Report

Prepared for DEEResearch Ltd.

April 2002

Deer and the Environment

A review of current knowledge to identify knowledge gaps and research priorities

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1 Executive Summary

Context

The New Zealand Deer Industry is a relatively young but rapidly expanding industry, and is the world's largest supplier of venison, velvet and other deer products. The major overseas markets are Europe (approx. 80% of all venison exports) and Korea (approx. 90% of all velvet exports).

Overseas consumers, particularly those in Europe, are increasingly concerned not only about the health and welfare of the animals but also the health and sustainability of the environment where the animals are raised. The development and adoption of sustainable management practices for deer farming will be critical for maintaining New Zealand's 'clean green' image overseas. Some of the other drivers for developing sustainable management practices for deer farming are, the protection of our natural resources, New Zealand's commitment to international agreements, and tourism.

The New Zealand Deer Industry has been very pro-active in developing these sustainable management practices by initiating the Deer Farmers' Environment Awards and developing a Deer Farmers' Landcare Manual.

The environmental science goal of DEEResearch Ltd. also reflect the desire to develop sustainable management practices: "Define the relationship between deer farming and the use of natural resources so that the NZ deer industry can ensure sustainable production and verify and enhance its "natural" image". DEEResearch Ltd. requested a review of the existing knowledge on deer farming and the environment to identify research that is required to achieve its goal.

Objective

This report presents a review of current knowledge on environmental issues in the deer industry, in order to identify knowledge gaps, key research areas and research priorities.

Approach

The report was prepared from a review of the national and international literature, and publications from the deer industry; discussions with representatives of the deer industry, and researchers at AgResearch, and Massey and Lincoln University; and contributions from staff from several Regional Councils.

Outcomes

The environmental issues relating to deer farming include soil and water quality, nutrient budgeting, greenhouse gas emissions, biodiversity and organic deer farming.

The effect of intensive deer farming on soil quality (compaction and erosion) and the subsequent risk of contamination of waterways through sediment loss and eutrophication are recognised as the main environmental issues. This problem is largely caused by the behavioural responses of deer to confinement (fence line pacing), which is enhanced when animals are under stress (e.g. during weaning, calving or mating, or through lack of shade and shelter). In addition, the wallowing behaviour of deer during hot weather or when shedding winter coats will enhance erosion of the stream margins and banks. Wallowing will lead to increased sediment loss and contamination of the waterways with nutrients and faecal bacteria.

Visually, fence line pacing creates bare tracks and considerable areas of bare ground, while wallowing creates muddy streams and eroded banks. Several management practices and techniques are already being recommended and adopted to limit these problems, e.g. altering fenceline placement, visual barriers, providing shade and shelter. However, little experimental evidence exists of the impacts of deer farming on soil and water quality. The only exception is probably a small study by Environment Southland (2000) who measured water quality parameters upstream and downstream from a deer wallowing site. The measurements showed that sediment loss and concentrations of ammonium and faecal coliforms were about 20 to 35 times higher at the downstream site, with ammonium levels toxic to fish life and faecal levels exceeding the recommended guidelines for stock water (Environment Southland 2000).

One way to determine potential excesses of nutrients that could be subject to losses to the environment is to calculate a nutrient budget. Although a nutrient budgeting model is available (OVERSEER®), the current equations are largely based on nutrient cycling research on sheep, beef and dairy farms, and more work is required to refine them for deer farming if OVERSEER® is to be applied extensively to deer farming systems.

Although the contribution of deer farming to the total agricultural greenhouse gas emissions in New Zealand is relatively small (about 3% in 1999), the industry is rapidly expanding and projections are that this contribution could double by 2010. This could become of particular importance if and when the Kyoto Protocol comes into effect. Direct measurements of methane and nitrous oxide emissions from deer farming have not been carried out and quantification of these emissions will become increasingly important. In addition, the impact of soil compaction on nitrous oxide emissions could be of particular importance for the deer industry.

A range of different deer farming systems in different landscapes offer different opportunities to demonstrate that the industry is proactive in maintaining and increasing plant biodiversity. On game reserves and extensive hill and high country breeding units emphasis will be on the retention of native plant biodiversity including forested areas where relevant, and tussock grassland landscapes. The role of deer browsing on the rate of ingress of invasive weeds into tall tussock could be very important. On intensively farmed arable lands pastures with a wider range of herbaceous plants than standard sheep and cattle pastures and trees to provide shelter and modify animal behaviour patterns, offer increased plant biodiversity and greater habitat for a wider variety of animal species. To gain a permanent benefit from these developments there is a need to devise management systems to maintain the enhanced pasture species diversity beyond 3-4 years.

The main issues for organic deer farming are the control of lung-worm, the need to develop an alternative method for velveting, and the need to control woody weeds. Information on the market premiums is limited, but due to the consumer perception that deer farming is ‘natural’ and therefore close to organic, organic deer farming would command only a small premium.

The success of sustainable management practices for deer farming not only depends on a sound understanding of the biophysical resources and interactions, but also on the implementation and adoption of these practices by deer farmers. The costs of new techniques or practices will be an important driver for their successful adoption. It is therefore important that economic implications of such techniques or management practices are investigated. The economic analysis should not only account for the direct costs to the deer farmer, but should also consider resource costs and environmental impacts. This could be of particular importance for the deer industry with the emerging concept of ‘food miles’. Resource Accounting could provide a mechanism to demonstrate the total resource costs and allows direct comparison of these costs from competing markets.

Research priorities

Soil and water quality

- Rates of sediment and nutrient transfer (especially phosphorus) and faecal contamination of waterways due to deer farming, over a range of farm conditions, managements, topography, and sources
- Effect of deer tracking on soil conditions
- Environmental impact of changing management practices to prevent soil, nutrient and faecal losses, and soil damage
- Above research priorities particularly in sensitive/erosion prone soil areas, e.g., southern South Island sedimentary soils with high rainfall.
- The impact of nutrient and faecal contamination of waterways on New Zealand's clean green image.
- Behavioural aspects of deer pacing, mob size and shelter provision, which may help to reduce erosion problems.

Nutrient budgets and greenhouse gas emissions

- Rates of N excretion by deer as affected by management practices, such as different diets and grazing management.
- Refinement of nutrient budgeting model OVERSEER® to account for differences in N utilisation and excretion between deer and sheep.
- Direct measurements of CH_4 emissions from deer.
- Effect of soil compaction due to deer tracking on N_2O emissions.

