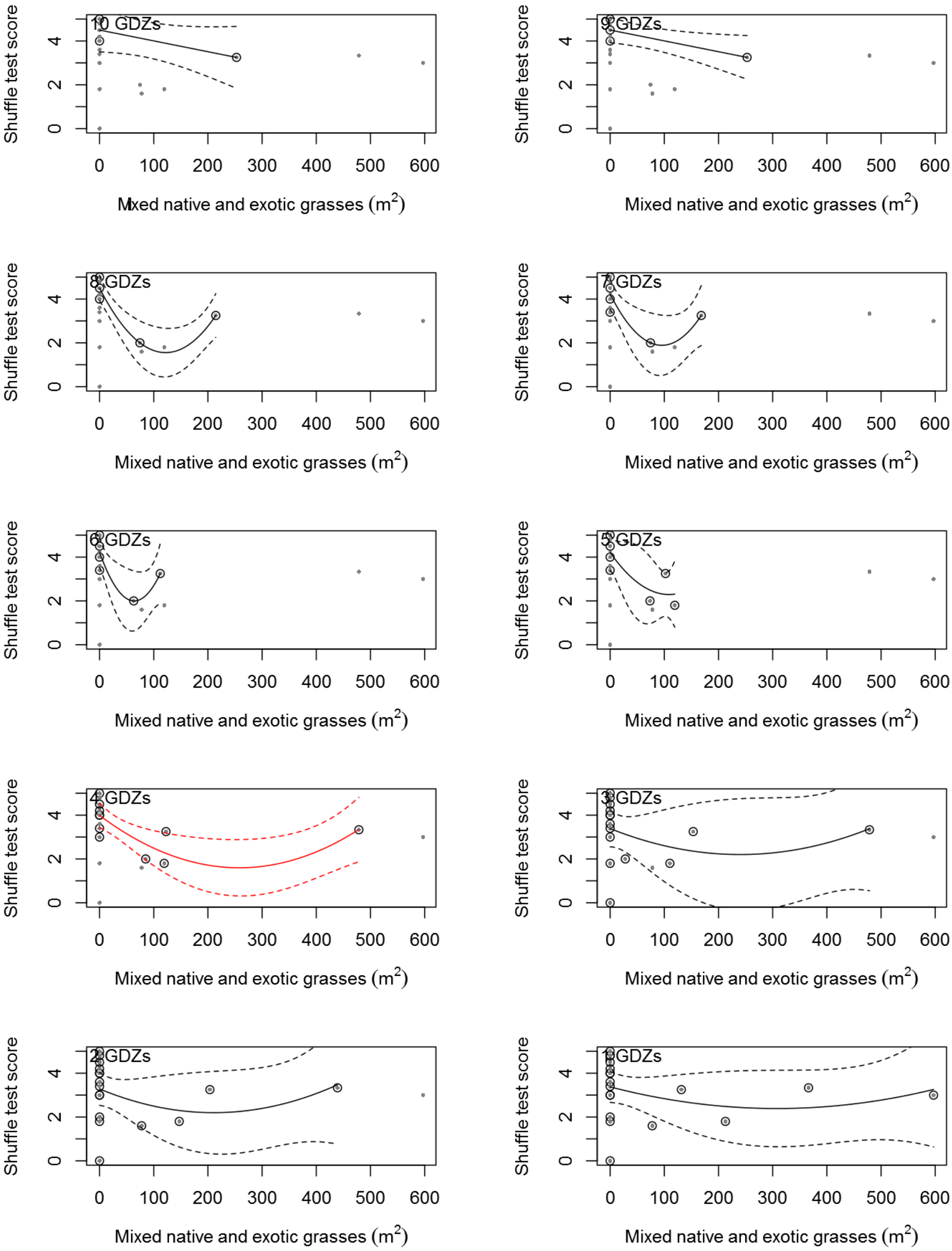
Appendix 6. Ten individual sequential regressions of mean residual pool depth (m) against the mean area of mixed exotic grass (m^2) from the upper catchment. The first regression, at the 100 m reach scale, compares residual pool depth in instream survey reaches to area of mixed exotic grass from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the area of mixed exotic grass is the mean from upstream GDZ incrementally included in the analysis.



