A review of feral goats as contributors to erosion and the benefits of goat control

horizons regional council

May 2016

Horizons Report 2016/EXT/1479

Envirolink Advice Grant 1636-HZLC130

Landcare Research Manaaki Whenua

Prepared for:

Dr Jon Roygard
Horizons Regional Council
Palmersto North

Date: May 2016
Report No. 2016/EXT/1479

Prepared by:

Phil Cowan
Landcare Research
Gerald Street
P O Box 69040
Lincoln 7640
Ph +64 3 321 9999
www.landcareresearch.co.nz

Report No. LC2520

LANDCARE RESEARCH
MANAAKI WHENUA

A review of feral goats as contributors to erosion and the benefits of goat control

Envirolink Advice Grant:
1636-HZLC130

A review of feral goats as contributors to erosion and the benefits of goat control

Phil Cowan

Landcare Research

Prepared for:

Horizons Regional Council

11-15 Victoria Avenue
Private Bag 11025, Manawatu Mail Centre
Palmerston North 4442
New Zealand

May 2016

Landcare Research, Gerald Street, PO Box 69040, Lincoln 7640, New Zealand,
Ph +64 3 321 9999, Fax +64 3 321 9998, www.landcareresearch.co.nz

Reviewed by:	*Approved for release by:*
David Latham Ungulate ecologist Landcare Research	Daniel Tompkins Portfolio Leader – Managing Invasives Landcare Research

Landcare Research Contract Report: LC2520

Disclaimer

This report has been prepared by Landcare Research for Horizons Regional Council. If used by other parties, no warranty or representation is given as to its accuracy and no liability is accepted for loss or damage arising directly or indirectly from reliance on the information in it.

Contents

Summary

Project and Client

- Horizons Regional Council requested a review of the contribution of goats to erosion and the benefits of their control, with particular reference to the Whanganui River catchment. This was completed by Landcare Research with funding from Envirolink Small Advice Grant 1636-HZLC130.

Methods

- Literature searches were undertaken for published material on feral goats and their impacts, with a focus on New Zealand. Material was reviewed and summarised for this report.

Conclusions

- It is difficult to separate the effects of goats on vegetation from those of other browsing mammals and thus their contributions to erosion. Despite this, available data from New Zealand and elsewhere suggest that goat control has benefits for soil retention and local-scale erosion control provided goat numbers are suppressed sufficiently and for long enough to allow vegetation recovery.
- There are no published data that relate monitored vegetation condition, goat density, and the efficacy and costs of goat control with which to assess the current situation in the Wanganui River catchment. There are also no data on the costs of damage by goats to erosion control plantings.
- At a broad scale, the relationship between the browse index of Sweetapple and Burns (2002) and goat faecal pellet counts provides some guidance as to the required reduction in goat density to allow forest vegetation to recover. This is expected to incur benefits for soil retention and decrease local erosion. Importantly, controlling goats to reduce unwanted impacts on native vegetation is sufficient justification in itself.

Recommendations

Horizons Regional Council should

- partner with the Department of Conservation to collate all available information on goat density, the efficacy and costs of goat control, and monitored vegetation condition to identify what information gaps need to be filled to enable an effective assessment of the costs and benefits of goat control for erosion control
- consider adopting the approach suggested in this report (Section 5) as a way to develop risk maps to assist future planning for goat control for erosion control in the Whanganui River catchment.

1 Introduction

Horizons Regional Council requested a review of the contribution of goats to erosion and the benefits of their control, with particular reference to the Whanganui River catchment. This was completed by Landcare Research with funding from Envirolink Small Advice Grant 1636-HZLC130.