Biodiversity

Evaluate the extent at which deer pacing behaviour is reduced on hill farms by

- Physical barriers,
- Planting of trees within blocks,
- Deer behaviour related to stress, age, sex, breed type and the strong seasonal influences of the biology of production.

Determine the extent of, and monitor changes in, biodiversity on:

- the game reserves and extensive hill and high country breeding units where there is increasing need to retain native forested areas and native tussock grassland landscapes.

- more intensively managed pastures to determine the rate of natural nitrogen inputs into pastoral systems through legumes, and the success or lack of it in maintaining a variety of selected herbaceous plants which are both preferred by browsing deer and enhance productivity

Investigating the role of deer to control of spread of invasive weeds notably *Hieracium lepidulum* and *H. pilosella*. The preference of deer for herbaceous browse plants indicates the animal could be an agent of biological control of the weeds.

Organic deer farming

- Development of management practices to control lungworm.
- Development of velveting techniques that do not require the use of drugs.
- Development of techniques or management practices for controlling wood weeds.

Economic implications

- Determine the total economic and resource costs of New Zealand deer farming products and compare with competing products.
- Determine the total economic impact of changing management practices to prevent soil, nutrient and faecal losses, and soil damage.
- Cost/benefit analysis of 'action' versus 'inaction' with respect to reducing greenhouse gas emissions.

2 Introduction

The environmental science goals of DEEResearch Ltd. reflect the need for developing sustainable management practices for the deer industry:

Define the relationship between deer farming and the use of natural resources so that the NZ deer industry can ensure sustainable production and verify and enhance its "natural" image.

- Quantify and design ways to reduce the impacts of deer farming on water and soil quality, biodiversity and the atmosphere.
- Develop and apply nutrient budgeting in the context of deer farming.
- Design and evaluate deer farm systems with low synthetic chemical inputs.

This review presents a summary of the existing knowledge in these areas and identifies the research priorities that are required to achieve these goals. It should be noted, that many New Zealand deer farming operations are part of sheep and beef farms. As a result, there could be interactions between the different livestock classes and their impact on the environment. However, since deer farms are largely managed as separate units within the farming operations, this review solely focuses on the environmental impact of deer on the environment.

2.1 Objective

To review current knowledge on environmental issues in the deer industry, in order to identify knowledge gaps, key research areas and research priorities.

2.2 Approach

The following steps were taken to prepare the review:

- Identification of 1) environmental issues currently facing the deer industry and 2) future trends in deer farming and their potential impacts on the environment, by researchers from the Land & Environmental Management platform and the Deer Group of the AgSystems platform.
- Review of national and international literature on current knowledge on environmental impacts of deer farming.
- Review documents relating to deer farming and the environment, prepared by the New Zealand Deer Farmer Association and the New Zealand Game Industry Board.

- Discussions with researchers at Massey and Lincoln University to identify current or proposed work on environmental impacts of deer farming.
- Draft report circulated for comment to:
  - Bala Tikkisetty and Gary Morgan (Environment Southland),
  - Ian Brown and David Horn (Otago Regional Council)
  - Alan Campbell and Dave Maslen (Environment Waikato)
  - Murray Harris (Land and Forest Management Consultant)
  - Russell Brown (member technical committee New Zealand Game Industry Board)
  - Tony Pearse, Jo Pollard, Jim Webster and Liz Wedderburn (AgResearch)

2.3 Outline

This review presents an analysis of,

- The current impact of New Zealand deer farming on natural resources.
- Existing knowledge and current research initiatives on the impacts of deer farming on soil and water quality, greenhouse gas emissions and biodiversity.
- Future trends in deer farming and their potential impact on the environment.
- Knowledge gaps and research priorities.

3 Current situation on deer farming and the environment

3.1 Overview of New Zealand deer farming systems

The New Zealand Deer Industry is a relatively young but rapidly expanding industry, with deer numbers increasing from about 1 million in 1990 to 2.6 million in 2001 (Baisden et al., 2001; New Zealand Game Industry Board, 2001).

There are four types of modern deer farming operation in New Zealand (Pearse and Drew, 1998):

1. Ecotourism and trophy hunting on steeper hill country, which was former feral range for red deer ("game estates").
2. Extensive grazing of breeding herds on semi or part improved native grassland on hill and high country. In these farming systems large herds of around 5000 hinds are placed into large high-country blocks of around 1000 hectares.
3. More intensive breeding and velvet production on highly stocked (12-15 su/ha) improved pastures on easy hill country. This is the predominant deer farming system in New Zealand.
4. Intensive venison production on fertile arable land. These intensive finishing operations are designed to meet the European demand of chilled product during the period August to October (Yerex & Spiers, 1987). This generally involves the break feeding of forage crops to young herds on high quality arable land during the wet winter months.

3.2 Drivers for developing sustainable management practices

New Zealand is the world's largest supplier of venison, velvet and other deer products with an estimated 95% of the New Zealand deer industry's production being exported (New Zealand Game Industry Board, 2001).

The industry's major markets are:

- Europe, which accounts for approximately 80% of all venison exports, with Germany being the single largest market, accounting for approximately 50% of all venison exports.
- Korea, which is the final market for an estimated 90% of all velvet exports.

Overseas consumers, particularly those in Europe, are increasingly concerned not only about the health and welfare of the animals but also the health and sustainability of the environment where the animals are raised. The long-term profitability of deer farming is therefore inextricably linked to the health of the farming environment (New Zealand Deer Farmers' Association 2001), and the development and adoption of sustainable management practices will be critical for maintaining New Zealand's 'clean green' image overseas. Although this is one of the main drivers for developing sustainable management practices for deer farming, other drivers include the protection of our natural resources, New Zealand's commitment to international agreements, and tourism and landscape aesthetics.

These domestic and international drivers for developing sustainable management practices for deer farming are summarised below.

- The protection and maintenance of the natural resources of New Zealand.

This is ultimately the responsibility of the Central Government, but has been placed under the guardianship of the Regional Councils through the Resource Management Act (RMA 1991). The Regional Councils develop Regional Policy Statements (e.g. Environment Canterbury 1998; Otago Regional Council 1998; Environment Waikato 2000) and Regional Plans relating to water, air, coast, and land, which highlight where they are investing effort in order to maintain and improve their environments. However, the ability of Regional Councils to control environmental issue varies depending on the issue involved. For example, Regional Councils have the legislative ability to control water use, lake damming and discharging. However, they do not have a mandate to set rules for biodiversity. They only have the ability to control biodiversity when they are related to water management (e.g. riparian management), but only as a secondary outcome (D. Horn, Otago Regional Council pers. Comm..).

- International agreements.

