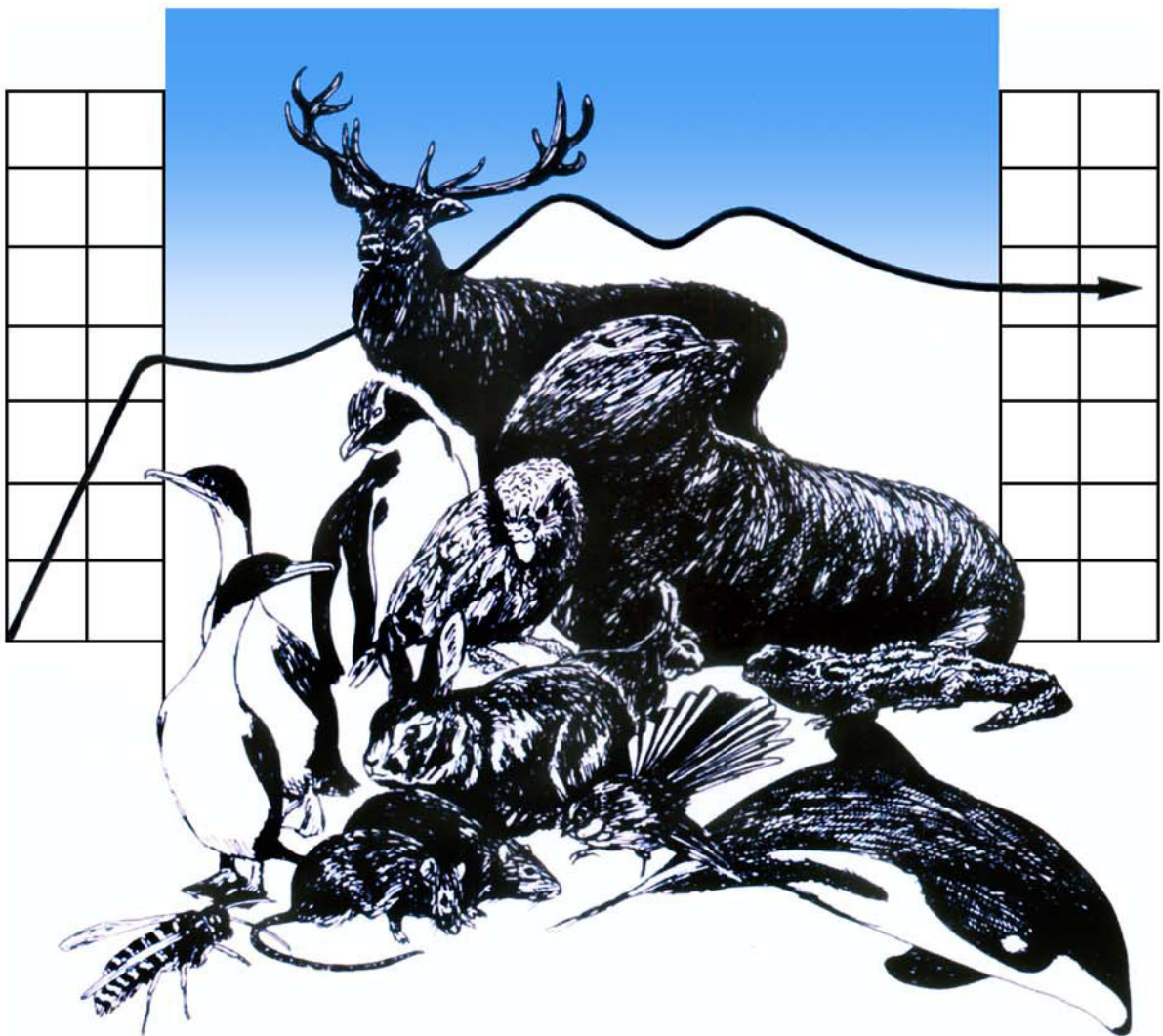




DEPARTMENT OF ZOOLOGY



WILDLIFE MANAGEMENT

**The Effects of Ungulates on
Species Composition and
Nutrient Cycles in Central
NZ Forests**

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Abstract

Since the late 19th century it has been recognised that ungulates* are causing major changes to our forests. This study used 18 paired exclosure plots (20m x 20m) across several forests in central North Island to show the effects of ungulates on species composition, litterfall and nutrient levels. Results were inconclusive due to the complexity of the system across large temporal and spatial scales. Despite this, it was suggested that research should be focussed towards specific management objectives and that current interest in carbon levels could open up new options for funding.