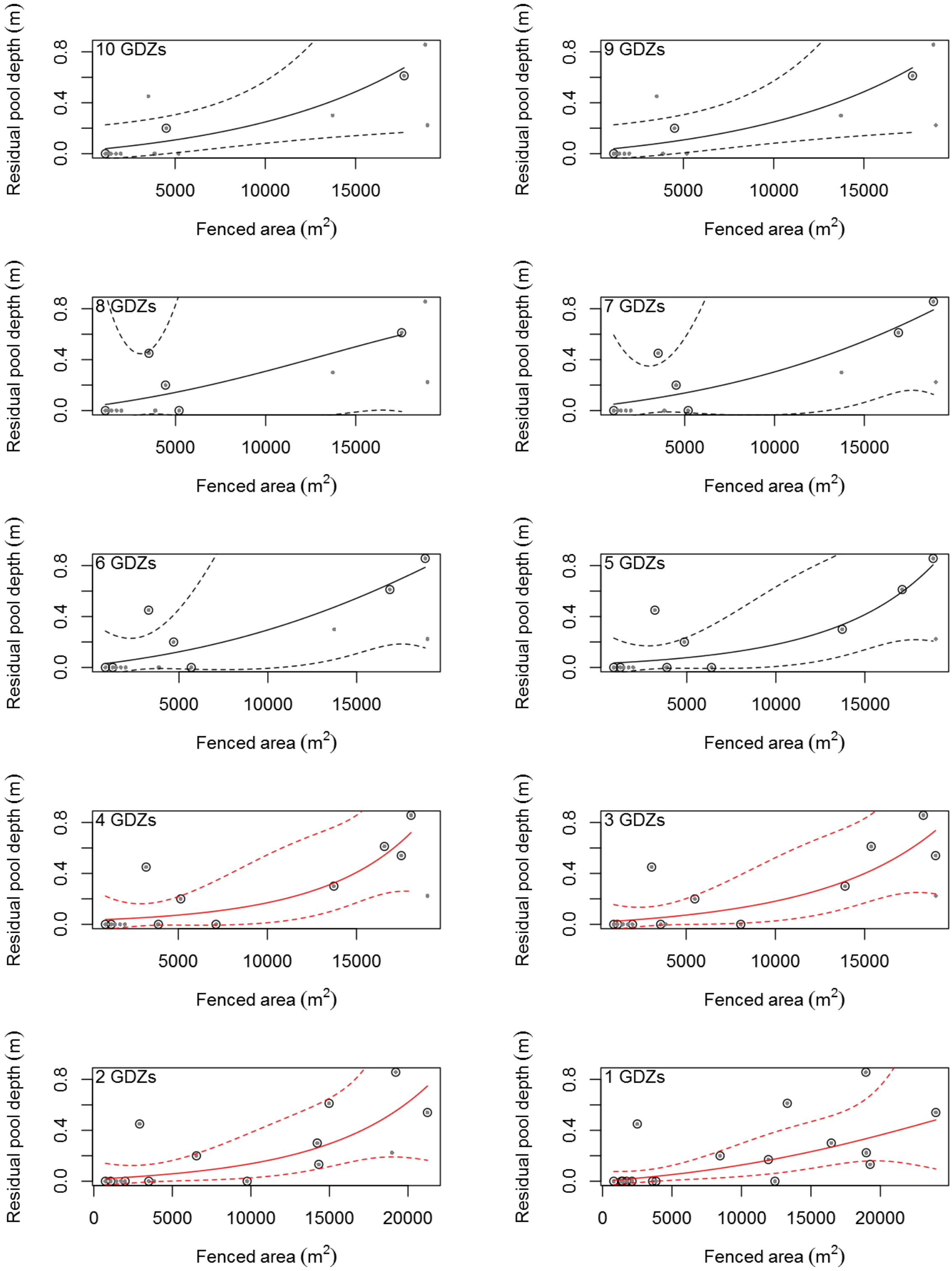
Appendix 7. Ten individual sequential regressions of fine sediment (mean % cover) against the mean area of mixed native and exotic grasses (m^2) from the upper catchment. The first regression, at the 100 m reach scale, compares fine sediment cover in instream survey reaches to area of mixed native and exotic grasses from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the area of mixed native and exotic grasses is the mean from upstream GDZ incrementally included in the analysis.