New Zealand is signatory to various international agreements (e.g. Convention on Biodiversity and the Kyoto Protocol) and will need to demonstrate that it is taking action to comply with commitments under these agreements.

- Pressures from non-government organisations

Regarding the impact of agriculture on resources (urban vs. rural values).

- Consumer demands

Increasingly our customers want products that are produced in sustainable farming systems, which requires New Zealand to demonstrate and uphold our 'clean green' image to retain our markets. In addition, "Food miles" is a concept that is gaining strength in Europe, particularly among those wanting less processed, less sprayed or organic food. The implication of this is that even if our food exports were all clean, green, and totally organic, they would still not be acceptable for those consumers because they had to be flown or shipped 12,000 kilometres to market, using resources to get there.

- Tourism and aesthetics.

Tourism is one of New Zealand's biggest foreign exchange earners (Tourism New Zealand 2002). The main attraction that draws visitor to New Zealand is our environment and the aesthetics of farming forms an important part of how visitors perceive New Zealand's agriculture.

3.3 Current initiatives for developing sustainable management practices

The New Zealand Deer Industry is clearly taking its own initiatives to be pro-active in developing sustainable management practices, including

- Initiating the Deer Farmers' Environment Awards (New Zealand Deer Farmers' Association, 2001).
- Developing a Deer Farmers' Landcare Manual (New Zealand Deer Farmers' Association, 2000).

The primary goals of the Environmental Awards are 1) to reward innovative deer farmers for implementing and practicing sustainable and profitable deer farming practices; 2) to promote the adoption of sustainable deer farming practices on all deer farms; and 3) to encourage the sharing of experience and proven best management practices and innovative methods in an easily accessible and reviewable resource - the Deer Farmers' Landcare Manual.

The Deer Farmers' Landcare Manual is currently being developed through a Sustainable Farming Fund project. The aim of the project is to develop a deer farmer derived reference and application manual of best practice in land management, which will accelerate farm adoption of best management practices and land care husbandry programmes, extend the market image, and add value and dimension to existing on farm Quality Assessment programmes (New Zealand Deer Farmers' Association, 2000).

The project recognises that there are land care problems that are specific to the deer industry, due to the behavioural responses of deer to confinement, intensification and evolving animal management systems. Because the deer industry is relatively young, there are few established protocols that either avoid the problems of soil erosion, compaction, damage and loss of vegetation or positively promote methods of sustainable management to minimise the risk.

The project fits well within the concepts promoted by Rowarth et al. (2000) in their address to the 25th New Zealand Deer Farmers Association Conference, which highlighted the need for research to maintain New Zealand’s reputation for good pastoral farming.

Regional Councils in New Zealand generally do not have an environmental policy that specifically targets the deer industry. However, best management practices that are promoted to minimise the impact of pastoral farming on soil and water quality (e.g. riparian management and minimising erosion) are also applicable to deer farming. The Deer Farmers’ Landcare Manual and its development process are likely to have a positive influence on local body planning with respect to the RMA and the subsequent implementation of control measures. By combining the resources and best practice approach, the manual and its implications will serve both groups’ needs in a proactive and positive sense. The manual is likely to have many similarities with “Market Focussed”, which is an environmental management system for New Zealand dairy farmers (Otago Regional Council, 2001).

The need for information on the environmental impacts of deer farming was further highlighted in an article by Barton (2000). He indicated that Environment Bay of Plenty considered reducing deer farming in areas within its district plan, but that little information is available for environmental policy makers on soil erosion and nutrient transfer to waterways from deer farms.

4 Current state of knowledge on environmental issues

4.1 Introduction

This section presents and overview of the current understanding of environmental issues relating to deer farming:

- Soil quality – soil compaction and soil erosion due to treading, fencline pacing and wallowing.
- Water quality – contamination of waterways with sediment, nutrients and pathogens due to run-off and leaching, soil erosion and wallowing.
- Nutrient budgeting – example of a nutrient budget for a ‘typical’ deer farm.
- Air quality – greenhouse gas emissions.
- Biodiversity.
- Organic deer farming.

Although most of these issues are intrinsically related they are separately discussed below, but reference to other issues is made where relevant. It should further be noted that soil and water quality can also be affected by other issues than those listed above, e.g. cultivation on steep land, burning of vegetation, draining of wetlands. However, these are not specific to deer farming and therefore not further considered in this review.

4.2 Soil quality, compaction and erosion

The primary cause of soil compaction and erosion is the behavioural responses of deer to confinement (fence line pacing), which is enhanced when the animals are under stress (e.g. during weaning, calving or mating, or through lack of shade and shelter). In addition, deer with access to streams are likely play and wallow in these streams. As a result, stream margins are trampled, vegetation cover removed and steeper stream banks destabilised (Ministry for the Environment 2001). Wallows will be particularly created by red deer in the rut and in late spring when they shed winter coats, and in summer when no shade is provided and the animals need to cool off.

Soil compaction

Compacted soil reduces soil aeration and water infiltration, which can reduce pasture production and increase run-off of soil and nutrients with rainfall.

Research on soil compaction, particularly for the dairy industry, shows that a good indicator of soil compaction is soil macroporosity. Macroporosity is the proportion of large pores in the soil responsible for soil aeration and drainage, which is important for plant growth (Drewry and Paton 2000; Drewry et al. 2002). Optimum macroporosities for good pasture growth vary depending on soil and/or climatic conditions, but soil with a macroporosity of less than 10% are generally considered to be compact (Drewry and Paton 2000).

Visually, fence line pacing by deer creates bare tracks and considerable areas of bare ground and soil erosion. However, although many studies have focused on behavioural aspects of deer fence line pacing (e.g. Pollard et al. 1998), a recent pilot study at the AgResearch Invermay deer farm is the only known study to investigate the effect of fence line pacing on soil compaction (Pollard et al. 2002b). The results showed that deer paddock tracks were very compact. Tracks on sloping land were more compact after calving, with very low macroporosities (down to 2.7%). In contrast, soil under pasture areas of the paddock were considered not to be compact (macroporosity 15.5–17.2%) and were therefore unlikely to be limiting pasture production at that particular time. However, the very low values and reduction in macroporosity post-calving on sloping tracks is likely to be a concern as overland flow may increase with increased soil compaction. Although this has not been demonstrated on deer farms, research on the impact of sheep and cattle treading in hill country (Nguyen et al. 1998; Sheath and Carlson 1998) showed that treading damage reduced macroporosity and water infiltration, which in turn led to increased sediment loss and nutrient losses following rainfall (see also section 4.3). These studies also showed that the concentration of suspended solids and nutrients tended to increase with an increase in soil damage, particularly in steeper areas.