Keywords: ungulates; herbivory; exclosure; nutrient; composition; management

* the ideas in this report mainly refer to deer spp however as exclosure studies cannot distinguish between browsing by deer and goats these two groups are combined as “ungulates”

1. Introduction

1.1 Overview

Since the late 19th century it has been recognised that ungulates (notably deer, *Cervus* spp and feral goats, *Capra hircus*) are causing major changes to our forests (eg Walsh 1892; Cockayne 1926; Holloway 1960; Veblen and Stewart 1982; Husheer and Robertson 2005). Mainly through species compositional change (eg Nugent et al. 2001), depletion of plant cover (eg Veblan and Stewart 1982) and a reduction or total elimination of canopy regeneration (eg Husheer et al. 2006). It is believed that at least on a structural/compositional level the effects of ungulates are more severe than that of smaller herbivores i.e. possums, *Trichosurus vulpecular* (Husheer and Frampton 2005; Nugent and Fraser 1993; Nugent et al. 1997; Smale et al. 1993) or other introduced mammals i.e. pigs, *Sus scrofa*. (Nugent et al. 2001)

1.2 Nutrient Cycle

One area of interest is the effects of ungulates on the nutrient cycle (eg Bardgett et al. 1998; Wardle et al. 2001; Wardle 2002). Ungulates can affect nutrient cycling in several ways; directly through excretion of more relatively labile forms of nutrients (Wardle et al. 2001), reduction in plant and litter biomass (McNaughton et al. 1998) or indirectly through altered resource quality (Bardgett and Wardle 2003). In the long term, ungulates can also cause changes in species composition; selective browsing is able to sufficiently remove large-leaved shade tolerant palatable species (Smale et al. 1995, Wallis and James 1972) such as *Griselinia littoralis* and *Raukawa simplex* (Forsyth et al. 2002; Husheer et al. 2003). In some situations this can lead to unpalatable or browse resistant species, e.g. small leaved *Coprosma* spp and *Pseudowintera colorata*, dominating due to reduced spatial and resource competition (Smale et al. 1995; Stromayer and Warren 1997, Nugent et al. 2001). This species compositional change can give rise to litter of altered nutrient quality and decomposability (Bardgett and Wardle 2003, Wardle 2002). This suggest herbivores can potentially have effects on belowground properties and processes; specifically storage of carbon (C), nitrogen (N) and phosphorus (P).

1.3 C, N and P

Carbon is a major component of many plant molecules including cellulose and starches (Hopkins and Huner 2004). Carbon is fixed from the atmosphere via photosynthesis and enters the terrestrial biome via litterfall and tree death. Plants are therefore considered important mediators of the exchange of carbon between the atmospheric and terrestrial carbon pools. Nitrogen and phosphorus enter plants through the soil. Nitrogen is an essential component of proteins while phosphorus is important in plant bioenergetics eg ATP (Hopkins and Huner 2004). Because of their importance to plant functioning it is important to determine the effects of ungulates have on these major nutrients. Furthermore shifts in the N and P availability have been shown to lead to changes in plant traits, vegetation composition and species diversity (Roem & Berendse 2000; Gusewell 2004) and it is therefore important to monitor long-term changes.

1.4 Aims

This study uses exclosure plots from central NZ forests to determine the effects of ungulates on species composition and changes in the levels of C N and P in the litter, humus and soil layers. Based on previous research it is expected that there will be a strong effect on the understorey composition specifically sapling and seedlings, and that ungulates will have some effect on the nutrient cycle which should result in altered levels of key elements (C, N and P). Furthermore I want to relate current knowledge to potential management actions and future directions of exclosure plots.

