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Effects of Livestock on Streams and Potential Benefits of Riparian Management. Issues and Options in the Auckland Region

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Effects of Livestock on Streams and Potential Benefits of Riparian Management. Issues and Options in the Auckland Region.

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1 Executive Summary

A literature review of the effects of livestock on streams has been conducted, involving 'filtration' of the literature by the authors for relevance to the Auckland Region. More than 250 papers and scientific reviews were screened, and 90 are cited in this report – with an emphasis on authoritative reviews, 'landmark' papers, and New Zealand literature. Much of the published literature focuses on cattle damage in the semi-arid American west, mainly natural grasslands which have always been subjected to some ungulate (hooved mammal) grazing pressure. In the humid Auckland Region, most streams were naturally forested by vegetation that was never exposed to ungulate grazing, and the stream ecology may be assumed to be adapted to conditions of heavy riparian shade. However, the general patterns of damage to riparian vegetation and soils, stream banks and channel morphology, and consequently to water quality and aquatic ecosystems, are likely to be broadly similar in different biomes.

Natural forested riparian systems in the Auckland Region had a range of functions ('ecosystem services') that maintained bank and channel stability and excellent water quality and in-stream habitat. Land clearance for pastoral agriculture, and the subsequent ingress of livestock to riparian areas and streams, has caused the following types of damage:

- Degraded remnant native vegetation in the riparian zone – further reducing biodiversity that was greatly reduced by the original land clearance
- Reduced shade and shelter – resulting in drying of soils and microclimate exposure in riparian zones, and heating of the stream water and growth of nuisance algae and macrophytes
- Compacted and damaged riparian soils – with reduced infiltration capacity and reduced trapping capacity for land contaminants
- Destabilised stream banks and channels – resulting in erosion, streambed siltation and water turbidity.
- Reduced water quality – owing to mobilisation of sediment, and direct input and overland flow of nutrients and faecal microbes from animal wastes.
- Degraded stream habitat and reduced stream health – resulting from the above damages - as indicated by changed composition of aquatic invertebrate animals, and reduced abundance of certain native fish.

Land drainage that is intended to remove excess soil moisture for pastoral farming may further degrade water quality as drains bypass the contaminant-trapping function of the riparian zone.

We expect that restricting livestock access to streams and riparian zones will mitigate much of the damage catalogued above. Permanent exclusion of livestock by fencing is the "obvious" management approach, and the only one that can be regarded as promoting 'ecological restoration'. However, other management options (temporary fencing, bridging of farm raceways, and provision of off-stream water and shade) are considered briefly in recognition of their potential benefits to certain attributes of streams and riparian zones, notably water quality. The extent of the riparian recovery depends on factors such as: type of livestock and riparian management, riparian buffer vegetation and buffer size (extent of the buffer either side of streams). Time is also an important component: some functions of riparian zones (e.g. contaminant filtering) are expected to recover rapidly following restriction of livestock access, other functions (e.g. channel stabilisation) may take decades to recover.

2 Introduction

Streams draining catchments in pastoral agriculture generally have poor water quality as has been documented in New Zealand (MfE 1997; Smith et al. 1993) and overseas (Novotny 1999). There is evidence that a large proportion of the contamination of rural streams by sediment, nutrients and faecal matter is derived from livestock access to the riparian zone and the stream channel itself. However, riparian zones can function as a *sink* in trapping contaminants from agricultural lands rather than a source where riparian vegetation is in good condition and livestock are excluded or restricted (Collier et al. 1995). Livestock are known to damage remnant native vegetation in the riparian zone (e.g., Sansom 1999) and destabilize stream banks, which as well as reducing contaminant trapping function, degrades ecological and biodiversity values (and amenity values) and stream habitat for aquatic life (Belsky et al. 1999). Unrestricted livestock access to streams and riparian zones appears to be widespread throughout the rural areas of New Zealand (MfE 1997) and the Auckland Region.

The Auckland Regional Council (ARC) is currently developing rules and policies as part of its Air, Land, and Water (ALW) Plan – a plan that will provide the framework for management of activities affecting the water quality of streams and other waters in the Auckland Region. Furthermore, a two-volume guideline for management of riparian zones in the region is in preparation (Ken Becker, ARC pers. comm.). The ARC requires a scientific review of the effects of livestock on streams and riparian zones and of potential benefits of approaches to control of livestock access to support the LAW plan and the riparian guideline in particular.

This report provides a technical foundation (justification and practical approaches) for managing stock access to streams. A brief review is given of the *functions* of intact riparian zones (comprising broadleaf forest in the Auckland Region). Based on a survey of the international and New Zealand literature, we categorise the *effects* of livestock on streams and their riparian zones - according to impacts on: (1) riparian vegetation and soils, (2) channel morphology and habitat, (3) water quality (4) stream life and (5) amenity values. This categorisation is used as a basis for discussion of the *benefits* of controlling livestock access to riparian zones. The benefits are not limited to water quality improvement and improved aquatic habitat and stream "health", but include benefits to the terrestrial ecology of riparian zones, indigenous biodiversity, and aesthetic and recreational amenity. The report discusses some practical *livestock control* approaches, particularly exclusion by fencing, but with reference also to "passive" control options such as off-stream provision of water and shade, and farm race bridges. The time-scales required for recovery of various riparian functions following management action may vary appreciably (months to decades or even centuries) and are the subject of active research.

The focus in this report is on permanent streams. Ephemeral and intermittent streams are not considered separately, although we recognise these as part of the expanded channel network during rainstorms that entrain contaminants from land. Intermittent streams may have lessened habitat value (because they sometimes lack flowing water), but in a general way the discussion that follows is applicable to these water bodies as well as permanent streams. Other aquatic resources besides streams, including riparian and headwater wetlands and in-line ponds, are not the primary focus of this report, although some of the options for livestock management that are discussed here may be useful to protect the margins of these waterways. Lakes and regionally significant wetlands (e.g., "Te Henga wetland") are beyond the scope of this report. Passing attention is given to the effect of livestock on sedimentation in, and water quality degradation of, downstream lakes and coastal waters.

For the purpose of this report, livestock includes mainly sheep and cattle, but reference is also made to deer and goats. Livestock access is defined as direct incursion by domestic animals into the channel or riparian zone of streams or rivers, including access for drinking, grazing, micro-climatic shelter and cooling, and crossing.