The results by Nguyen et al. (1998) and Seath and Carlson (998) and the observed decrease in macroporosity of deer tracks during calving (Pollard et al. 2002b) suggest that sediment and nutrient losses could increase due to fence line pacing during calving. Deer pacing at weaning and during the rut may also influence soil (and water) quality although there have been no studies to quantify this.

Soil erosion

New Zealand research on the effects of deer farming on soil erosion is limited. Wodzicki (1950) summarised the information available at that time and concluded that the existing factual evidence of the influence of (feral) red deer on the acceleration of soil erosion was limited, but that their effect on the alpine soils was likely to be greater than in the forest below. That is not to say deer were not implicated elsewhere, only that it was difficult to separate their effects from burning and overgrazing generally.

Thorrold and Trolove (1996) measured the effect of fence line pacing on soil erosion in a small survey in the Ngongotaha Valley, Lake Rotorua. Based on fence line channel measurements and bare ground estimates, they estimated that the amount of sediment generated in 3 deer paddocks was 2.1, 2.2 and 22 t/ha/year, i.e. erosion in one paddock was about 10 times higher than in the other two paddocks. However, these were simply estimates of the size of holes and track channels generated by the deer and may not reflect the export of sediment beyond the paddock or farm boundary. Due to the preliminary nature of the study it would be unwise to extrapolate the results to estimate soil erosion losses from deer farming in general, as there are many variables that can affect the extent of erosion losses (e.g. soil type, slope, rainfall). Thorrold and Trolove (1996) also indicated that, although the proportion of the paddock affected by erosion was small (e.g. 1 or 2%), the effects on promoting weed growth through bare ground, undermining and burying of fence lines and creation of visually unattractive areas, was probably of more significance.

Results from the study by Thorrold and Trolove (1996) were also used in a study by Rodda et al. (2001) to predict the likely effects of land use change on soil erosion and sediment transport on a catchment scale (Ngongotaha). Model simulations considered the effect of increased area under deer farming and forestry within the catchment on the amount of sediment delivered at the catchment outlet. Although the model predicted that differences in annual rainfall had the greatest effect on runoff, the simulations also suggested that sediment loss from land under deer farming was up to four and a half times greater than from land under other livestock farming or forestry. They also predicted that sediment yield could be halved if deer farming was restricted to slopes under 20% (i.e., 0.2 m m^{-1}) and that further benefits would arise if riparian buffer zones were used. The modelling approach used identified “hot-spots” of high sediment losses within a catchment, which were related to areas of deer farming, particularly on steep slopes. Again, due to the preliminary nature of the study by Thorrold and Trolove (1996), the conclusions from this modelling study showed also be treated with caution.

The effect of deer tracking on soil erosion was also highlighted in a study in Norway, where soil degradation has increased with increasing reindeer numbers

(Evans 1996). In open landscapes where tracking and trampling occurred, soil erosion was most likely to occur where mineral soils have slopes of less than 7 degrees. In areas where stock numbers were confined by fencing or topography, soil erosion could occur on slopes of as low as 4 degrees. Trampling damage along a 22.5 km fence line was reported to be severe (> 30% bare soil exposed over 90 m perpendicular to fence), for 38% of its distance. The consequence of reindeer treading and rainfall was high soil erosion rates at approximately 1–3 mm per year. Evans (1996) also noted the importance of wind erosion on accelerated soil loss once the vegetative cover is removed.

Information on the effect of deer wallowing on soil erosion is limited to a small study by Environment Southland who measured water quality upstream and downstream from a site where deer had accessed the waterway (Environment Southland 2000). The results suggested that downstream of the deer wallowing site the concentration of suspended solids was about 35 times higher than upstream, which represented soil erosion losses of over 2.3 tonnes per day.

Minimising the effects of deer soil compaction and erosion

A review of the national and international literature did not reveal any scientific studies on mitigation options for reducing soil compaction and erosion specifically from deer farms. However, many mitigation practices are derived form popular observations, which are summarised below.

The deer farming community is well aware of the soil compaction and erosion problems, and deer farmers have adopted various techniques to reduce the risk of erosion: altering placement of fence lines, use of electric fencing, visual barriers between mobs, and shifting deer regularly (Anon, 2000). The results of a recent survey showed that 80% of the respondents believed that pacing along fence lines could also be reduced by the presence of trees and shrubs to provide shade and shelter (Pollard 2001).

Other management practices that are reported in the popular press include avoiding frequent grazing of pasture during drought or wet or cold weather, avoiding heavy grazing, filling in eroded fence lines with gravel or placement of gravel piles to slow water movement, careful siting of fences, and the fencing off and placement of riparian areas with suitable buffer zones near waterways (Malcolm 1996).

Central and local governments are also well aware of the problems and equally promote management options to minimise the potential impacts of deer. For example, in their report on riparian management the Otago Regional Council (1996) suggested practices such as fencing off of riparian areas, proving shade and shelter, alternative reticulated water supply, and bridge or culverted water body crossings.

The Ministry for the Environment (2001) suggested prevention of overstocking and overgrazing and exclusion of deer from wet areas may reduce erosion problems. Although not specifically deer-related, the Ministry for the Environment (2001) also presented the general principles of reducing soil erosion. These include reducing pasture damage particularly on wet areas prone to treading and pugging damage; avoiding overgrazing; minimising, intercepting or slowing surface runoff; and constructing adequate farm road drainage. Thorrold and Trolove (1996) also suggested that grass filters help reduce sediment runoff, with the amount of sediment movement being affected by the distance of the erosion site from the stream, contour and pasture length.

4.3 Water quality

It is recognised that the most ubiquitous water quality problems in the world today are eutrophication, and the contamination of water with sediment or faecal bacteria. These are all highly visible and can impact severely upon the quality and quantity of useable water. However, while sediment loss is often averted by simple soil conservation measures in defined areas, eutrophication is subject to large scale diffuse transfer of the two principal limiting nutrients, phosphorus (P) and nitrogen (N). Faecal contamination of waterways can occur either through direct inputs of faeces to the streams or via the disposal of waste from the deer slaughter plants.

Eutrophication

Eutrophication is the enrichment of surface waters with nutrients, which can accelerate the growth of cyanobacteria (blue-green algae) and aquatic weeds, which can interfere with the use of water for recreation, extraction and drinking (foul taste and odor and treatment problems such as the formation of carcinogens during chlorination). Upon plant death, increased microbial activity depletes oxygen supply and increases fish mortality (Environment Southland).