2 Goats and soil erosion

Soil erosion is a natural, continually occurring process caused when soil is exposed to water and/or wind energy, often through loss of protective vegetative cover. The impacts of both are intensified on sloping land (Pimentel & Kounang 1998). Vegetation density and distribution patterns also play a crucial role in soil erosion processes. Elwell and Stocking (1976) and Seuffert et al. (1999) suggested a vegetation cover of 30–40% was sufficient to protect soil surfaces against degradation although considerably denser vegetation cover may be needed in shrublands in mountain regions (Ries 2005). Hawley and Dymond (1988) reported that 100% tree canopy cover reduced storm damage and landslides by at least 70%. Erosion rates tend to be especially high on marginal and steep lands that have been or are being converted from forests to agricultural use (Pimentel & Kounang 1998). Soil type also influences susceptibility to erosion; soils with medium to fine texture, low to medium organic matter content and weak structural development are most easily eroded (Foster et al. 1985). By diminishing soil organic matter and soil quality, erosion reduces biomass productivity, which ultimately may have a profound effect on the diversity and biomass of organisms in ecosystems (Pimentel & Kounang 1998). Erosion may also have indirect effects on ecosystems; for example, loss of plant species diversity leading to increased drought proneness (Tilman & Downing 1994) or native fauna decline (Chynoweth et al. 2013).

The natural process of erosion may be accelerated by animals, particularly herbivorous mammals, if they deplete or substantially alter the vegetation cover of erosion-prone habitats. This may occur where native herbivores become overabundant (e.g. sika deer *Cervus nippon* in Japan; McCullough et al. 2009) or introduced mammalian herbivores attain high densities in areas previously naïve to browsing and grazing by those species (e.g. European rabbits *Oryctolagus cuniculus* in Australasia; Williams et al. 1995). However, it can be difficult to disentangle the proportional impacts of overabundant or invasive animals versus natural erosion processes (Grant 1985). This was epitomised by the debate about how much wild deer contributed to erosion of mountain lands in New Zealand. From about the 1930s–1950s, deer were believed to be largely responsible for a number of major erosion events that occurred at that time, but it is now considered that a period of atmospheric warming and associated heavy rainstorms and floods was significantly more influential than the impacts of deer browsing (Grant 1989). Although deer and other mammalian herbivores such as goats do not seem to substantially contribute to catastrophic erosion events, their feeding habits, trails created by their movements and burrows can cause local erosion and increase the yield of fine sediments that can impair downstream water quality (Grant 1989; Williams et al. 1995; McCullough et al. 2009).

Introduced feral goats are notorious for their negative impacts on ecosystems, particularly on islands (Coblentz 1978). Feral goats have been associated repeatedly with the decline of native plants and animals, the alteration of plant and animal communities (Chynoweth et al. 2013), and with accelerated rates of soil loss and erosion (Coblentz 1978; Bayne et al 2004;

Chynoweth et al. 2013; Hata et al. 2014). Impacts of goats and their contribution to increased erosion result principally from two activities and the interaction between them. First, trampling by goats, especially at high density, causes soil surface damage by destruction of soil crusts, loosening and mobilisation of soil material and physical dislodgement of soil and other debris (Atkinson 1964; Bayne et al 2004; Ries et al. 2013). Second, feeding by goats includes barking of trees and shrubs, browsing of shrub and tree crowns and browsing of forest understory (Atkinson 1964). Long-term intensive browsing by goats can change vegetation composition and structure in ways that increase susceptibility to disturbance and erosion; for example, by conversion of shrublands to grasslands (Coblentz 1978; Parkes 2005). Browsing of understory shrubs and regenerating trees may impact on succession processes. Such impacts will be exacerbated by slope and soil type effects.

Because goats are predominantly browsers, their habitat is mostly forest- or scrub-covered uplands though they will also exploit rough grasslands. They prefer a rocky substrate and their agility allows them to exploit steep slopes and ledges. Goats prefer sunny rather than shady faces, so vegetation damage and erosion are often worse at such sites (Greaves & Wedderburn 19955; Parkes 2005). Their surefootedness allows them to access steep, eroding slopes, their browsing removes vegetation cover and inhibits regeneration at such sites, and their trampling promotes soil breakup and loss (Parkes 2005).

Plantings, especially of poplar and willow poles, are a key part of Horizons Regional Council erosion control strategy. However, such plantings are highly susceptible to damage by goats. Thus goats may also contribute to ongoing erosion through the destruction of remedial plantings.

3 The diet of goats

Goat diet is relevant to the issue of soil loss and local erosion as it can indicate vegetation communities potentially most at risk of change in ways that would increase erosion risk in the absence of adequate goat control. Goats have catholic tastes although they also have strong dietary preferences. They readily browse seedlings, saplings and epicormic shoots and litter-fall. At any one site a wide range of plant species may be eaten. For example, in the Rimutaka Range 120 different plants were eaten, with 3 making up more than 50% of the diet and 40 making up 98% of the diet (Rudge 1990). The diet of goats in areas with established goat populations in the Raukumara Range differed from that of goats in newly colonised areas, suggesting prolonged goat browsing had depleted highly palatable species (Parkes 1993).