2. Methods

2.1 Study Sites

This study was conducted using 18 paired exclosure plots covering forest types throughout central New Zealand between July 2008 and July 2009. The paired plots are both 20 x 20m, with one being surrounded by a 2.2m fence designed to exclude deer and goats (Husheer et al, 2005), it is unable to exclude smaller herbivores i.e. rats and possums (Wardle et al. 2001) or other introduced animals i.e. pigs (Husheer 2007). Plots are paired on the basis of elevation, canopy species, slope, aspect and are

generally adjacent (S. Husheer 2009, pers. comms.).

2.2 Sampling Protocol

2.2.1 Above Ground Data

Identical methods were used for all measurements of paired exclosure plots following Hurst and Allen (2007). Plot was split into the 16 subplots (A-P) and the 24 seedling subplots were systematically located (fig 1). To measure overstorey composition, all stems for each tree species (>2.5 cm dbh) were identified, tagged, and the diameter over bark at breast height (135 cm) measured according to their sub-plot (A-P). To measure forest understorey composition, all saplings (>135 cm high, <2.5 cm dbh) were counted and identified according to their sub-plot (A-P). All established woody seedlings (15–135 cm high) were identified and counted according to the 24 circular subplots (49-cm radius)

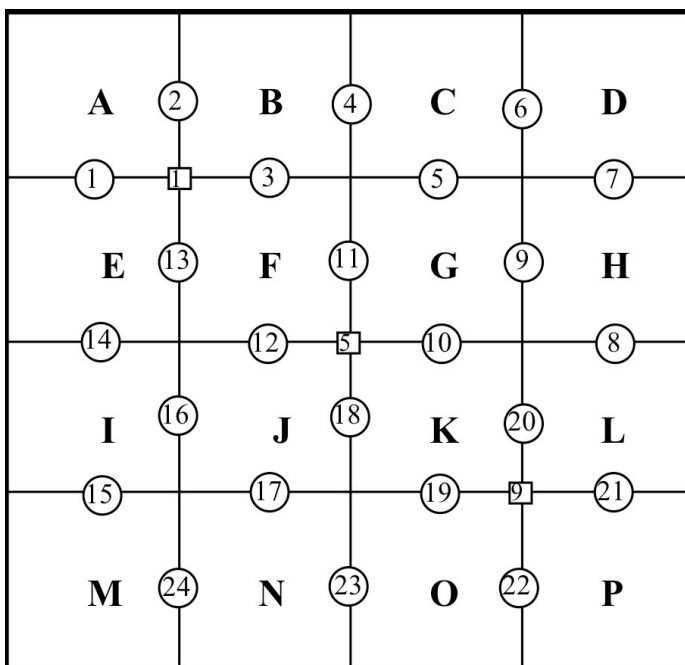


Figure 1. Permanent plot layout including 5m x 5m subplots (A-P), twenty four 49cm radius seedling subplots (1-24), and three 31.6cm² subplots for litter, humus, and soil sampling (1,5,9). Image from S. Husheer (2009)

2.2.2 Nutrient Data

Separate litter, humus and soil tier (0-100mm) samples were collected from within three 31.6 x 31.6cm subplots, situated at overstorey sub-plot intersections. They are labelled the first, fifth, and ninth subplots (figure 1). Separation of layers was based on the following (S. Husheer 2009, pers. comms.);

- Litter samples; debris <2.5 cm diameter of recognizable plant material, includes faecal pellets, but excludes live plant/lichen/moss tissue, and gravel
- Humus samples; decomposed litter, made up of unrecognisable plant material and may contain mineral soils due to biological mixing
- Soils; mineral soil with no decomposed litter

Litter and humus from the three subplots were pooled and the full sample removed. The soil tier was pooled, mixed, and then a representative sub-sample of known weight was removed from site (roughly 1kg). The remaining soil was weighed and then returned to the holes. All samples were collected in plastic zip lock bags.

2.3 Analysis

Labratory Analysis was carried out at Lincoln University. Dry Weight values were calculated using a sub-sample of each tier of known proportion. These were completely dried for ~3hours in 105oC oven. From this the weight per hectare was calculated and averaged to give mean value for fenced and unfenced.