3 Methods

This report is based on a review of the literature with emphasis on scientific papers and reviews in refereed journals. Despite our preference for peer-reviewed scientific work we have given due regard to the wider literature including position papers and guideline documents. There are comparatively few relevant New Zealand publications, so we have had to interpret and 'filter' the international literature for application to New Zealand's, and the Auckland Region's, particular combination of climate, biogeography and farming operations.

In this report we have used mainly *reviews* of the international scientific literature and New Zealand references where they are available. A search on the literature database "Aquatic Sciences and Fisheries Abstracts" (ASFA) was carried out with the search terms: ('stream' or 'riparian') and ('cattle' or 'livestock' or 'cow' or 'sheep'). This uncovered about 220 references between 1978 and 2001, of which over 100 were inspected directly. This literature was augmented by the authors' own 'Current Contents' profiles and a library on riparian papers produced by DIALOG. A search was also made of SIRIS, the crown research institute's database, in order to uncover New Zealand literature (particularly 'grey' literature) not otherwise abstracted in these international databases. More than 250 references in total were inspected, of which 90 are cited in this report. The bibliographic system EndNote (Niles Software Inc., Berkeley, CA 94710, USA) was used to keep track of citations and construct the bibliography for this report.

Although the international and New Zealand literature was central to our approach, this report relies considerably on the *personal judgement* of the authors regarding relevance to the Auckland Region. Many of our statements and interpretations are, therefore, *speculation* rather than scientifically well-proven ideas. These areas of speculation are often priority topics for research.

4 Functions of Riparian Zones

A good way to conceptualise the natural functions of intact, undisturbed riparian zones is the following 'thought experiment' with reference to Figure 1 (from Collier et al. 1995). The following discussion is similar to that given by MfE (2001). Consider the pristine streams in the Auckland Region, prior to human disturbance. The Auckland Region is in a forest biome, consequently the streams are surrounded by riparian associations of plants at high foliage density which merge upslope with mixed podocarp-broadleaf lowland forest. We can reasonably assume that stream ecology in the Auckland Region is adapted to the high shade (around 1% lighting – Davies-Colley & Payne 1998) of dense riparian forest.

Figure 1: Characteristics of riparian zones (from Collier et al. 1995)

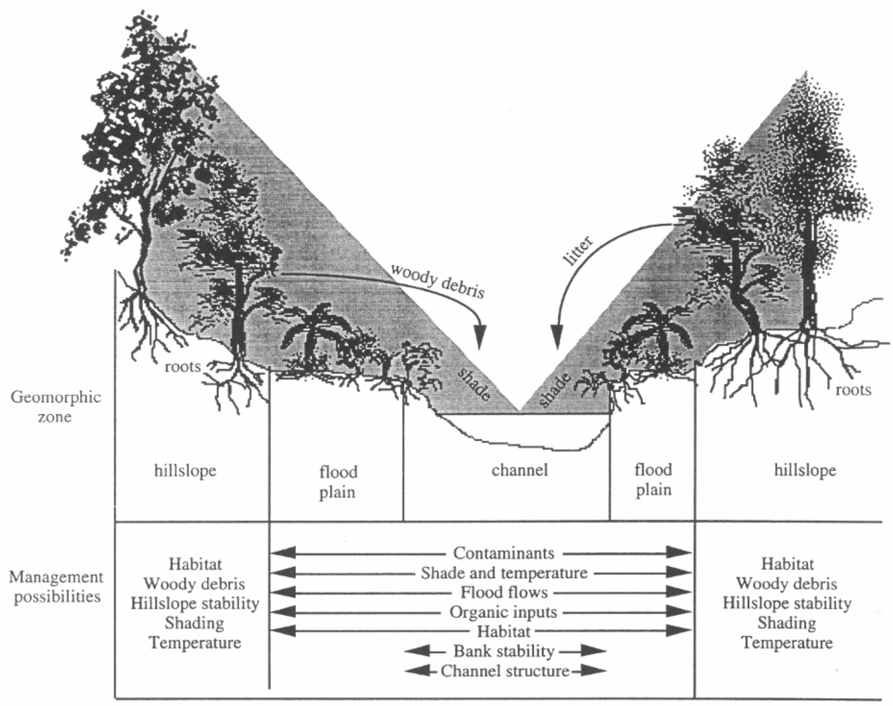


Table 1 (slightly modified after Davies-Colley 2000b) categorises the functions of the riparian zone of such streams. The riparian forest filters and traps particulate contaminants (sediment and nutrients) generated on land, mainly by infiltration (Lowrance et al. 1997), with the result that water quality is very high as indicated, for example, by high visual clarity. Dissolved nutrients in surface and subsurface flows are also processed and removed or retained (phosphorous) in the riparian zone. Nitrate is stripped from runoff water by denitrification in riparian or wetland soils or by nutrient uptake by the riparian vegetation.

The near-complete forest cover, with only a minor or no canopy gap over the channels (Davies-Colley & Quinn 1998), shades the streams and their banks from sunlight and solar heating, shelters the riparian zone from wind exposure and desiccation, and stabilises the banks to flood erosion. Trees in the riparian zone that die and fall into the channel provide large pieces of woody debris that are very stable, particularly owing to attached root wads that 'anchor' against all but extreme floods (Evans et al. 1993b). Such wood may be particularly important in stabilising the channel of forested streams, in retaining bed sediment and organic matter, and providing habitat (Evans et al. 1993a). Catchment-derived dissolved organic matter and leaf litter that falls into the stream dominate the energy base of aquatic food webs – given that the low lighting limits in-stream primary production.

Last, but not least, these streams in their natural state are beautiful and a focus for human scenic appreciation and recreation. Little research internationally seems to have been done on the aesthetics of riparian corridors, but a panel study in NZ by Mosley (1989) suggests that the "naturalness" conferred by indigenous forest on the banks is a strong predictor of aesthetic quality of 'riverscapes' in New Zealand.

There are no native ungulate animals occurring naturally in the riparian zone of these streams, and the only browsing (originally) was that by large ratite birds (moa). Introduction of ungulate livestock, whether or not all the original riparian forest was cleared or burnt, may be expected to have produced a cascade of ecological changes.