While both nitrogen (N) and phosphorus (P) contribute to eutrophication, P is the limiting nutrient in most freshwaters, and thus the main cause of eutrophication, as N may be obtained from the atmosphere. However, contamination of waterways with nitrate-N is also considered an important environmental concern and various nitrate leaching studies have been carried out recently, particularly on dairy farms (e.g. Ledgard et al. 1999a, 2000; Monaghan et al 2000). Nitrate leaching studies have not been carried out for the deer industry. However, an estimate of nitrate leaching for a 'typical' deer farm was made using a nutrient budgeting model, and showed that the nitrate concentration of the drainage water was below the recommended maximum level for drinking water (see further section 4.4 and Table 1) .

Although a natural process, eutrophication is accelerated through inputs of P from most agricultural systems (McDowell et al. 2001a). However, since much P transfer is associated with sediment movement, it is likely that the overall load of P to nearby waterways under deer farming is larger than under other agricultural systems, due to increased erosion losses. For example, considering soil contains around 0.1 to 0.3% P then the erosion losses from deer farming estimated by Thorrold and Trolove (1996) could result in annual P losses of 2-22 kg P/ha. This is an order of magnitude greater than annual P losses of 1-2 kg P/ha estimated in the majority of agricultural catchments (McDowell et al. 2001a). However, it should be noted that the study by Thorrold and Trolove (1996) was very preliminary and that more work is required to verify their estimates of soil erosion.

Similar to the findings by Rodda et al. (2001), recent work by McDowell et al. (2001b) has also shown that "hot-spots" occur within a catchment, which account for the majority of P loss events although they comprise only a small part of the catchment. Based on actual measurements, a hypothesis was proved which identified "hot-spots" as critical source areas for P loss using an indexing approach (McDowell et al., 2001c). This approach predicts P loss by ranking simple farming or management factors (e.g., fence line pacing or fertiliser use) and couples these with soil and climatic factors likely to encourage P movement in eroded sediment and overland and subsurface flow. Such an approach can therefore highlight areas within a catchment that are at greatest risk of P losses, and is being considered for application to agricultural systems such as deer farms in the South Island.

Nutrients derived from dung patches can also be a source of contamination to waterways. Williams and Haynes (1995) showed that concentrations of P and N of deer manure were less than in dairy manure, and suggested that the risk of water contamination from deer farms is likely to be less than for cattle farms. However, dung patches could become a major source of contamination if deer concentrate, and thus deposit the dung, in areas that are exposed to significant erosion (e.g. tracks) and/or in wallows.

The latter conclusion is supported by the results of the study from Environment Southland (2000), which showed that the concentration of ammonia-N in a stream was about 25 times higher downstream of a site were deer had accessed the waterway compared to upstream of this site. The downstream concentration of ammonia was at levels that are toxic to fish life. Although the study did not include measurements of P concentration in the stream, based on the estimated soil erosion loss of 2.3 tonnes per day and P concentrations in soil of around 0.1 to 0.3%, P losses to the stream could be about 2 to 7 kg P per day.

Sediment in water

Contamination of waterways with soil particles (suspended solids) is a direct result of soil erosion and reduces water clarity and light penetration. This limits plant growth, restricts predatory fish to visually feed, and hampers the treatment drinking water (Environment Southland 2000).

As for soil compaction and erosion, little experimental evidence exists of the extent of sediment contamination due to deer farming. The only direct information available comes from the study by Environment Southland (2000), which showed that the concentration of suspended solids of a stream were 35 times higher downstream of a wallowing site compared to upstream of the site.

Faecal contamination

The microbiological contamination of waterways with faecal bacteria creates health risks for human and stock (Environment Southland 2000), as many diseases identified in NZ deer herds (Gill, 1998) are considered important water borne diseases in NZ (Ball and Till, 1998). Faecal contamination is caused, either through direct inputs of faeces to the streams or via the disposal of waste from the deer slaughter plants. However, apart from the preliminary measurements by Environment Southland (2000), there has been no research into impacts of deer farming on the faecal contamination of waterways. The results from Environment Southland showed that downstream of a deer wallowing site the levels of faecal coliforms were about 20 times higher than upstream of the site, and exceeded the recommended guidelines for stock water (Environment Southland 2000).

Minimising the effects of deer on water quality

As for soil compaction and erosion, mitigation options for reducing the impact of deer farming on water quality have not been investigated in scientific studies. However, there is some anecdotal evidence of potential management options, many of which are very similar to practices used to reduce soil erosion. For example, fencing off of riparian zones, providing shade in summer to reduce wallowing, and preventing overstocking.

A report by the Ministry for the Environment (2001) reported on a Southland deer farmer, who had permanently fenced out all streams and drains on his property. The riparian strips between the fence and the stream or drain were at least 5 meter and rank grass provided a filter for surface run-off. These grassy filter strips were very effective at intercepting overland flow and entrained sediment (Ministry for the Environment, 2001). Another Southland deer farmer had developed wide races, fenced drains, shelterbelts and soak holes to combat some problems.

4.4 Nutrient budgeting

A nutrient budget is a balance sheet showing nutrients coming on to a farm and nutrients going off the farm. Nutrient budgets, together with soil tests, are important tools for monitoring soil fertility levels and are recognised as prime indicators of sustainable management. The aim of nutrient budgeting is to balance inputs and outputs, so that fertility levels are maintained at optimum production levels without excessive use of nutrients. If the nutrient inputs and outputs are in balance, soil test levels should remain more or less the same over the years. A positive nutrient balance (i.e. more nutrient coming on to the farm than going off the farm) generally results in an increasing trend in soil test levels, and increased risks of nutrient losses to the environment.

AgReseach has developed the software package OVERSEER® that calculates nutrient budgets for the four major nutrients – nitrogen, phosphorus, potassium and sulphur – in New Zealand farm systems (Ledgard et al. 1999b). It covers pastoral farming systems (sheep, beef, dairy and deer) as well as some arable (wheat and potatoes) and horticultural (apples and kiwifruit) crops. It provides average estimates of the fate of N P, K and S in kg/ha/year, ignoring year-to-year variability due to climate and other factors. The pastoral version of OVERSEER® was developed by AgResearch, with funding from MAFPolicy, Ministry for the Environment and FertResearch.

Table 1. A nutrient budget for a developed MAF monitor farm calculated using the nutrient budgeting model OVERSEER®. Farm N surplus and leaching losses are also included.