Carbon and Nitrogen values were calculated via combustion in an ELEMENTAR vario MACRO cube N. 0.5g ± 0.001 samples were analysed to give percentage estimates for each element. 1 in every 20 samples was repeated to ensure consistent results. Phosphorus concentration (mg/kg) was calculated using an ICP VARIAN T20-ES following HNO₃ extraction. Detrended Correspondence Analysis (DCA) scores for; seedlings, saplings and trees were calculated using the default option in VEGAN (CRAN 2009) to summarize species composition for all surveys. Paired t tests (N=18, df=17) were used to compare DCA scores, litter and humus dry weight, and carbon, nitrogen and phosphorus

levels in the litter, humus and 0-100mm soil tier.

3. Results

3.1 Species change

DCA scores are a measure of species composition based on density and species type. Significantly different scores suggest a change in species composition (S. Husheer 2009, pers. comms.) Fenced and unfenced plots showed a variety of vegetation responses. Saplings were the only species composition to show a significant difference ($t_{17} = 1.501$, $p = 0.041$) based on mean DCA scores. Overstorey tree species and saplings were not significantly different ($t_{17} = 1.501$, $p = 0.152$, and $t_{17} = 2.247$, $p = 0.6$ respectively).

Table 1. Mean Detrended Correspondence Analysis (DCA) scores for seedlings, saplings and trees with associated standard error of the means (sem) value. Paired T-test ($n=18$), . Dbh = diameter over bark at breast height.

	Fenced		Unfenced		T-test	P-value
	Mean	sem	Mean	sem		
Specie Compositions						
Trees (dbh >2.5cm at 135cm)	1.55	0.35	1.11	0.25	1.501	0.152
Saplings (height >135cm, dbh <2.5cm)	2.2	0.4	1.8	0.4	2.247	0.041
Seedlings (height 15cm<, <135cm)	2.3	0.4	2.2	0.3	0.536	0.600

3.2 Litter and Humus

Ungulates are suggested to have no effect on the mass of litter and humus with neither showing a significant difference between fenced and unfenced (table 2). However for both components fenced was slightly highly.

Table 2. Mean Litter and Humus dry weight for the fenced and unfenced plots with associated standard error of the means (sem) value. Paired T-test (n=18). Units are in tones per hectare

	Fenced		Unfenced		T-test	P value
	Mean	sem	Mean	sem		
Surface Components (tonnes/ha)						
Litter	16.8	1.9	15.4	1.1	0.737	0.471
Humus	44.6	8.4	36	6.8	1.112	0.282

3.3 Nutrients

Ungulates appeared to have no effect on carbon in any of the three layers studied. This is shown by the non-significant difference between fenced and unfenced for all of the layers (fig 2). The analysis however suggests clear separation of carbon levels between the three layers with highest carbon level in the litter (fenced = 42.4%, unfenced 41.1%) and lowest in the soil (fenced =8.3%, unfenced 8.5%). This implies that the methods were successful for distinguishing the separate layers. The layered pattern however was not consistent with the nitrogen (%) and phosphorus (mg/kg) levels. For both of these nutrients the humus layer had the highest concentration (fig 2)

Ungulates were suggested to have little effect on the mean nitrogen levels in the litter layer ($t_{17} = 1.64$, $p = 0.119$) with the fenced plot being on average slightly higher than unfenced. This trend, however was not continued with the other two layers, which showed no significant difference. Phosphorus levels in the litter had a similar effect as the nitrogen; the fenced plot was found to have on average significantly higher phosphorus levels ($t_{17} = 2.147$, $p = 0.047$). However like the nitrogen, the humus and soil layers showed no significant differences between phosphorus levels in the fenced and unfenced.