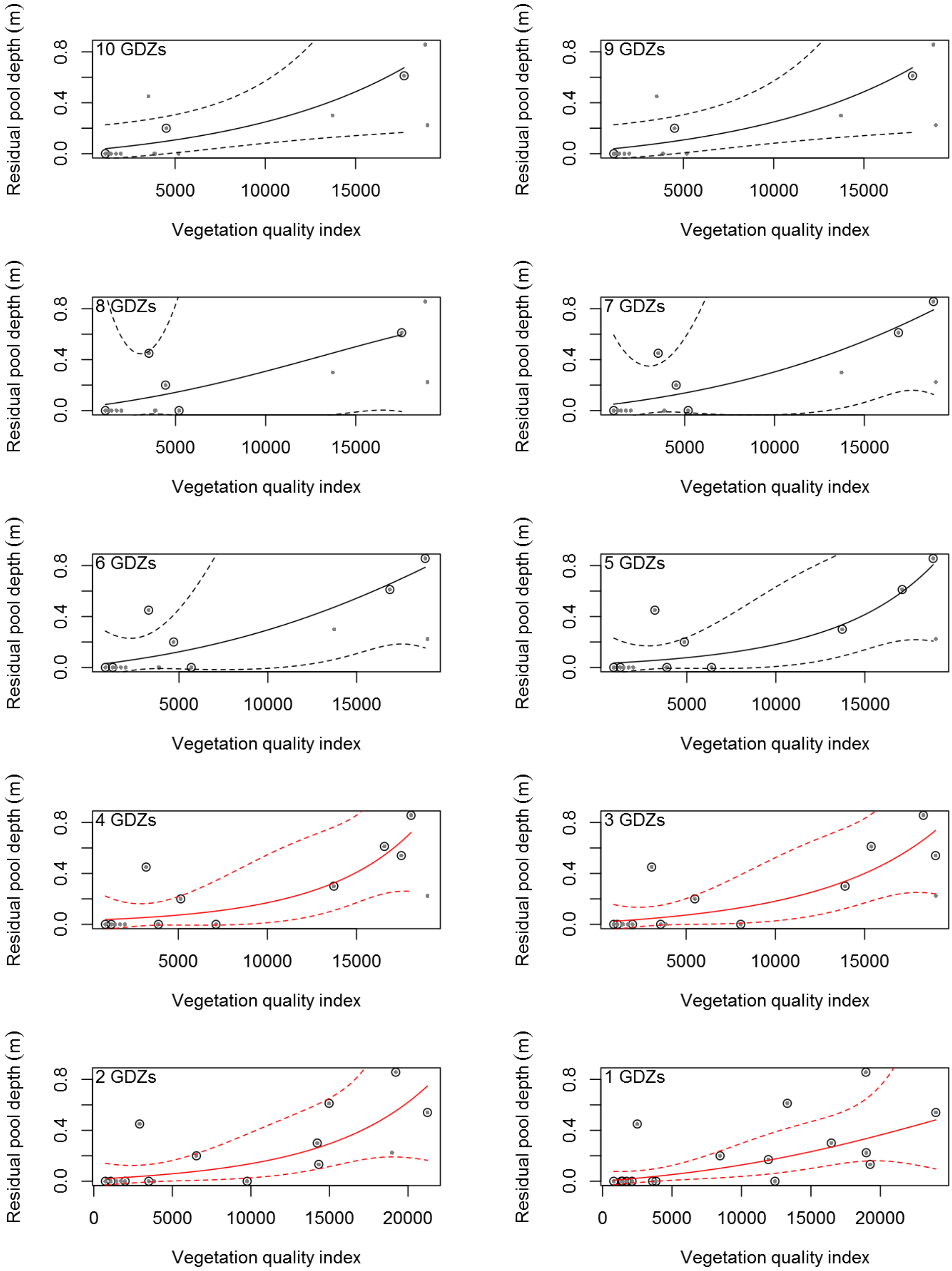
Appendix 8. Ten individual sequential regressions of mean shuffle test score against the mean area of mixed native and exotic grasses (m^2) from the upper catchment. The first regression, at the 100 m reach scale, compares shuffle test score in instream survey reaches to area of mixed native and exotic grasses from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the area of mixed native and exotic grasses is the mean from upstream GDZ incrementally included in the analysis.