Some plants, however, appear to be unpalatable to goats, and such species may become dominant where there is prolonged goat browsing (Atkinson 1964). Various lists of vegetation preferences are available for goats (Sweetapple & Burns 2002; Parkes 2005; Husheer 2006) and these can be used to indicate both potential changes in vegetation composition under prolonged browsing by goats and suitable candidate species for monitoring to assess the outcomes of goat control. However, goats have a great capacity to digest roughage and in the absence of more palatable vegetation can survive on harsh woody vegetation such as blackberry (*Rubus fruticosus*) and gorse (*Ulex europaeus*). This capacity enables their persistence in areas even in the face of extensive changes in vegetation cover (Coblentz 1978).

4 Density-impact relationships and the benefits of goat control

Cost-effective management of feral goats requires knowledge about the minimum control effort or maximum allowable goat density that is needed to achieve a defined outcome. However, these relationships are poorly quantified for feral goats, meaning that managers risk not applying enough effort or overcommitting scarce resources (Norbury et al. 2015). Additionally, there is no such thing as a 'single' pest density threshold for a given area, but rather densities at which negative impacts occur that probably vary for each asset being protected. Thus, managers need to define what asset(s) need to be protected and what pest density will achieve that protection (Putman et al. 2011).

To illustrate this point, Pisanu et al. (2005) found only weak evidence in forest environments in Australia that goats significantly impacted rainforest vegetation at a site with c. 20 goats per km^2 compared to a site with c. 0.2 goats per km^2. However, Bayne et al. (2004) found that erosion at the same rainforest study area was five times higher at the high goat density site compared with the low goat density site, and that there was a reduction in erosion following goat control to low density at the high density site. Thus the goat densities at which negative impacts occurred varied for each asset being protected (i.e. soil versus rainforest vegetation). This highlights the importance of defining the problem; that is, why is a pest being controlled and what is the expected outcome following control?

There are a number of ways to determine the relationship between pest density and the condition of the asset or resource that is affected by the pest. The simplest approach is to apply a 'best guess' target pest density, with the expectation that this will deliver a specific conservation gain. The effects of control on pest and resource are monitored and the control effort increased or decreased according to observed outcomes (Parkes & Murphy 2003). More formally, pest–asset relationships can be quantified using density–impact functions or damage functions (Norbury et al. 2015). Density–impact function curves can take a number of theoretical linear and non-linear forms (Norbury et al. 2015; Figure 2). An asset or resource may respond incrementally or proportionately to changes in pest density, and non-linear functions may indicate disproportionate responses to changes in pest density and thus can have high utility for determining intervention densities (Norbury et al. 2015).

Attempting to determine pest density-impact relationships for feral goats is complicated because their contribution to vegetation damage is usually interrelated with the impacts of other introduced herbivores (Parkes 2005). Other than Sweetapple and Burns (2002), there have been few studies that have attempted to separate the effects of different browsing mammals. They developed new sampling methods for assessing the response of forest understories to reductions in feral goat populations and tested these in both North and South Island forests in areas with and without goat hunting. They concluded that goat kill, plant browse and goat faecal pellet data together suggested that substantial understory recovery was achieved by reducing goats to levels where kill rates were about or below one per day (which required up to 3 hunting days/100 ha/year in podocarp/hardwood forest), seedling browse indices were below c. 0.4, or pellet frequencies were below c. 4% (Figure 1). Improvements in understorey condition following possum control were negligible in the absence of effective goat control.