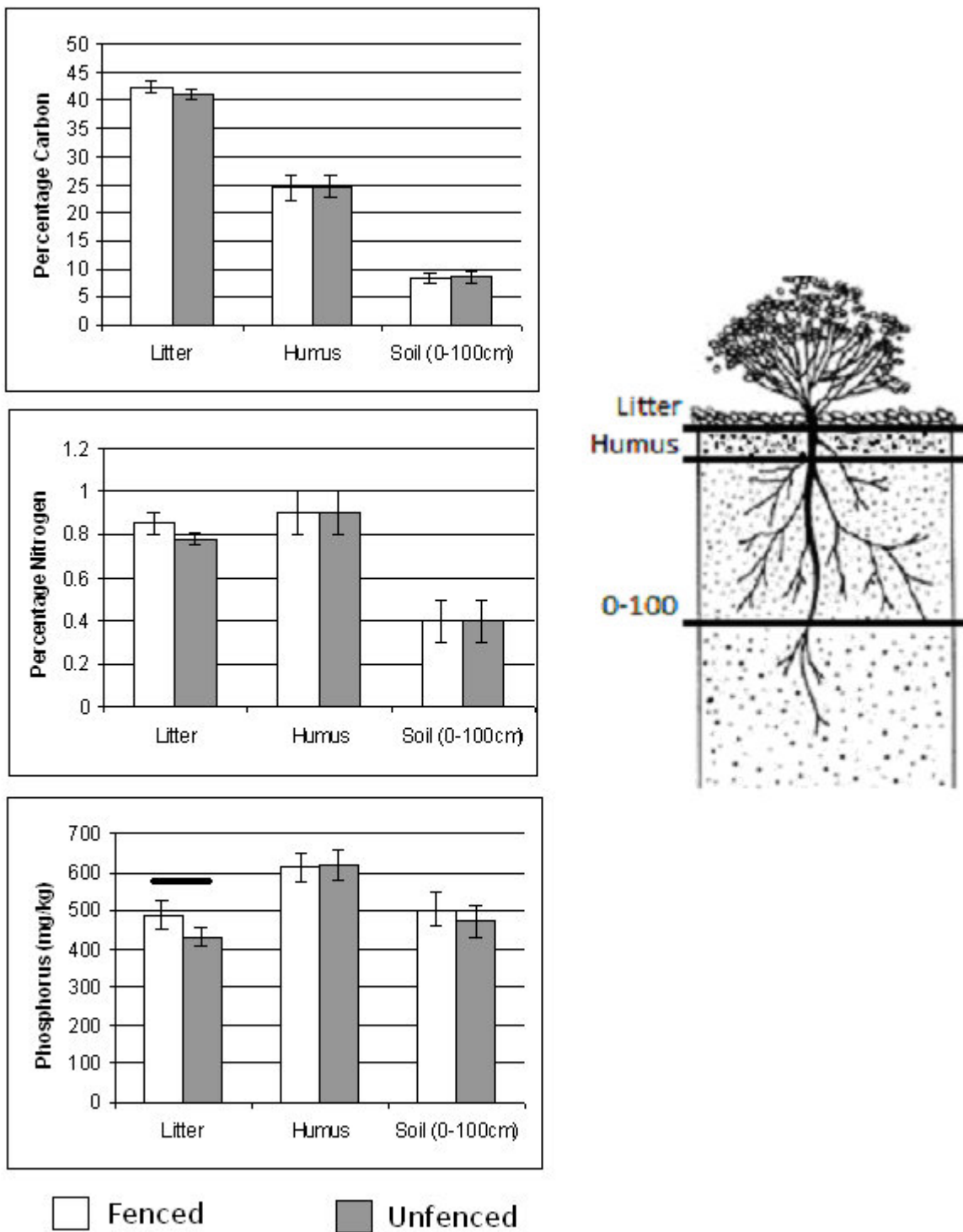


Figure 2. Graphical Summary of the nutrient levels of the litter, humus and soil (0-100cm) layers for 18 paired exclosure plots. Carbon (top) and Nitrogen (middle) are expressed as a percentage per kilogram. Phosphorus is expressed as micrograms per kilogram. Fenced results are white, unfenced are the grey. Error bars are SEM (standard error of the mean). Significantly different results are marked with a black horizontal bar. Diagram on the right highlights the positions of the three layers in relation to one another. Modified from http://www.cmhc-schl.gc.ca/en/co/maho/la/la_001.cfm.