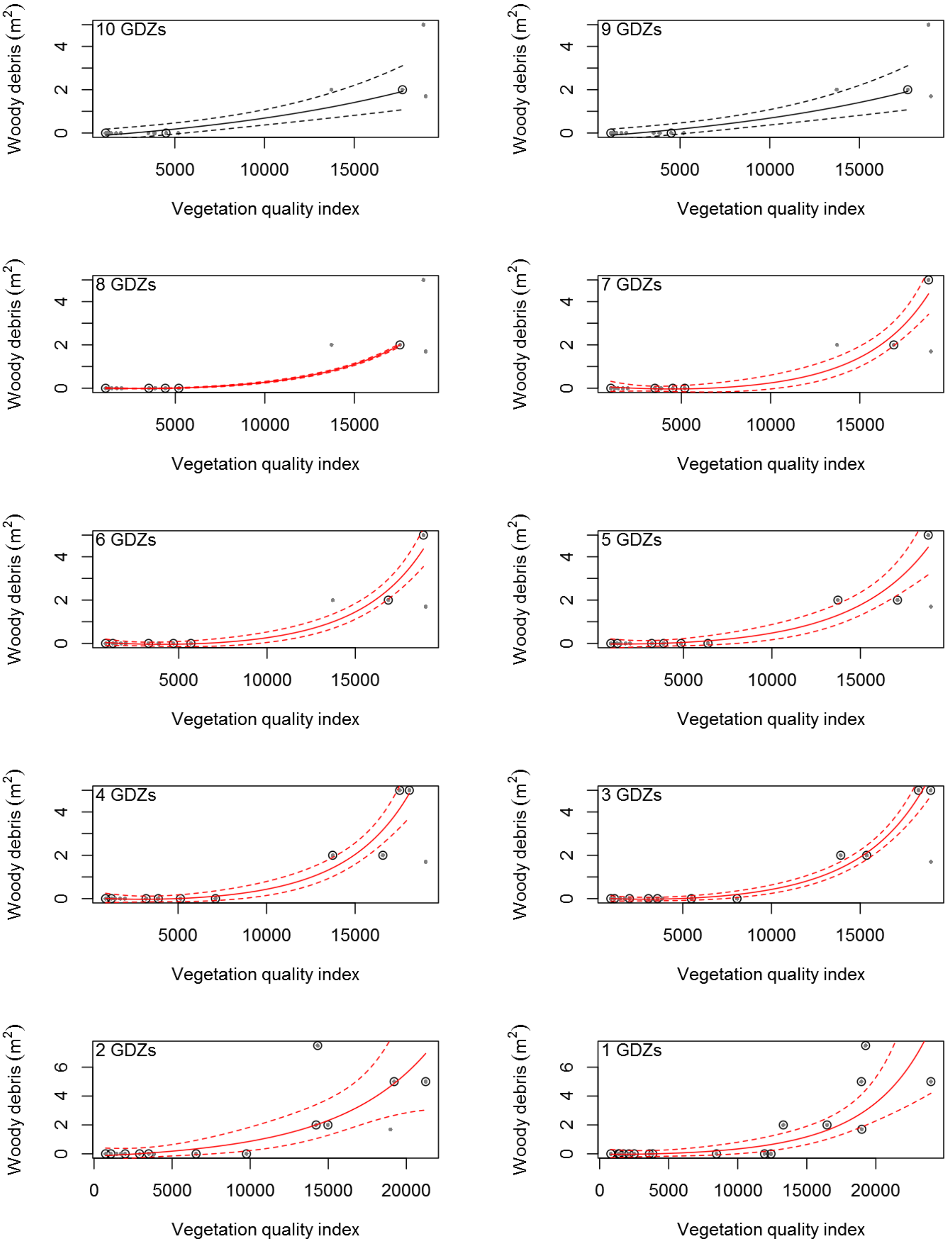
Appendix 9. Ten individual sequential regressions of residual pool depth (m) against the mean area of riparian stock exclusion fencing (m^2) from the lower catchment. The first regression, at the 100 m reach scale, compares residual pool depth in instream survey reaches to the fenced riparian area from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the fenced riparian area is the mean from upstream GDZ incrementally included in the analysis.



Appendix 10. Ten individual sequential regressions of residual pool depth (m) against the mean area-weighted riparian vegetation quality index from the lower catchment. The first regression, at the 100 m reach scale, compares residual pool depth in instream survey reaches to the vegetation quality index scores from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the vegetation quality index scores is the mean from upstream GDZ incrementally included in the analysis.



Appendix 11. Ten individual sequential regressions of woody debris (m^2) against the mean area-weighted riparian vegetation quality index from the lower catchment. The first regression, at the 100 m reach scale, compares woody debris in instream survey reaches to the vegetation quality index scores from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the vegetation quality index scores is the mean from upstream GDZ incrementally included in the analysis.



Appendix 12. Ten individual sequential regressions of mesohabitat diversity (mean number of different mesohabitat types) against the mean area of riparian stock exclusion fencing (m^2) from the lower catchment. The first regression, at the 100 m reach scale, compares mesohabitat diversity in instream survey reaches to the fenced riparian area from adjacent GIS Defined Zones (GDZ). For each subsequent regression, the fenced riparian area is the mean from upstream GDZ incrementally included in the analysis.