Table 1: Functions of (intact, forested) riparian zones (modified after Davies-Colley 2000b)

Major category	Functions	Example NZ references
Water quality	Low erosion, stable banks, little sediment	Wilcock (1986)
	Denitrification, nutrient uptake	Cooper (1990) Cooper et al. (1995)
	Filtration of land contaminants	Smith (1989) Williamson et al. (1996)
Stream habitat	Shade and temperature moderation	Davies-Colley & Payne (1998) Rutherford et al. (1997)
	Food (particulate organic matter, POM)	Collier et al. (1995)
	Tree roots and large woody debris (LWD)	Collier et al.(1995)
	Geomorphic aspects (banks, substrate)	Quinn et al. (1997) Davies-Colley (1997)
Terrestrial ecology	Microclimatic shelter and shade	Davies-Colley et al. (2000)
	Biodiversity	MfE (1997)
	Migration corridors	MfE (1997)
Scenery, recreation	Forest confers 'naturalness' to the riverscape	Mosley (1989)

5 Effects of Livestock on Streams and Riparian Zones

Much of the research on the effects of livestock on streams has been done in the semi-arid rangelands of Western North America, and this body of work has been most recently reviewed by Belsky et al. (1999). This research, and mounting political pressure for improvement, has recently led to law changes regarding livestock use of riparian areas (Feller 1998). This is despite criticism by Rinne (1999) that the literature on livestock impacts on streams in the American west often lacks scientific rigour as regards replication and proper control of experimental studies (much was categorised by Rinne as "opinion", "summary" or "review" rather than reporting new scientific data). A problem for wider application of findings from the American West is that the research in this semi-arid landscape, mainly natural grasslands that have always been subject to some grazing pressure from ungulates, may not always apply to more humid areas that were naturally forested (e.g., Clark 1998) - such as the Auckland Region of New Zealand.

Table 2 categorises the impacts of livestock on attributes of the stream and its riparian zone. We have modified this table after that of Belsky et al. (1999) with reference to a broadly similar table given by Rutherford et al. (1999). In doing so we have taken account of the humid climate of the Auckland Region (in a forest biome) as well as regional characteristics of pastoral farming. According to Belsky et al. (1999) all of the environmental changes induced by livestock access to streams and riparian areas in the American west are negative (degrading). This will certainly be so in the Auckland Region in which streams were never naturally subjected to ungulate grazers.

5.1 Riparian vegetation and soils

Grazing pressure by ungulate livestock acts to 're-set' the successional processes by sustaining pasture in originally forested areas such as the Auckland Region where natural (undisturbed) succession favours ultimate reversion to forest. Where remnant native vegetation persists, browsing by livestock clips back the vegetation and prevents regeneration of seedlings, so that the original forest is fragmented into isolated stands of mature trees (Askey-Doran & Petit 1999; MfE 1997). These stands are often in poor condition owing to microclimate exposure. Browsing by goats is probably more damaging to trees and shrubs than that by sheep and cattle, but the relatively high hoof pressures of cattle may be very damaging to tree roots (Williatt & Pullar 1983). Sheep graze grass very closely to the soil, and major damage to upland soils, vegetation and biodiversity in Britain has been attributed to increases in sheep stocking rates since World War II (Sansom 1999).

One of the most damaging results of the destruction of remnant forest and the artificial maintenance and extension of pasture in the riparian zone of streams is severe microclimatic exposure of the stream and its banks. This microclimate exposure combined with dense growth of light tolerant, often alien, species (such as grasses) discourages regeneration of forest plants, resulting in further increases in number and dominance of alien species (Petit et al. 1995). In addition, the source of woody debris to the stream is removed with the destruction of the forest – with long-term ramifications for the stability of channels and for organic retention and micro-habitat.

As well as damaging vegetation, livestock damage the underlying riparian soils by trampling (Belsky et al. 1999). Compaction and break-down of soil aggregates may be the most damaging result (Nguyen et al. 1998), with consequent reduced infiltration and increased contaminant runoff (Cooper et al. 1995). Soil erosion, as indicated by land surface degradation of tracks versus residual patches of un-impacted soil, can be rapid under heavy livestock pressure in riparian zones (Trimble & Mendel 1995). The soil damage in the riparian zone may cause appreciable reduction in the trapping of contaminants from upslope, and result in the riparian zone becoming a source of sediment (Trimble & Mendel 1995) and other pollutants.

5.2 Channel morphology and habitat

Effects of livestock, primarily cattle, on riparian soils, stream banks and channels have been comprehensively reviewed by Trimble & Mendel (1995). Cattle actively seek riparian zones – in humid New Zealand as well as in semiarid regions (AgResearch-NIWA 2000), for shelter and cooling as well as drinking water and forage. Their large weight and high hoof pressure makes them particularly damaging to riparian soils and stream banks. In the semi-arid American west, widening of stream channels is a frequent result of cattle damage (Belsky et al. 1999; Kauffman & Krueger 1984; Platts 1991). However, widening can be limited mainly to cattle access points ("cattle ramps" – Trimble 1994) where cattle force a path to the channel and then progressively 'develop' that track over time (Plate 1). In humid zones such as the Auckland Region, hummocky topography near streams caused by bank slumping induced by cattle seems anecdotally common.

Sheep seem appreciably less damaging to stream banks than cattle (e.g., May & Davis 1982 cited in Kauffman & Krueger 1984; Williamson et al. 1992) probably because of their lighter weight and consequently lower hoof pressures (ORC 1996). Also, sheep have less affinity for water than cattle and seem less likely to actively force access to riparian zones (Askey-Doran 1999). Thus stream bank slumping and destabilised channels seem to be more of a feature in cattle land than sheep-grazed land. However Armour et al. (1994) illustrate recovery, after sheep removal, from appreciable damage to a stream in Idaho. There seems to be an absence of scientific literature relevant to deer and goats, but we might expect their stream damage potential to be intermediate between that of cattle and sheep. Deer seem to seek out water and anecdotally their 'wallowing' activity is very damaging to headwater wetlands.