4. Discussion

4.1 Species change

Ungulates were shown to have mixed effects on species composition (table 1). The overstorey and seedling species composition were not found to be significantly different between inside and outside the fence, while a significant difference was found for the sapling species composition. Previous studies have shown that ungulates are capable of completely removing palatable species outside the fence, and thus favouring the growth of “better defended” unpalatable species (Nugent et al. 2001; Smale et al. 1995; Stromayer and Warren 1997), while exclosures have been shown to quickly allow the regeneration of palatable species (Tanentzap et al. 2009), therefore creating contrasting species composition inside and outside the fence. You would expect seedlings to have the strongest effect and, over a period of time, these opposing changes would eventually manifest to a difference in the sapling layer and then the overstorey. However, our data only found a significant difference between the sapling composition, suggesting that there are more complicated interactions involved. Without the necessary information on ungulate density and plot history it is difficult to speculate. The lack of overstorey composition changes maybe due to a short time interval in which changes have not yet manifested in the canopy. This highlights a potential limitation in the current plot method. By grouping the overstorey layers into “trees”, it limits the ability of researchers to determine the stages of compositional change. Canopy species could be split into several layers based on height or dbh. This would allow researchers to determine specific time frames in which compositional changes occur.

4.2 Litterfall

There was not a significant difference seen between litter or humus dry weights. This was unexpected as litter and foliage contribute extensively to ungulates diets (Nugent 1990, Nugent et al. 1997). However the composition of the litterfall was not recorded. This is an important variable as litterfall and accompanying decomposition are “important determinates of overall recycling of nutrients and maintenance of soil fertility in terrestrial ecosystems” (Nugent 1990). Therefore the litterfall is a possible vector for nutrient shifts. This means that an index of both quantity and quality is needed

before changes in litterfall can be linked to changes in nutrient levels and therefore should be included in future studies.

4.3 Nutrients

Our data suggests that ungulates are having little to no effect on the nutrient cycles in the forests (fig 2). This is supported by the lack of significant results for species composition and litterfall (table 1 and 2). However it is more likely that the complexity of the system is confounding our results. Plant communities and nutrient cycles respond to herbivores through complex interactions across a broad range of temporal and spatial scales (Bardgett and Wardle 2003; Wardle 2002, Wardle et al. 2004). It is therefore likely that nutrient levels are dependent on local phenomena occurring in relation to specific species suits and abiotic factors. This is consistent with a review by Bardgett and Wardle (2003) in which it was highlighted that C and N levels varied in response to herbivory both across studies and within them. For example Wardle et al. (2001) showed that effects of herbivory on C mineralization, and C and N sequestration were “highly idiosyncratic” with different sites having positive and negative effects in response to herbivory. This suggests that we may have been naïve in expecting a general trend for these nutrients across a variety of forest types and seasons. Therefore although our results suggested that phosphorus and nitrogen were slightly higher in the fenced plot it is impossible to determine the mechanisms driving it or even the reliability of the results. A more comprehensive study is needed before these trends can be confirmed. Future studies should focus on forests of similar composition over a smaller sampling period. This will reduce the bias of different species compositions as well as seasonal and geographical variation. For example this data was from samples collected across different sites and seasons. This could affect our results through variation in deer diet (Forsyth et al. 2002), deer density (Stohlgren et al. 1999), species composition (Wardle et al. 2001) and plant productivity (Bardgett and Wardle 2003), which can all potentially confound results. Studies should be directed towards local managers e.g. doc regional offices with the aim of determining local effects and providing scientific evidence to drive management responses.

4.4 Managers

The idea that ungulates are negatively affecting our forests is nothing new (eg Walsh, 1892; Cockayne, 1926, Veblen and Stewart 1982, Husheer and Robertson 2005) however they still remain in our forests. This is because the incentives, funds and knowledge are not available to completely remove them (S. Husheer 2009, pers. comms.) nor is there a reason to. Ungulates enhance recreation, economic and aesthetic values of native forests (Nugent and Fraser 1993; Veblen and Stewart 1982). Therefore a compromise needs to be reached. Key forested areas need to be identified for conservation and protected through continued management or total eradication. An important role of enclosure studies is therefore presenting conservation managers with the information needed to complete this effectively and efficiently. The main questions that managers need to know are;