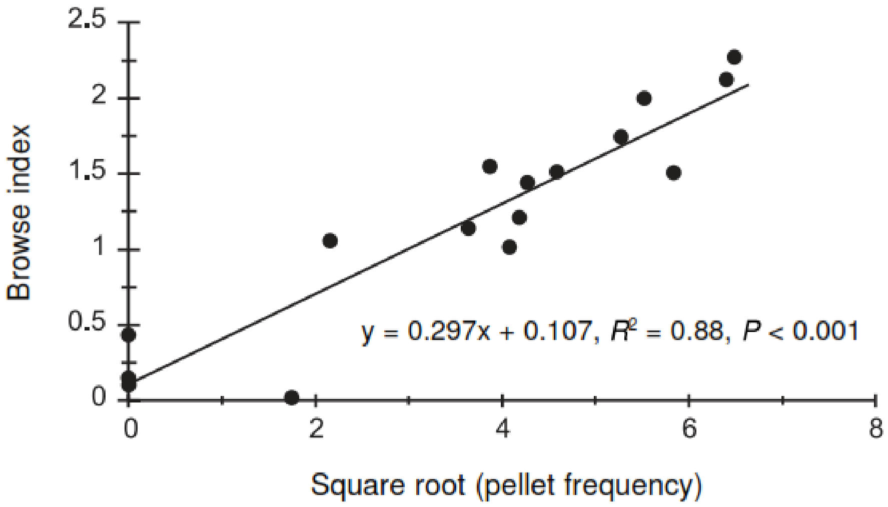

Figure 1. Browse index for all goat-palatable herbs versus goat pellet frequency in different treatment blocks across three study areas (from Sweetapple & Burns 2002).

While Figure 1 provides an indication of the magnitude of goat population reduction required to effect significant change in browse damage, ongoing benefits of control will generally only be achieved if goat populations remain suppressed (Parkes 1990). That may be difficult because the reproductive abilities of feral goats enable rapid population growth with annual growth rates of 10–35% (Watts & Conley 1984). Rudge and Smith (1970) predicted that a goat population reduced by 80% could recover to 90% of its original level in 4 years.

While there have been a range of studies that have assessed the impacts of goats in New Zealand (reviewed in Parkes 2005) there are few studies of the benefits of goat control and those are mostly focussed on forest vegetation recovery (reviewed in Sweetapple & Burns 2002; Parkes 2005). Husheer (2006) attributed the high numbers of goat-palatable seedlings on vegetation plots in Egmont National Park to the goat culling in the early 1980s, which reduced goat densities to c. 10% of habitat carrying capacity and of former population density, and the lower intensity control since then. Clearly, effective goat control can mitigate damage and allow vegetation recovery which, in general, should reduce impact of erosion. However, as found by Bayne et al. (2004) and Pisanu et al. (2005) in Australia, the benefits of reduction in goat numbers for the protection of one asset are not necessarily matched by similar beneficial outcomes for another asset.

No studies in New Zealand appear to have specifically addressed the benefits of goat control for preventing or mitigating erosion. In steep gorge country in New South Wales the initial reduction in erosion following goat removal was rapid, followed by a continuing slower decline over the next two years coincident with the relative increase in ground cover (Bayne et al 2004). Greene et al (1998) found that high-intensity grazing by goats resulted in increased erosion susceptibility from grass and shrub depletion, and the increase in unpalatable vegetation.

On Nakoudojima in the Ogasawara islands, where the original forest cover was destroyed by feral goats, herbaceous plants re-established extensively, with the consequent reduction in bare ground presumably resulting in reduced erosion (Hata et al. 2014). The regrown vegetation differed significantly from the original forest cover and the extent to which it provides protection from erosion relative to the original plant cover is unknown. Thus goat control alone may not completely restore pre-existing resistance to erosion. However, the benefits of goat control for reducing erosion may be quite rapid as Bayne et al. (2004) noted.

5 Goats and the Whanganui River catchment

Assessing the risk and/or impact of feral goats on the Whanganui River catchment and the benefits for soil erosion of goat control would require

1. the identification of eroding and erosion-prone areas in the catchment
2. the identification of which, if any, erosion prone areas are classed as threatened environments (Walker et al. 2015) or contain threatened plant species (http://www.doc.govt.nz/nztcs)
3. information on current goat distribution and densities or goat density indices within the catchment
4. information from monitoring of vegetation and land cover to assess changes resulting from goat control
5. detailed records of costs (labour and operating) of goat control and vegetation monitoring.