Plate 1: Channel widening as a result of cattle access to streams

An important point to keep in mind when considering the damage to stream banks caused by stock is that pasture streams are appreciably *narrower* than in forest – owing to the accumulation of sediment and armouring of the banks by grass turf (Davies-Colley 1997; Sweeney 1993; Trimble 1997). The widening induced by livestock (especially cattle) seems unlikely to reverse the narrowing (typically 50% - Davies-Colley 1997) that has occurred since clearance of the original forest for grazing. Indeed, widening of stream channels in the Auckland Region seems likely to ensue with restriction of livestock access if this results in invasion of woody plants that shade out riparian grasses (Davies-Colley 2000a).

Mobilisation of riparian soils and bank slumping promotes 'siltation' of the sediment bed of streams by fine sediment (clay, silt, sand). This results in increased suspendible sediment in the substrate (Quinn et al. 1997) and increased 'embeddedness' of coarse grains (e.g. cobbles) as well as increased sediment yield and turbidity (= reduced visual clarity) in receiving waters.

Livestock damage to riparian vegetation, not to mention the original clearance of forest for grazing, leads to reduced shade and, consequently, increased solar heating of the stream water. Solar heating is typically the single most important term in the heat balance of water in small streams (Rutherford et al. 1997). Consequently, the diurnal temperature maxima on bright days are appreciably higher (often by 8 °C) in small pasture streams, compared with maxima under forest shade, possibly resulting in elimination of sensitive aquatic invertebrates (Cox & Rutherford 2000; Quinn et al. 1994) and stress some native fish (Richardson et al. 1994) from exposed streams. Even tall grasses can produce appreciable shade over very small streams, such that reduction of this shade by grazing livestock can markedly increase peak temperatures (Quinn et al. 1992b).

5.3 Water quality

Smith et al. (1993) have reported that streams in New Zealand draining pastoral agriculture are elevated in all of the 'big dirty three' contaminants of non-point source (NPS) pollution: sediment, nutrients and faecal matter (refer also the State of the Environment Report, MfE 1997).

Several studies have shown greater sediment yields (typically by a factor of 5) from pasture compared to forest catchments in New Zealand (Smith et al. 1993; Wilcock 1986). Livestock damage to riparian vegetation and soils (Plate 2) destabilises the banks and leads to mobilisation of fine sediment (Trimble 1994), that in turn causes sedimentation in the channel and turbidity (= reduced clarity) in the stream water column (e.g., Waters 1995). In addition, more runoff of sediment occurs from soils disturbed and compacted by livestock trampling (Nguyen et al. 1998). The resulting increased sediment load and accompanying particulate nutrients may contribute to eutrophication and sedimentation of lakes and estuaries down-stream (e.g., Williamson et al. 1996). Some studies (e.g., Owens et al. 1996) have shown that exclusion of livestock from channels and riparian areas by fencing can appreciably decrease sediment yields from catchments.

Plate 2: Cattle trampling of stream banks

Livestock contribute nutrients directly to streams and riparian areas in their dung and urine. Deposition on soils damaged by treading (Nguyen et al. 1998; Trimble & Mendel 1995) may be significantly contaminating because of a strong interaction of riparian geomorphic damage and water quality. Apparently, faecal material deposited in the riparian zone is readily washed overland into the stream with little opportunity for filtration of contaminants by (reduced, damaged or absent) vegetation or infiltration into (compacted) soil.

Much work in New Zealand has focussed on nutrient contamination of agricultural streams, and has shown generally much higher nutrient yields from grazed catchments (e.g., Cooper & Thomsen 1988) – in broad agreement with findings overseas (e.g., Duda & Finan 1983). The introduction of nitrogen-fixing clovers, use of nitrogen fertilisers, including the practice of spreading animal wastes on pastures, and direct addition of stock urine and faeces in pastures have increased the amounts of nutrients yielded from pastoral catchments. However, the relative importance of these sources of nutrients do not appear to have been determined experimentally. In Auckland, as in New Zealand generally, the *intensity* of livestock NPS pollution is moderate, but the *widespread scale* of this pollution produces a large amount of *total* pollution (MfE 1997; Smith et al. 1993; Wilcock 1986) – measured as nutrient yield from a catchment. Grass buffer strips that are fenced to exclude stock have been shown to be effective at filtering sediment and sediment-associated pollutants (particularly P and N, Smith 1989), although forested buffers are better for removal of nitrate from subsurface flows (Fennessy & Cronk 1997, Martin et al. 1999). Headwater and riparian wetlands are known to be key sites of denitrification (Cooper 1990), and trees planted in riparian zones could potentially shade or dry out these wetlands so reducing their nutrient attenuation function.

By comparison with nutrients and sediment, faecal contamination has received less research effort until recently, possibly because of prevailing perception that animal faecal matter is of lesser sanitary significance than human faecal contamination. However, Donnison & Ross (1999) showed that a range of human pathogens occur in wastewaters and waters contaminated mainly or exclusively by domestic livestock in New Zealand, including *Cryptosporidium* and *Campylobacter* (for which NZ has one of the highest reporting rates in the world). This suggests that livestock faecal contamination of streams must be regarded as a significant health risk. Smith et al. (1993) have reported that faecal contamination is appreciably higher in pasture than forested streams, and Davies-Colley & Smith (1995) have shown that the characteristic level of faecal contamination of streams increases with proportion of the catchment in pasture. As well as being of major concern for recreational exposure, faecal contamination of streams is a concern for shellfish harvesting and recreation in downstream coastal waters (G. McBride, NIWA, pers. comm.). It is interesting to highlight evidence that sheep faecal matter may carry a *greater* burden of potential human pathogens than cattle, possibly because sheep are flock animals that suffer appreciable cross-infection (Andrea Donnison, AgResearch, pers. comm.).

The relative importance of deposition of faecal matter in the channel versus the catchment of rural streams seems to be an open research question with major management implications. At present the relative importance to overall faecal contamination of direct voiding during the 1% or so of the time that livestock are in the channel (AgResearch-NIWA 2000), compared with overland flow from the catchment, is not clear from the literature but probably depends on a number of factors including land topography, land use (effluent irrigation), soil drainage characteristics, and rainfall distribution. However, the efficient trapping of faecal indicator bacteria by even very narrow (few m) grass filter strips, suggested to Larsen et al. (1994) that direct voiding may be the more important source of stream faecal pollution. The summer peaks of seasonal NPS faecal contamination of the New Zealand freshwater bathing waters studied by Till et al. (2000) suggests that direct deposition is important, because overland flow contributions would be expected to dominate in winter. If direct deposition in the water dominates stream yields then exclusion of livestock from stream channels should confer major water quality benefits. However, if material deposited on land dominates stream yields, then, to significantly improve water quality, livestock will need to be excluded from contributing areas (where overland flow occurs - including riparian zones, ephemeral channels and headwater wetlands), rather than merely the permanently flowing channels.