1. What are the consequences of compositional change? This will increase awareness of the problem, and could be used to gain public support. For example Husheer (2007) suggested Kokako and other native avifauna feeding habits might be disrupted by ungulate driven species compositional change. Because of the high profile of this species, it could be a powerful focal point for public opinion.
2. What species are responsible? Different species of ungulates have been shown to have different effects (Husheer et al. 2006) therefore this might influence the design of the management. Furthermore other introduced herbivores such as possums may be having an effect (eg Nugent et al. 2001) therefore combined eradication might be needed.
3. Are the changes reversible? Systems that are shown to be readily reversible are more appropriate than irreversible ones. Husheer et al (2003) suggested irreversibility could occur if ungulates have “shifted competitive balances between plants, altered successional pathways and ecosystem processes, or eliminated seed sources” therefore this needs to be assessed
4. What ungulate densities allow regeneration? Studies suggest that even at low densities ungulates might still prevent regeneration (see Nugent et al. 2001), therefore guidelines indicating maximum threshold need to be established (Husheer and Frampton 2005).

In answering these, managers will be able to effectively make decisions about where and how management can be implemented. Exclosure studies should aim to provide conservation managers with more accurate predictions on the effects of ungulates on palatable plant regeneration over gradients of hunting intensity, ungulate density, and forest productivity and composition (Augustine and McNaughton 1998; Côté et al. 2004).

4.5 Challenges/improvements with plots

Despite being considered a robust technique for monitoring vegetation change in forests (Sweetapple and Burns 2002) exclosure studies have some major weaknesses. Firstly the effect of herbivory on forest composition needs to be studied over several decades to fully understand the various forest dynamics present in the NZ system (Bellingham et al. 2000). This is due to the different temporal scales present in our forests (Wardle 2002); short term exclosure studies can quantify browse tier replacement (Nugent et al. 2001) and regeneration suppression (Husheer et al. 2005) however determining if this will lead to canopy compositional changes may take decades or even centuries to become apparent.

The close proximity of fenced and unfenced plots can be both positive and negative. Adjacent plots are likely to be more closely paired with similar canopy species, elevation, soil characteristics etc (S. Husheer 2009, pers. comms.). This improves the ability of the study to determine the effects of herbivory as these potentially confounding factors are matched. However, negative impacts include increased browsing pressure and increase recruitment in unfenced plots. Exclosures sometimes attract grazing animals therefore increasing the browsing pressure adjacent to the exclosures (Stohlgren et al. 1999). Also established exclosures have been shown to have an increased amount of mature palatable species (Husheer et al, 2007). Therefore adjacent areas would be expected to have higher than average seed recruitment of palatable species. These factors could either over or under exaggerate the effect of herbivory between fenced and unfenced.

It is also naive to assume, that in the absence of human influences, vegetation will be in an equilibrium condition (Vblan and Stewart 1982). Forest understories are spatially and temporally variable, responding to a matrix of resource and competitive gradients (Sweetapple and Burns 2002) making the effects of herbivores over large scales very hard to disentangle. This highlights the limitations of exclosures when it comes to size. Exclosures are expensive to construct so are generally small and poorly replicated (Stohlgren et al. 1999) this means they are vulnerable to “unique local conditions, edge effects, or poor representation of larger scale processes” (e.g., patchy disturbance and seed dispersal effects) (Daubenmire 1940, Woodward et al. 1994).

These limitations can potentially confound results therefore it is important that they are monitored and incorporated into the design of future studies. Studies should be restricted to specific areas over specific time frames to minimize the impact of these factors. Also regular replication is needed to determine the changes in forest structure and nutrient levels over time, which will give a better insight into the long-term effects of herbivory.

4.6 A new direction

Due to the current worldwide concern for global carbon emissions (UNFCCC 1997, IPCC 2000, Copenhagen 2009), increasing carbon sequestration and retention of natural systems is now of considerable value. In December 2002 New Zealand sanctioned the Kyoto Protocol (treasury 2010). This international agreement commits New Zealand to reducing its average net emissions of greenhouse gases over 2008-2012 to 1990 levels or to take responsibility for the difference (Treasury 2010).