Dymond et al. (2010) developed an erosion model and used it to produce maps of predicted mean erosion rates for the North Island of New Zealand under current land cover. Such a model could be applied to the Whanganui River catchment following the example provided by Dymond et al. (2010) for the Motueka catchment. Erosion hot spots that affect downstream water quality are already a focus of the Horizons Regional Council Whanganui Catchment Strategy Operational Plan 2015-16, assisted by funding from the Whanganui River Enhancement Trust (Horizons Regional Council 2015). An erosion map and a map of threatened environments in the Whanganui River catchment can be created using the Landcare Research Our Environment tool (http://ourenvironment.scinfo.org.nz/ourenvironment).

Currently goats are widely distributed in the Whanganui River catchment, mostly at medium density (Figure 2; Fraser et al. 2000).

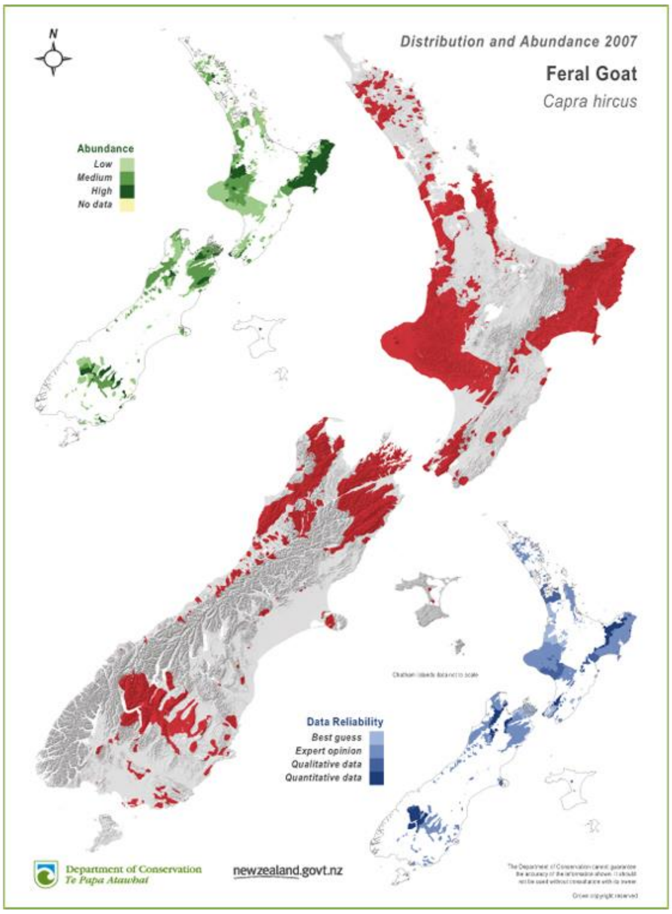

Figure 2 Distribution and abundance of feral goats in New Zealand. Biodiversity Data Inventory (BDI) 2007. Crown Copyright: Department of Conservation Te Papa Atawhai, 2014.

Table 1 summarises the various types of land cover in the Whanganui catchment according to the Land Cover Database (https://lris.scinfo.org.nz/layer/412-lcdb-v40-deprecated/). Those highlighted in yellow are all likely to be susceptible to greater or lesser extents to damage from goat browsing.

Table 1 Area (ha) of various land cover types across the Whanganui catchment

Land cover type	Area (ha)
Alpine Grass/Herbfield	1717
Broadleaved Indigenous Hardwoods	54746
Built-up Area (settlement)	2795
Deciduous Hardwoods	1393
Exotic Forest	49381
Fernland	556
Flaxland	1244
Forest - Harvested	7778
Gorse and/or Broom	4917
Gravel or Rock	4042
Herbaceous Freshwater Vegetation	2410
High Producing Exotic Grassland	218147
Indigenous Forest	264160
Lake or Pond	302
Landslide	101
Low Producing Grassland	31706
Manuka and/or Kanuka	55566
Matagouri or Grey Scrub	67
Mixed Exotic Shrubland	644
Orchard, Vineyard or Other Perennial Crop	110
Permanent Snow and Ice	152
River	2092
Sand or Gravel	98
Short-rotation Cropland	916
Sub Alpine Shrubland	5486
Surface Mine or Dump	84
Tall Tussock Grassland	8491
Transport Infrastructure	186
Urban Parkland/Open Space	540
TOTAL	719826

While goats are widespread in the catchment, they are controlled in the Whanganui National Park area by the Department of Conservation. According to Hawcroft and Husheer (2009), goats have been hunted in the Mangapurua River Valley, the Whanganui River trench and the Matemateaonga Range at varying levels of intensity since the 1970s. Between 1994 and 2005, operations were limited to the regenerating scrub of the Mangapurua and the river trench. In 2005, goat control began in approximately 10 000 ha between the Matemateaonga Walkway and the Whanganui River. Between 1700 and 2000 hours of hunting occurred annually in the first 3 years of this operation, and kill rates were approximately 0.5 kills/hour of hunting. The Department of Conservation (DOC) has established a number of vegetation monitoring plots and enclosures within the National Park that should allow for assessment of the outcomes of goat control.