The bulk of the faecal contamination in streams in grazed land is in the stream sediments rather than the water column (Stephenson & Rychert 1982), such that any sediment disturbance including animal wading or flood flows – or recreational use – can cause re-contamination of the water column of the stream. Faecal contamination following disturbance of pasture stream sediments is the subject of current work by Rob Davies-Colley with microbiologist colleagues at AgResearch (Muirhead 2001).

5.4 Stream life

The degree of catchment development to pastoral land use, water temperature and level of nutrient enrichment were identified as the most important factors affecting invertebrate community structure in a study of 88 New Zealand rivers (Quinn & Hickey 1990). Benthic invertebrate communities have increased in density and biomass in many pasture streams, but the community composition has changed to favour pollution-tolerant species (Quinn et al. 1997, Scott et al. 1994). The lack of stream shade appeared to be the most important factor affecting invertebrate populations in Waikato hill-country streams (Quinn et al. 1997). In small streams in Southland, intensive grazing (15 stock units per ha) of riparian vegetation by cattle greatly reduced shade and consequently raised water temperatures and changed invertebrate communities (Quinn et al. 1992b).

Direct impacts on biota of livestock entering streams are difficult to separate from those of general pastoral land use such as deforestation and nutrient inputs from overland flow. For instance, increased light levels from tree removal can facilitate the growth of algae, but nutrients found in animal wastes also stimulate algal and aquatic plant growth, and these may be deposited directly by animals or washed in from overland flow of grazed paddocks.

Studies comparing ungrazed versus grazed riparian areas and rotational grazing practices can potentially be used to distinguish impacts from direct livestock use of waterways. For instance, in North American streams, Weigel et al. (2000a) found that the macroinvertebrate community response suggested higher organic pollution in continuously grazed sections compared to woody buffered sections, but grassy buffers and rotational grazing had macroinvertebrate assemblages that showed intermediate effects. Weigel et al. found that catchment differences produced greater overall differences in the invertebrate communities than between different grazing treatments along the same stream. This is a common problem with interpretation of riparian buffer zone studies, as the inherent variability of streams, often reflecting wider catchment (e.g., hydrological) factors, can mean that the same management technique can have variable outcomes in different stream systems (Belsky et al. 1999). Sovell et al. (2000) also found that faecal coliforms and turbidity were greater at continuously grazed stream sections than at rotationally grazed sites, but were unable to show associated changes to the macroinvertebrate or fish communities. These results suggest that livestock with direct access to streams cause nutrient and faecal pollution, and turbidity, but impacts on invertebrate and fish communities are more subtle (or non-existent), depending on stream characteristics.

The main potential impacts to fish populations from livestock access to streams include: trampling of stream banks, which destroys undercuts and other bank refuges that are micro-habitat for fish and crayfish, decreased visual water clarity (which interferes with prey capture for sight-hunting fish (Rowe & Dean 1998), increased siltation and smothering of gravel habitat, and trampling or browsing of streamside vegetation that provides cover or spawning habitat for fish (Belsky et al. 1999; Jowett 1997; Kauffman & Krueger 1984; Williamson et al. 1992). In North America, there is evidence that livestock grazing has reduced fish biomass and the percent of salmonid fishes (Kauffman & Krueger 1984), although it is still difficult to discern whether this is solely the effect of livestock or an interaction with lack of shading (which can also be promoted by livestock browsing) and consequent increased peak water temperatures (Belsky et al. 1999). In New Zealand, indigenous fish (predominantly eel) abundance and biomass has increased in pasture streams, apparently due to increased temperature, nutrient enrichment and consequently increased primary production (Hicks & McCaughan 1997), but the diversity of species has declined, possibly due to a reduction in suitable habitats (e.g., woody debris) and increased siltation (Hanchet 1990). Grazed riparian areas may also impact on spawning habitat and microclimate conditions for inanga in lowland streams and potentially for other galaxiid fishes in upland streams (Richard Allibone pers. comm.)

The degree to which livestock access to streams affects benthic invertebrate biodiversity and habitat depends on a number of factors including: size of streams, steepness of banks, frequency of storms, intensity of grazing, soil type, and number of riparian trees (see Clark 1998). For instance steep tall stream banks may deter stock from entering streams and access may be limited to crossing areas. There is some evidence to suggest that the effect of livestock crossing on biotic diversity is locally severe, but attenuated within relatively short distances downstream (Clark 1998). However, where banks are low, particularly in small streams, areas of visible bank damage can be much more extensive in grazed as opposed to fenced riparian areas (Parkyn unpubl. data) and therefore the effects on habitat and water quality are spread over a greater stream length.

5.5 Amenity values

We were not able to find any studies in the refereed international literature, or in New Zealand literature, on the impact of livestock on scenic and recreational amenity values of streams. This would seem to be an important research gap, because few would doubt the scenic beauty of streams (Mosley 1989), and their amenity value may be lessened by livestock damage to stream banks, vegetation, and by accumulations of faecal matter. Recently, Meyer (1997) made a plea for stream ecologists to consider 'human dimensions', including aesthetic qualities of streams, in overall assessment of stream health. A panel study in New Zealand by Mosley (1989) suggests that the riparian condition is a major factor in river scenic quality, the single best predictor being amount of native forest in the riverscape. Slumped stream banks and degraded riparian vegetation, not to speak of livestock faecal deposits, seems likely to suggest "pollution" to many people, including tourist visitors to New Zealand.

Table 2: Effects of livestock on stream attributes (Table modified after Belsky et al. 1999; see also, Rutherford et al. 1999).