At present the “carbon debt” that this country owes is equal to \$196 million dollars but has been as high as one billion dollars (Treasury 2010). Furthermore with the formation of an emissions trading scheme by the National government, carbon is becoming of significant value.

Ungulates can potentially affect the carbon storage capabilities of our forests through reduced litterfall, accelerated erosion, suppressed canopy regeneration, species compositional changes and

foliage browsing. If this could be quantified through studies, then ungulate removal could potentially represent considerable value to the community.

For example litterfall; A substantial fraction, up to one half, of the carbon annually fixed in forests is transferred to the forest floor as litterfall (Ovington 1961). This potentially means that even a small change in the amount of litterfall (ie through herbivory) could dramatically affect the amount of carbon available to the terrestrial pool. Although there was no difference found on the amount of Carbon in the litter layer in this study (fig 2), if you took our unfenced data as an example of an undisturbed natural NZ system (see fig 3) just a 5% reduction in the amount of litterfall NZ wide could account for roughly two million tonnes of carbon which is worth \$47,000,000 (at \$21.29/C Treasury 2010). Although this is only an estimate it gives an idea of the potential scale of the ungulate impact.

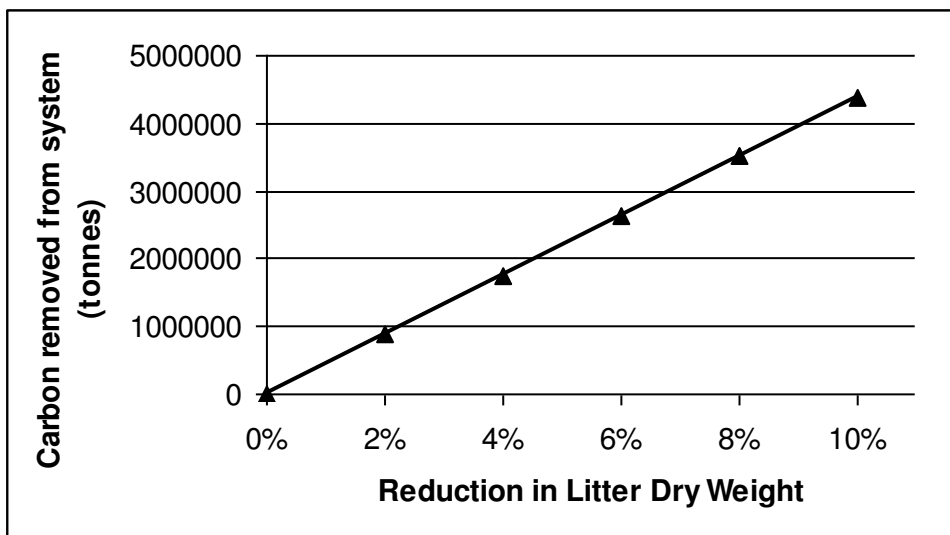


Figure 3. Graph showing potential impacts of ungulates on the NZ forest carbon cycle. It uses the enclosure data as a reference to an undisturbed, natural system. Key data inputs; litter dry weight of 16.8tonnes/ha (table 2), Carbon at 42.4% (Fig 2). New Zealand forested area at 6.19 million hectares (native forest cover 23%, total land area 26.9million hectares (Ministry of the Environment 2010). Data was calculated in Microsoft excel 2003.

This provides managers with a potential source of funding in the face of revenue cuts to the conservation sector. Managers should therefore exploit this interest in carbon for forest conservation. It has already sparked some interest by energy companies looking to offset carbon footprints (S. Husheer 2009, pers. comms.). However it has a much greater potential with both governmental and

private sectors able to buy into the research and corresponding management. The funding could initially be directed at quantifying the effects of ungulates on carbon storage, and when this is known progress to the management or removal of ungulates.

5. Conclusions

Despite the impact of ungulates on our forests being well documented there is still a strong need for management based research in NZ. Managers need to have up to date, local information on the most efficient and effective management options to control ungulate numbers. Exclosure studies have the potential to be a key part of this research. However, clear study design and objectives are vital for obtaining robust and informative data. Managers also need to be innovative when seeking solutions to problems (e.g. funding) as without new resources, conservation in NZ will be under the knife.

6. Acknowledgements

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