Horizons Regional Council has undertaken little goat control in the catchment in recent years but will begin control again during 2016 (E Dodd pers. comm.). As part of the Kia Whārite Biodiversity Project, a joint partnership between Horizons Regional Council, the Department of Conservation and local iwi and landholders aimed at improving the health of over 180 000 ha of private and conservation land within the Whanganui River catchment, over 10 000 goats were culled during 2008–2013.

Within the Whanganui River catchment there are already a number of vegetation plots and exclosures that have been established either to assess the benefits of goat control (Hawcroft & Husheer 2009) or as part of the wider environmental monitoring programmes of DOC's Biodiversity Monitoring and Reporting System Tier 1 (http://www.doc.govt.nz/our-work/monitoring-and-reporting-system/ – see Figure 3) and the Ministry for the Environment's carbon monitoring system (http://www.mfe.govt.nz/climate-change/tracking-greenhouse-gas-emissions/measuring-forest-carbon). However, there has been no specific analysis to date of the monitoring data in relation to goat impacts. The Kia Whārite operational plan 2008–2013 (http://kiawharite.govt.nz/p/experiencing-kia-wharite.html) goat control section specifies the use of exclusion plots to assess the benefits of goat control but the results of this monitoring do not appear to be publicly available.

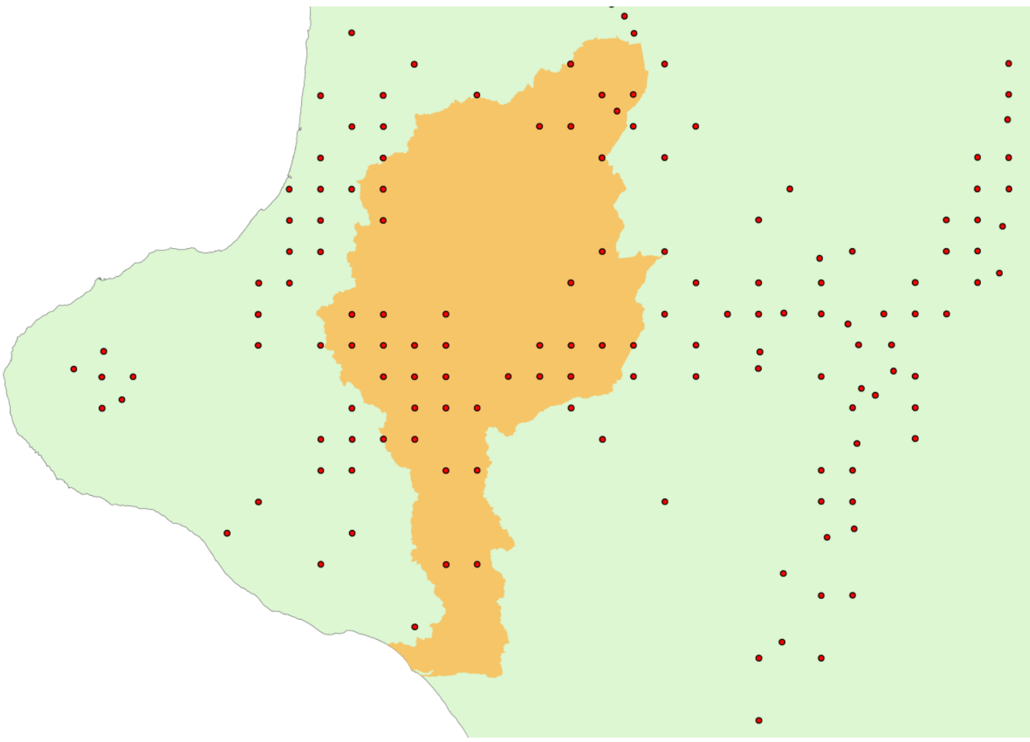

Figure 3 DOC Biodiversity Monitoring and Reporting System Tier 1 monitoring plots (red dots) situated within the Whanganui River catchment (orange shaded area).