Attribute	Responses	Mechanisms	Impacts	Selected references
Riparian vegetation and soils				
Tree and shrub cover	Generally reduced (fragmented) Altered spp. composition	Livestock browsing, Livestock damage to roots and stems Exposure to wind and sun – drying	Exposure and desiccation Reduced shade, incr. temp. Reduced channel stability Reduced food supply to the stream Weed invasion	Trimble (1994) Kauffman & Krueger (1984) Fleischner (1994) Trimble & Mendel (1995) Sansom (1999)
Herbaceous cover	Reduced Altered spp. composition	Livestock grazing and browsing	Reduced shade, incr. temp. Reduced cover for fish Weed invasion	Kauffman & Krueger (1984) Petit et al. (1995) Trimble & Mendel (1995) Sansom (1999) Quinn et al. (1992b)
Native biodiversity	Reduced	Livestock grazing and browsing and mechanical damage to vegetation	Reduced conservation value	Fleischner (1994) MfE (1997)
Soil condition	Degraded	Increased bare ground, Compaction and reduced infiltration	Greater surface runoff, Soil erosion Increased delivery of contaminants	Trimble & Mendel (1995) Belsky et al. (1999) Sansom (1999) Cooper et al. (1995) Nguyen et al. (1998)
Channel morphology and physical habitat				
Channel stability	Reduced	Streambanks disturbed by livestock	Bed siltation, local widening Reduced in-stream habitat quality	Kauffman & Krueger (1984) Platts (1991) Trimble & Mendel (1995) Williamson et al. (1992)
Channel width	Reduced * (increased locally)	Pasture grasses armour against fluvial erosion and trap sediments Channel width may *locally* increase at livestock crossings	Reduced benthic habitat Reduced *quality* of benthic habitat	Sweeney (1993) Trimble (1994) Trimble & Mendel (1995) Davies-Colley (1997)
Bed sediment texture	Decreased	Siltation of the streambed by fines	Reduced interstitial water exchange Reduced epilithic food quality Reduced benthic habitat quality	Myers & Swanson (1996) Quinn et al. (1992a) Quinn et al. (1997)
Water temperature	Peaks increase	Reduced riparian shade (in part by browsing, most through deforestation)	Elimination of cool-water organisms (incl. some fish and some inverts) Increased growth of nuisance plants	Platts (1991) Li et al. (1994) Rutherford et al. (1997) Cox & Rutherford (2000)

Attribute	Responses	Mechanisms	Impacts	Selected references
Contaminants degrading water quality				
Sediment load & turbidity … Visual clarity	Increased …Reduced	Trampling and grazing leading to bank erosion and sediment suspension Reduced entrapment in riparian vegetation	Bed siltation, reduced interstitial water exchange, Altered habitat for sighted animals Reduced epilithic food quality	Trimble & Mendel (1995) Waters (1995) (see Wood & Armitage (1997) for review) Stassar & Kemperman (1997)
Nutrients (N & P)	Increased	Voiding in stream channel Runoff from contributing areas in catchment Reduced entrapment in riparian vegetation	Proliferation of nuisance plants in streams Eutrophication of downstream waters	Duda & Finan (1983) Smith et al. (1993) Cooper et al. (1995) Williamson et al. (1996)
Faecal microbes	Increased	Defaecation in stream channel Runoff from contributing areas in catchment Reduced entrapment in riparian vegetation	Health risk to humans Health risk to domestic livestock Increased water treatment costs Contamination of shellfish in downstream estuaries	Stephenson & Rychert (1982) Larsen et al. (1994) Smith et al. (1993) Donnison & Ross (1999)
Stream life				
Nuisance plant growths (algae and macrophytes)	Increased	Increased lighting and nutrients	Nuisance growths pH and dissolved oxygen excursions	Li et al. (1994) US EPA (1995) Biggs (2000) Wilcock et al. (1995)
Macrophytes		Trampling and grazing	Reduced in-stream nutrient attenuation	Belsky et al. (1999)
Invertebrates	Altered community	Higher water temperatures Bed sedimentation and reduced food quality Higher algal biomass	Lower IBI Less mayflies, stoneflies and caddis flies	Weigel et al. (2000b) Quinn et al. (1997; 1992b) Quinn (2000)
Fish	Altered spp.	Generally degraded habitat, Reduced cover Higher water temperatures Higher turbidity and bed sedimentation Altered invertebrate food	Reduced salmonid production Reduction in diversity of native spp (possible local extinction) Increase in pollution tolerant fish (e.g. eels)	Platts (1991) Li et al. (1994) Armour et al. (1994) Rinne (1999) Kauffman & Krueger (1984) Hicks & McCaughan (1997) Hanchet (1990) Rowe et al. (2000)
Amenity values				
Scenery & recreational appeal	Degraded	Damaged vegetation and slumped banks Reduced native tree and shrub cover Deposits of faecal matter	Reduced scenic quality Reduced recreational values	Mosley (1989) MfE (2001)

International references are major reviews or landmark papers *(New Zealand references given where available/known)*

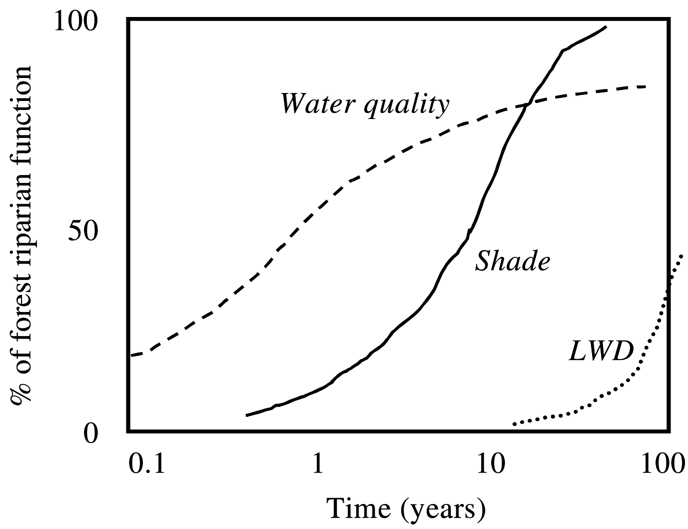
* Channel width is increased by ungulate grazing damage in the semi-arid American West. However, in naturally forested humid areas, channel width tends to be decreased in grazed pasture owing to armouring by grass turf - with the exception of livestock crossing areas which may be widened (Davies-Colley 1997; Trimble & Mendel 1995)

6 Benefits of Reduced Livestock Access to Riparian Zones

Reduced livestock access to riparian zones and stream channels is expected to have major benefits to stream water quality and stream ecosystem health by partial reversal of the impacts categorised in Table 2. Most of these benefits are general and are enjoyed mainly by downstream water users – including other graziers. However some benefits potentially accrue to the grazier on site (Askey-Doran & Petit 1999) – healthier stock through unpolluted water supply, reduced loss of animals trapped in wetland areas or from grazing of poisonous riparian or semi-aquatic plants (e.g., sweetgrass, Barton et al. 1983), easier mustering and stock management, and provision of shelter near riparian trees (Gregory 1995). Yet another benefit to the grazier is the 'feel-good' factor of being a good citizen in the environmental sense. A glossy US EPA publication targeted at ranchers (Chaney et al. 1993), gives graphic examples of livestock damage to streams in the American West, and appeals to graziers' sense of citizenship to improve riparian conditions. There are also moves by producer boards towards quality assurance guidelines on 'sustainable' farming operations so as to maintain ability to trade on New Zealand's 'clean-green' image (e.g., NZ Dairy Board, pers. comm. Jim Barnett).