Farm details				
Effective area	140 ha			
Topography	Rolling			
Clover levels	Medium			
Distance from coast	40 km			
Rainfall	1200 mm			
Soil type	Volcanic			
Stocking rate	12.7 SU/ha			
Farm production	916 kg velvet			
Nutrient Budget (kg/ha)	N	P	K	S
Inputs				
Fertiliser	20	25	25	31
Atmospheric (N fixation and with rain)	56	0	2	4
Slow release from soil	0	3	27	0
Outputs				
Product	6	1	1	1
Gaseous losses	34	0	0	0
Leaching/runoff	24	1	17	37
Immobilisation/absorption	12	25	0	1
Balance (change inorganic soil pool)	0	1	36	-4

Nitrogen and the Environment	This farm	Average NZ farm
Farm N surplus* (kg N/ha)	70	30-80
Leaching loss (kg N/ha)	24	5-25
Average nitrate concentration in drainage water** (mg N/L)	5 +/- about 25%	2-8

* Sum of fertiliser and atmospheric N inputs minus N output in product

** Recommended maximum for drinking water is 11 mg N/L

OVERSEER® is freely available from MAF Policy in Wellington.

Equations used in the model were derived from summaries of New Zealand research relevant to the different farming systems. However, due to the lack of experimental evidence on nutrient cycling in deer farming, the equations are primarily based on information from sheep, beef and dairy farms. For example, the model currently assumes that deer are the same as sheep in the way they utilise and excrete N. Work by Williams and Haynes (1995) indeed suggests that sheep and deer manure contain similar concentrations of P and N, and have similar effects on pasture production and soil nitrate levels when applied to the soil. However, their study did not include grazing animals and more work is required to refine the equations currently used for the deer model. This will be particularly important with the increasing deer numbers and the effect of N excreta on greenhouse gas emissions (see section 4.5).

An example of a nutrient budget for a MAF monitor farm is given in Table 1. The table also details an Environmental N page, which is included in the latest version of the model. Currently, this environmental page details N losses and nitrate leaching, which has been the main environmental concern in recent years. However, as mentioned above, phosphorus losses to waterways can also have a major environmental impact and the inclusion of P to the environmental page of a future version of OVERSEER® is currently being explored.

4.5 Greenhouse gas emissions

Ratification of the Kyoto Protocol will commit New Zealand to reduce its greenhouse gas emissions to 1990 levels, on average, between 2008 and 2012 (New Zealand Climate Change Programme 2001). These are challenging reduction targets given the continued growth of CO_2 equivalent emissions and the large contribution of agricultural methane (CH_4) and nitrous oxide (N_2O) to New Zealand's total emissions (about 55%). The principle source of methane is enteric fermentation in the digestive tract of ruminants. Other minor sources of agricultural methane include the anaerobic fermentation of animal wastes and animal dung deposited directly onto pastures. Nitrous oxide emissions from agriculture are largely a result of the deposition of excreta nitrogen to the soil when the animals are grazing. This nitrogen is then transformed into N_2O via the biological soil processes denitrification and nitrification (Haynes, 1986).

The deer industry recognises the importance of climate change and the need for a world-wide response to the issue. However, in its submission to the government's

Climate Change consultation paper (New Zealand Climate Change Programme, 2001), the Game Industry Board expressed concern that New Zealand appears to be rushing into ratification of the Kyoto Protocol without fully understanding the implications this would have on the New Zealand economy and on the agricultural sector (New Zealand Game Industry Board, 2001). The main reason for this concern is the lack of information on the preferred policy options to meet the obligations under the Kyoto Protocol. Similar sentiments were expressed by other agricultural sectors at a recent strategy meeting on Climate Change (National Science Strategy Committee for Climate Change 2002). The reluctance from the private sector to commit to the Kyoto Protocol is largely due to the uncertainties about the policies that the government intends to adopt to meet New Zealand obligations under the Kyoto Protocol. As a result the industry is unsure what the (financial) implications will be of ‘action’ versus ‘inaction’ (e.g. sector trading, taxes, levies etc). In addition, there are uncertainties about the alignment of greenhouse gas mitigation options with industry goals; i.e. what are the potential benefits of adopting mitigation strategies (e.g. increased production, increased market access, maintain New Zealand’s green/clean image)?

The contribution of the deer industry to New Zealand’s agricultural greenhouse gas emissions is relatively small, but has doubled from about 1.5% in 1990 to about 3% in 1999 (Table 2). Based on the projections of animal numbers (Ministry of Agriculture and Forestry, 2001) it is expected that by 2010 this contribution could be about 7%.

Table 2. Relative contribution (%) of animal sectors to total greenhouse gas emissions from livestock in New Zealand in 1990 and 1999 (adapted from Baisden et al., 2001 and Ministry of Agriculture and Forestry, 2001).

Livestock type	1990	1999	2010
Sheep	58	48	35
Dairy Cattle	19	25	32
Beef Cattle	21	23	24
Deer	1.5	3	7

These estimates are based on the methane emission value for deer of 22.6 kg CH_4 per animal per year (Clark, 2001), and on a nitrogen excretion rate and a N_2O emission factor of 19.7 kg N per animal per year and 1% of nitrogen excreted, respectively (Ministry for the Environment, 2000).

Research on mitigation options for reducing methane and/or nitrous oxide emissions from agriculture is limited, and almost non-existing for deer farming (Clark et al., 2001). However, potential mitigation options for reducing CH_4 and N_2O emissions from dairy cows have recently been evaluated (de Klein and Clark, 2002). Although experiment evidence of the effect of these strategies or management practices is limited, they are likely to be applicable to the deer industry as well.

Options for reducing methane emissions from livestock can broadly be grouped into those that improve animal productivity so that less CH_4 is produced per unit of product, and those that directly affect the activity of the microbes in the rumen so that less CH_4 is produced per unit of feed intake (Clark et al., 2001).

The options evaluated by de Klein and Clark (2002) include:

1. Improving animal productivity by feeding the animals better quality feed.
2. The use of additives.
3. Improving N use efficiency.
4. Optimising soil conditions.

1. Improving animal productivity is likely to reduce both CH_4 and N_2O emissions per unit of product, as the proportion of feed intake required for maintenance decreases and a larger proportion can be used for growth and product. Alternative forages or diets can reduce CH_4 production by increasing animal productivity. White clover results in significantly better animal performance than the common forage grasses and less common species such as sulla and chicory have also been found to be superior to grasses (e.g. Waghorn & Sheldon 1997). Similarly, Hoskin et al. (2000) found that deer fed sulla had higher live weight gain and carcass weight than deer on a lucerne diet. In addition, certain forages may directly affect the microbial activity in the rumen. For example, Woodward et al. (2001) found that methane emissions from sheep and dairy cows fed *Lotus corniculatus* silage were lower per unit of product (i.e. increased animal productivity) and per unit of feed intake (i.e. direct effect on activity of the rumen microbes), compared to animals on ryegrass silage.