6 Conclusions

- It is difficult to separate the effects of goats on vegetation from those of other browsing mammals and thus their contributions to erosion. Despite this, available data from New Zealand and elsewhere suggest that goat control has benefits for soil retention and local-scale erosion control provided goat numbers are suppressed sufficiently and for long enough to allow vegetation recovery.
- There are no published data that relate monitored vegetation condition, goat density, and the efficacy and costs of goat control with which to assess the current situation in the Wanganui River catchment. There are also no data on the costs of damage by goats to erosion control plantings.
- At a broad scale, the relationship between the browse index of Sweetapple and Burns (2002) and goat faecal pellet counts provides some guidance as to the required reduction in goat density to allow forest vegetation to recover. This is expected to incur benefits for soil retention and decrease local erosion. Importantly, controlling goats to reduce unwanted impacts on native vegetation is sufficient justification in itself.

7 Recommendations

Horizons Regional Council should

- partner with DOC to collate all available information on goat density, the efficacy and costs of goat control, and monitored vegetation condition to identify what information gaps need to be filled to enable an effective assessment of the costs and benefits of goat control for erosion control
- consider adopting the approach suggested in Section 5 (above) as a way to develop risk maps to assist future planning for goat control for erosion control in the Whanganui River catchment.

8 Acknowledgements

Andrew Gormley assisted with extracting information from the National Land Cover Database and DOC's Biodiversity Monitoring and Reporting System Tier 1. John Parkes assisted with background information on goats. The report was reviewed by David Latham and Bruce Warburton and edited by Leah Kearns.

9 References

Atkinson IAE 1964. Relations between feral goats and vegetation in New Zealand. Proceedings of the New Zealand Ecological Society 11: 39–44.

Bayne P, Harden R, Davies I 2004. Feral goats (*Capra hircus*) in the Macleay River gorge system, north-eastern New South Wales, Australia. I. Impacts on soil erosion. Wildlife Research 31: 519–525.

Chynoweth MW, Litton CM, Lepczyk CA, Hess SC, Cordell S 2013. Biology and impacts of Pacific Island invasive species. 9. *Capra hircus*, the feral goat (Mammalia: Bovidae). Pacific Science 67: 141–156.

Coblentz BE 1978. The effects of feral goats (*Capra hircus*) on island ecosystems. Biological Conservation 13: 279–286.

Dymond JR, Betts HD, Schierlitz CS 2010. An erosion model for evaluating regional land-use scenarios. Environmental Modelling & Software 25: 289–298.

Elwell HA, Stocking MA 1976. Vegetal cover to estimate soil erosion hazard in Rhodesia. Geoderma 15: 61–70.

Foster GR, Young RA, Ronkens MJM, Onstad CA 1985. Processes of soil erosion by water. In: Follett FR, Stewart BA eds. Soil erosion and crop productivity. Madison, Wisconsin, American Society of Agronomy and Crop Science Society of America. Pp. 137–162.

Fraser KW, Cone JM, Whitford EJ 2000. A revision of the established ranges and new populations of 11 introduced ungulate species in New Zealand. Journal of the Royal Society of New Zealand 30: 419–437.

Grant PJ 1985. Major periods of erosion and alluvial sedimentation in New Zealand during the Late Holocene. Journal of the Royal Society of New Zealand 15: 67–121.

Grant PJ 1989. A hydrologist's contribution to the debate on wild animal management. New Zealand Journal of Ecology 12 (Suppl.): 165–169.

Greaves LA, Wedderburn ME 1995. Comparison of the behaviour of goats and sheep on an eroded hill pasture. Applied Animal Behaviour Science 42: 207–216.

Greene RSB, Nettleton WD, Chartes CJ, Ley JF, Cunningham RB 1998. Runoff and micromorphological properties of a grazed haplargid, near Cobar, NSW, Australia. Australian Journal of Soil research 36: 87–108.

Hawley LG, Dymond JR 1988. How much do trees reduce landsliding? Journal of Soil and Water Conservation 43: 495–498.