Not all these benefits will occur immediately after removal (exclusion) or reduction in livestock access. Some aspects of riparian function may recover very rapidly, others may take decades or even centuries. Figure 2 shows schematically how hypothetical 'recovery curves' might track for three riparian functions following livestock exclusion and riparian planting.

Figure 2: Schematic showing the hypothetical time course of recovery of some riparian forest functions following livestock exclusion and tree planting (from Davies-Colley 2000b)



An immediate water quality improvement is expected once livestock are removed/managed because of removal of the *source* of animal waste deposition in the stream channel and contributing near-channel areas. Thereafter water quality may continue to improve more slowly (months to years) as riparian soil and vegetation recovers and faecal bacterial stores are flushed from the stream sediment and riparian zone. Water quality may never be restored completely to that of a fully forested catchment if some or most of the catchment continues to be grazed by livestock, because nutrient trapping in riparian zones is not 100% efficient, and some sources may bypass the buffers, e.g. runoff from farm roads and discharge from field drains.

7 Options for Livestock Management to protect Streams

Grazing animal damage to streams and riparian zones is dependent on timing of animal access, fencing, and access to water and shade/shelter as it affects livestock behaviour (Askey-Doran & Petit 1999; Clark 1998). The most 'obvious' management intervention for livestock control is permanent fencing to exclude livestock from stream channels and a greater or lesser amount of the riparian land. Table 3 lists some management approaches to reducing or removing livestock impact on streams and riparian zones, beginning with permanent fencing.

Askey-Doran (1999) gives a number of useful suggestions for permanent and electric fencing near and across streams, including novel methods to avoid flood damage to fencing infrastructure. Some guidelines on fencing are also given in Collier et al. (1995). AgResearch-NIWA (2000) recognise that the international and New Zealand literature provides evidence for the benefits of fencing, but maintain that landowners such as dairy farmers need assistance to make site-specific decisions on placement of fences and priority areas for fencing. Note that exclusion of cattle from the stream by riparian fencing will generally require provision of off-stream water.

There are a number of other options designed to reduce livestock damages to streams, that do not attempt to restore the riparian zone to the original native vegetation, but may still confer useful benefits (mainly as regards water quality) (Fitch & Adams 1998; Leonard et al. 1997). These options (Table 3) include:

- grass buffer strips that are maintained by weed control, light grazing or mowing (e.g., for hay production)
- grazing regimes that permit limited recovery of (grass) vegetation and banks between grazing episodes,
- space planting of trees with controlled grazing beneath
- encouraging livestock away from the stream with off-stream water and shelter/shade trees,
- bridging stream channels where farm raceways intersect the channel.

Grazing animal management, by definition, requires considerable investment of time and appreciable fencing infrastructure (which may be temporary fencing) by comparison with unrestricted livestock access to the channel. However, such management has the potential to continue livestock production on the riparian land while maintaining a riparian grass buffer strip in good condition (for contaminant runoff interception) and stream bank integrity, particularly by avoiding heavy trampling/grazing damage when soils are wet. Animal management regimes in which riparian grazing continues at some (reduced) or intermittent level may be useful in the Auckland

Region for reducing water quality degradation. However these approaches may do little towards improving stream shade and cover (except in very small streams), and will probably contribute negligibly towards restoring indigenous terrestrial biodiversity in the riparian zone of Auckland Streams.

Table 3: Options for livestock management in riparian zones

Management approach	Benefits	Notes (e.g., costs, side effects, sustainability)	Example references (NZ refs - where available -italicised)
Permanent fencing	Removal of livestock pollution and geomorphic damage Maximum (eventual) recovery of vegetation – 'restoration'	Fencing cost, planting costs Weed and pest management required Planting needed for best outcome? (terrestrial biodiversity benefits) Sustainable indefinitely? (nutrient P saturation?)	Many references internationally (esp. Askey-Doran 1999) MfE (2001) Parkyn et al. (2000) Cooper et al. (1995)
Temporary fencing (electric fence)	Protects banks and channel Can be used to selectively control animal access particularly when soils are wet Short term grazing by sheep (e.g. 4h) could remove nutrients (through consumption)	Considerable management required (e.g. sheep grazing for weed control and maintenance of grass sward) No regeneration of native forest?	MfE (2001) AgResearch-NIWA (2000)
Rest-rotation grazing, 'cell' grazing	Permits soil and grass recovery between grazing episodes	Requires considerable fencing and stock management Maintains grass buffer No regeneration of native forest?	Platts (1991) Earl & Jones (1996) Askey-Doran (1999) Sovell et al. (2000)
Off-stream watering (necessary with corridor fencing)	Removes one incentive for livestock to access streams Reduced bank damage and pollution? Better stock drinking water quality	Water may not be only or main reason for stock to access streams No regeneration of native forest?	Bouchier (1996 in Askey-Doran 1999) Miner et al. (1992) MfE (2001)
Off-stream shade and shelter*	Removes one incentive for livestock to access streams Reduced bank damage and pollution?	Shade and shelter may not be only or main reason for stock to access streams No regeneration of native forest?	Askey-Doran (1999) AgResearch-NIWA (2000)
Livestock bridges on farm races	Removes livestock access where raceway intercepts stream channel	Costly? Main application on dairy farms?	AgResearch-NIWA (2000)

* Note that riparian forest, even where fenced, can provide livestock with shade and shelter along the up-slope edge

8 Issues for Riparian Zone Management Following Stock Exclusion

Once stock have been removed permanently from riparian areas, successional processes are likely to begin so that the buffer zone will eventually revert to forest, in a naturally forested area like the Auckland Region. Shade, stream temperature and microclimate shelter over the stream channel may be expected to recover slowly (years to decades) as trees re-grow in the riparian zone (Fig. 2). Recovery of the supply to the stream of large woody debris (LWD) of a size that provides habitats for fish and significantly stabilises stream channels will obviously take hundreds of years.