2. Some experimental evidence with dairy cows on high concentrate diets suggests that additives, such as ionophores or probiotics, could increase animal productivity by about 5-8% (Clark et al., 2001). There are also suggestions that these products can influence rumen fermentation and reduce CH_4 production per unit of feed intake. However, there is very little evidence of their direct effect on methane emissions.

3. The single largest source of N_2O in New Zealand's pastoral systems is the animal excreta that are deposited to pasture during grazing particularly under wet soil conditions (de Klein et al. 2002). Management practices that reduce this amount of excreta N, or those that utilise this N more efficiently, thus provide the largest potential to reduce N_2O emissions. Recent calculations for the dairy industry suggested that diet manipulation (including maize silage to reduce N content of feed) and winter grazing management (avoiding grazing under wet soil conditions) had the highest potential of reducing N_2O emissions. Although N_2O emissions from deer pasture have not been measured, it is likely that similar principles apply for deer farming. Various studies have shown the effect of diet on N concentrations in deer excreta (e.g. Freudenberger et al., 1994; Masuko et al., 1997). In general, deer fed on diets with higher N contents had higher N excretion rates.

4. As mentioned above, N_2O emissions from soil are higher under wetter conditions. As a result, poorly and imperfectly drained soils generally emit more N_2O than free-draining soil (e.g. de Klein et al. 2002). In addition, various studies have shown that N_2O emissions are enhanced as a result of soil compaction (McTaggart et al. 1997; R.A. Carran and P. Theobald unpublished data; C.A.M. de Klein unpublished data). The latter could be of particular importance for deer farming given the effect of deer on soil compaction (see section 4.1).

4.6 Biodiversity

Effects of red deer on forest plant biodiversity

Most information on deer effects on New Zealand plant biodiversity has been from forest environments because red deer were one of the introduced mammal species best adapted to forests. Their success in this environment threatened native forest sustainability; and threatened stability of the soil in some forested areas. So research on deer ecology and the effects of deer population control policies resulted in knowledge of the plants preferred by the deer and the resilience of the plants given a relaxation of grazing pressure from deer. Effects of deer on forest plant biodiversity have been severally reported over the past 5 decades (Nugent et al. 2001, Wardle 1991, Challis 1990, Gibb and Flux 1973, Wodzicki 1950). Many of the later reports no doubt rely on earlier ones for their information. However, Nugent et al. (2001) offers the latest summary of deer diet studies completed over a period from 1987 to 2000 (see their Table 3). A combination of the information in Nugent et al. (2001), including one important summary table modified from a Landcare report by Forsyth et al. (2000; see their Table 4), and Wardle (1991), probably provides a contemporary compendium of the state of current knowledge from forested situations. Data tabulating the plant species preferred by browsing red deer are in general agreement across the various publications. The one obvious exception in the most recent published list (Nugent et al. 2001 Table 4, based on Forsyth et al. 2000) is the classification of *Prumnopitys ferruginea* (miro) as an unpreferred or avoided species. Miro was ranked as susceptible to browsing in the Grey River catchment by Wardle (1991) and was similarly ranked as a preferred species in the Ruahine Mountains (Wodzicki 1950).

Information on species palatability for New Zealand is derived from a series of localised studies. At each of these sites the species eaten was dependent on the range of species available and on the length of time the sample area had been subjected to deer browsing, because preferred species tended to be lost and choice of plant browse changed with time. Thus deer have often initiated a successional trend towards a more browse tolerant vegetation by selective removal of preferred species. Where deer are removed the transition of species is reversible provided local seed sources remain.

Nugent et al. (2001) summarise as follows: "Foliage of sub-canopy trees predominates (deer diet) especially broadleaf, lancewood, marbleleaf, mahoe, kamahi and large leaved *Coprosma* species. Main canopy species are seldom important in the diet except perhaps for miro. Grasses most ferns and shrubs are less preferred. Fallen leaves were a crucial component of diet (up to 70% of diet)". The preferred species tend to have largish soft, glabrous, leaves and high nutrient contents; while low palatability is conferred by harsh foliage with low nutrient content (e.g. most podocarps); or distasteful ingredients e.g. *Pseudowintera.* The net effect of deer browsing on native forests is often the replacement of faster-growing, light-demanding, early-successional species with slower growing late-successional species, which they least prefer.

Data of the palatability of native plants to red deer summarised by Nugent et al. (2001; Appendix 1). Examples of results from individual forest enclosure studies are shown in Appendices 2 and 3.

Effects of red deer on grassland plant biodiversity

Research on deer effects on grassland was less simple, because on all except alpine grasslands, sheep and possibly rabbits and hares and/or goats etc were also present and it was impossible to measure the effect of deer *per se* on the much altered grassland plant biodiversity.

In alpine grassland Zotov cited by Wodzicki (1950) implicated red deer in damage to foliage of *Cordyline indivisa* while severe grazing damaged many grasses such as *Aciphylla colensoi* and *Danthonia antarctica*; this could result in bared ground; and replacement of grass with bog species.

Solly (1998) showed that defoliation simulating deer grazing could have different effects on snow tussock than defoliation simulating that of the original herbivore, the takahe. There was no evidence that the morphology of the tall tussocks was in any way adapted to the grazing behaviour of the earlier herbivory. Recovery from deer defoliation was relatively rapid provided the vegetation was previously undisturbed for a period of several years.

In lower altitude short tussock grassland there is no longer a feral red deer population (Nugent et al. 2001), but reintroduction of extensive farming of breeding herds of deer on short tussock grassland will require a watching brief to be applied. Amongst the limited data reviewed relating to short tussock grassland is the record of the stomach contents of a single red deer analysed by Ruth Mason in 1946 and reported in Wodzicki (1950). The deer was shot at Molesworth Station; the stomach contained "much leaf, seed, and thorns of *Rosa rubiginosa*, few fruits of 2 species of *Carex* and leaves of 1 species of *Carex*, and leaves of *Poa cita".* Deer are only one of several animals responsible for the spreading of seed of sweet briar (*Rosa*). The list would appear to be a good representation of the vegetation available at Molesworth in 1946.