Hata K, Kohri M, Morita S, Hiradate S, Kachi N 2014. Complex interrelationships among aboveground biomass, soil chemical properties, and events caused by feral goats and their eradication in a grassland ecosystem of an island. Ecosystems 17: 1082–1094.

Hawcroft A, Husheer S 2009. Vegetation monitoring in Whanganui National Park. DOC Research & Development Series 315. Wellington, Department of Conservation.

Horizons Regional Council 2015. Whanganui Catchment Strategy Operational Plan 2015-16. Palmerston North, Horizons Regional Council.

Husheer SW 2006. Changes to the forests of Egmont National Park 1977–2001. DOC Research & Development Series 257. Wellington, Department of Conservation.

McCullough DR, Takatsuki S, Kaji K eds 2009. Sika deer: biology and management of native and introduced populations. Tokyo, Springer.

Norbury GL, Pech RP, Byrom AE, Innes J 2015. Density–impact functions for terrestrial vertebrate pests and indigenous biota: guidelines for conservation managers. Biological Conservation 191: 409–420.

Parkes JP 1990. Feral goat control in New Zealand. Biological Conservation 54: 335–348.

Parkes JP 1993. Designing solutions for a designer pest. New Zealand Journal of Ecology 17: 71–83.

Parkes JP 2005. Feral goat. In: The Handbook of New Zealand Mammals, 2nd edition, King CM ed. Melbourne, Victoria, Oxford University Press. Pp. 374–391.

Parkes J, Murphy E 2003. Management of introduced mammals in New Zealand. New Zealand Journal of Zoology 30: 335–359.

Pimentel D, Kounang N 1998. Ecology of soil erosion in ecosystems. Ecosystems 1: 416–426.

Pisanu P, Bayne P, Harden R, Eggert A 2005. Feral goats (*Capra hircus* L.) in the Macleay River gorge system, north-eastern New South Wales, Australia. II. Impacts on rainforest vegetation. Wildlife Research 32: 111–119.

Putman R, Langbein J, Green P, Watson P 2011. Identifying threshold densities for wild deer in the UK above which negative impacts may occur. Mammal Review 41: 175–196.

Ries JB 2005. Soil erosion on abandoned fields in Mediterranean mountains – Monitoring of processes and development. Journal of Mediterranean Ecology 6: 43–52.

Ries JB, Andres K, Wirtz S, Tumbrink J, Wilms T, Peter KD, Burczyk M, Butzen V, Seeger M 2015. Sheep and goat erosion – experimental geomorphology as an approach for the quantification of underestimated processes. Zeitschrift für Geomorphologie DOI: 10.1127/0372-8854/2013/S-00158.

Rudge MR 1990. Feral goat. In: The Handbook of New Zealand Mammals, 1st edition, King CM ed. Auckland, Oxford University Press. Pp. 406–423.

Rudge MR, Smith TJ 1970. Expected rate of increase of hunted populations of feral goats (*Capra hircus* L.) in New Zealand. New Zealand Journal of Science 13: 256–259.

Seuffert O, Herrig K, Ollesch G, Busche D 1999. REI – An integrated rainfall erosivity index for assessing and correlating rainfall structure, runoff and erosion. Geookdynamik 20: 1–54.

Sweetapple PJ, Burns BR 2002. Assessing the response of understoreys to feral goat control with and without possum control. Science for Conservation 201. Wellington, Department of Conservation.

Tilman D, Downing JA 1994. Biodiversity and stability in grasslands. Nature 367: 363–365.

Walker S, Cieraad E, Barringer J 2015. The Threatened Environment Classification for New Zealand 2012: a guide for users. Landcare Research Contract Report LC2184.

Watts T, Conley W 1984. Reproductive potential and theoretical rates if increase for feral goat populations. Journal of Wildlife Management 48: 814–822.

Williams K, Parer I, Coman B, Burley J, Braysher M 1995. Managing vertebrate pests: rabbits. Canberra, Australian Government Publishing Service.

horizons regional council

11-15 Victoria Avenue
Private Bag 11 025
Manawatu Mail Centre
Palmerston North 4442

T 0508 800 800
F 06 952 2929
help@horizons.govt.nz
www.horizons.govt.nz