Woody weeds such as gorse may invade and dominate for a period of decades, unless suitable trees (e.g., kanuka, manuka) are planted at the time of riparian fencing to achieve rapid canopy cover, and providing that adequate weed control measures are taken (MfE 2001). Note however, that trees may *never* re-grow if any significant livestock grazing pressure remains in the riparian zone (e.g., Petit et al. 1995). 'Ecological restoration' of riparian zones necessarily requires complete stock exclusion because indigenous forest cannot co-exist with ungulate livestock (MfE 1997). However, rehabilitation to improve functions that enhance stream health may not necessarily require complete exclusion of stock (See Section 6 and Parkyn et al. 2000).

Riparian forest will also contribute towards restoring indigenous terrestrial as well as aquatic biodiversity in the Auckland streams. The forest provides shade and shelter from wind exposure and the consequent drying conditions of open land. Thus the microclimate of the forested riparian zone is much more equitable than in open land (Davies-Colley 2000b). Because of the sheltered forest microclimate, and also the gradients in soil fertility and moisture, the riparian zone may be habitat for a distinct assemblage of plants and animals of high overall biodiversity. These sheltered, protected, zones also provide important corridors for movement of terrestrial animals and birds (Fitch & Adams 1998).

However, there is evidence that at least one aspect of stream health, namely the sediment yield and associated water turbidity, may actually get *worse* before it gets better. Davies-Colley (1997) has shown, consistent with reports from overseas (Sweeney 1993; Trimble 1997; Zimmerman et al. 1967) that stream channels in pasture are generally narrower than in native forest. The narrower pasture channels result from sediment storage in small floodplains that are consolidated by pasture grasses – which also armour the banks against fluvial scour at high flow. Re-afforestation of pasture stream banks, following deliberate planting or invasion of woody plants, is expected to reverse this narrowing (Davies-Colley 2000a) owing to shading and eventual extinction of the grass under a developing canopy (Fig. 3). As the banks recede, the sediment stored in the stream banks will be remobilised over a period of perhaps decades and considerable sedimentation of the channel and water turbidity is expected.

This bank recession phenomenon appears to be underway in streams in the Hakarimata Range near Ngaruawahia that were converted to pine plantations about 15 years earlier from the pasture that had dominated for 70 years following the original forest clearance (Quinn et al. 1997). Avoiding such bank recession, and temporary (years to decades) degradation in habitat and water quality, may require active management of the riparian vegetation (e.g., tree pruning, weed removal, light grazing by sheep only) after livestock are excluded or reduced, so that the pastoral grass growth is not drastically limited by shading and weed competition. Such active management might only be feasible where the riparian zone is to be retained as a grassy sward to intercept contaminants and used for hay, or where tree crops are planted for which silvicultural work is economic. A possible option for small streams may be to establish a native grass/sedge community (particularly immediately adjacent to stream banks), although we do not know whether (or for how long) such a community can resist invasion by woody plants. Deciduous trees may provide another 'compromise' option, providing summer shade, bank stability, and grass filters, although limited terrestrial biodiversity benefits. Observations at Whatawhata in the Waikato indicate that a pasture sward is able to persist beneath spaced riparian plantings of poplars and willows.

When fencing and planting of indigenous species is the preferred option for riparian management, for example where near-complete recovery of natural riparian functions is desired (i.e., 'ecological restoration'), the immediate problem is how wide to make the fenced buffer. Parkyn et al. (2000) have reviewed the issue of buffer widths in the Auckland Region. They regard a 10 m buffer as the "minimum necessary for the development of sustainable indigenous vegetation", and recommended a 10-20 m range of buffer widths in order to restore most riparian functions. However, full restoration of the microclimate characteristics of a forest stream may require buffer widths of the order of 40 m (Davies-Colley et al. 2000).

Some riparian attributes (for example, avoiding animal damage to stream banks and removing direct faecal contamination by animals) may be achieved by very narrow buffers, possibly only a few metres in width. Parkyn et al. (2000) discuss the factors involved in assessing how wide buffer zones should be to fulfil various aquatic functions with reference to both grass buffer strips (maintained by light grazing or mowing) and forested buffer strips, including treatment of channelised flow and wetland areas.

9 Conclusions

In general, the literature suggests that livestock cause appreciable damage to streams and the riparian zone (Belsky et al. 1999). Livestock, particularly cattle, damage riparian vegetation and soil structure, and cause stream bank erosion, and degraded water quality. Cumulative effects of deforestation and grazing have also led to reduced stream health as indicated by invertebrate and fish communities, both in New Zealand and overseas. However the severity of these impacts may be highly variable between streams depending on climate, hydrology, landform, soil type, stream size and geomorphology, as well as vegetation cover and grazing type and intensity. In a humid environment, such as the Auckland region which is known for high intensity rainfall and in which the original riparian ecosystem was forest never subjected to ungulate grazing, the potential damage may be more severe than where grazing ungulates have 'always' been present.

Clark (1998) states that the severity of degradation of waters by livestock is "localised, site-specific and manageable, rather than being generalizable and unavoidable". We think that this is broadly correct for the Auckland Region. However, we would point out that water quality degradation is hardly "localized" if appreciable contamination of downstream water bodies, including lakes and coastal waters, occurs as a result of "local" livestock activity. The main implication of Clark's assertion, however, is that *something can be done about the damage of livestock to streams and their riparian zones*. The philosophy of this report is that reducing livestock pressure on the riparian zone, by approaches ranging from permanent fencing through to 'incentives' for stock to seek shade and water off-stream, has the potential to appreciably reduce a range of impacts on streams. This is a testable hypothesis, one that *has* in fact been tested to some extent overseas (e.g., Sovell et al. 2000), and one that warrants testing by adaptive management, guided by monitoring and scientific experiment, in the Auckland Region.

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