Red deer pasture grazing studies have clearly demonstrated the preference by red deer for herbaceous plants from improved pastures (Stevens et al. 1992, Hunt and Hay 1990, Semiadi et al. 1995, Barry et al. 1993). Hunt and Hay (1990) reported that the order of preference of 16 pasture species was as follows: red clover > lotus, chicory, white clover and sheeps burnett > lucerne, sainfoin, and sulla > other grasses or dock. Semiadi et al. (1995) similarly showed the red deer preference for red clover, this time amongst a choice which also included shrub plants. Bootsma et al. (1990) found that weaned red deer stags actively selected white clover when grazing rygegrass/white clover pastures.

The deer habit of selecting herbs before grasses has large potential in considering the animal as potentially a form of biological control of one or more invasive weeds of the natural grassland of New Zealand. Deer may be employed to help control the spread of tussock hawkweed in the relatively early stages of its invasion of wetter natural tussock grasslands, particularly when under controlled grazing in the sprng/early summer with relatively large numbers of deer. Tussock hawkweed (*Hieracium lepidulum*) has been noted as invading tall and short tussock grassland associations in the South Island, being especially obvious in the 2001-2002 growing season when favourable moisture conditions have resulted in a large excess of grassland production over grazing requirements. The leaf, stem, and flowers of the erect growing tussock hawkweed are readily eaten by sheep (Espie 2001) and so could be expected to be even more attractive to the herb preferring deer. Similarly it may be possible to have a degree of control over the flowering and thus seed production of the even worse species *Hieracium pilosella* (mouse-eared hawkweed). However, the impact of the use of deer to control the spread of *Hieracium* on other grassland species should also be taken into account.

Effects of other deer species on biodiversity

Semiadi et al. (1995) compared the dietary preferences of red deer and sambar deer (*Cervus unicolor*) given the same plant species in individual plots within in a field experiment. Red deer preferred legumes (especially red clover) before grasses (and ryegrasses before Yorkshire fog and prairie grass); and grasses before shrubs (willow and poplar). Red deer spent on average 4% of their grazing time on the shrub plots. In contrast, sambar deer spent more time browsing the shrubs (mean 66% of time) than they did on ryegrasses, then legumes and least on Yorkshire fog and prairie grass plots.

Nugent et al. (2001) reported evidence of differences in the rumen morphologies of red deer and sika deer (*Cervus nippon*) living in the same habitat in the Ahimanawa and Kaweka Ranges in the North Island. The differences made sika deer better adapted to digesting fibrous forage and this was offered as a partial explanation of why sika were replacing red deer in the Kaweka Range. Similarly rumination in sambar deer is thought to be more efficient than in red deer, which may influence their choice of willow and poplar in the above study (Semiadi et al. 1995), and allows them to digest pine bark more easily than red deer. Studies with sambar in their coastal Manawatu range showed them to eat a mainly grass diet (65% of total diet; Stafford 1997).

Rusa deer (Cervus timorensis) largely live in a localised area of radiata pine forest in the North Island and appear to rely mainly on woody plants (61% of diet) and pasture grasses (29%) and also a number of minor but moderately important foods (Nugent et al. 2001).

Effects of deer on other native biodiversity

The effect of deer on native biodiversity other than higher plants is not well recorded. Although deer alone cannot be blamed for losses of native birds, deer in association with other mammals including possums, rats, mustelids, cats, and dogs have helped to decimate populations of native birds in most of the native forests.

Wodzicki (1950) cites the Cockayne (1926) belief that red deer could destroy the bryophyte carpet of the beech forest floor, which was so important in holding water.

The most relevant recent study concerns soil and litter fauna and flora (Wardle et al. 2001). Wardle et al. (2001) measured the effect of deer on this biota by comparing the biota in forest enclosures from which deer were excluded, with adjacent areas where deer browsed. They showed that where deer were present there were consistently lower numbers of large invertebrates (>2 mm) than in the enclosures; this was not necessarily due to a change in vegetation caused by the deer, but may be attributable to disturbance of the litter by the deer. With other litter and soil biodiversity fractions there were often effects of browsing on different groups but the differences were not unidirectional.

4.7 Summary of environmental impact of deer farming systems

This section summarise the environmental impact of the four farming systems described by Pearse and Drew (1998).

1. Ecotourism and trophy hunting

These systems probably have very low impacts on soil and water quality and on greenhouse gas emissions due to the low stock densities. Biodiversity concerns of these farming systems are associated with preference for understory forest plants historically defoliated and displaced. Damage will have to be monitored but the deer numbers will be highly managed on these blocks and stocking densities will invariably be low to improve the sport. The major issue will be the maintenance of the appearance of the native forest and tussock grassland.

2. Extensive breeding systems on high and hill country

In these systems deer will have free access to the streams within these blocks, which could lead to high levels of soil erosion and increased inputs of nutrients and faeces directly into the streams. These problems will be further exacerbated by the fact that upland headwaters are the most sensitive to eutrophication and faecal contamination. In terms of biodiversity, extensive grazing of breeding herds on alpine grassland and tall tussock grassland could increase losses of slow growing native grasses. With sheep, dry unimproved tussock grassland typically supports less than 0.5 su/ha. It will not support more than the equivalent stocking rate with deer. If higher rates are proposed then stock should be fenced within developed/improved tussock grassland. If this type of farming is largely the preserve of corporate farming companies, there is a possibility that capital funds will be more readily available for fencing and possibly development, than on a one man property. Maintenance of tall tussock grassland will always require specialist management perhaps even protection from all grazing. In this environment research should be undertaken to quantify the effects of deer and/or development on native plant biodiversity and the effects, if any, of deer browsing on herbaceous invasive species such as several Hieracium species.

3. Intensive hill and down lands breeding and velvetting units

The impact of these systems on soil and water quality will probably be higher compared to any other farming system, due to their more intensive nature and because they are the predominant deer farming system in New Zealand. Soil compaction and erosion problems are most pronounced in this type of farming, and probably represent the greatest management concerns for farmers. Soil compaction and erosion increases the risks of sediment and nutrient losses due to increased run-off of rainfall. In addition, animals can also have access to wallows and thus create the same erosion, eutrophication and faecal contamination issues as described under 2. Pollard et al. (2002a) demonstrate that New Zealand deer farmers are particularly interested in the question of shelter particularly as it affects fence line trampling leading to losses of plant cover and hence possible soil erosion. Trees for erosion control, shelter and shade, and the maintenance of productive pastures containing species that are palatable to deer probably represent the main biodiversity issues. If erosion were to worsen then the downstream effects of it on the biodiversity of streams and possibly of flooded land becomes a problem.

4. Venison finishing operations

In these systems, intensive grazing on wet soils can also lead to soil damage and increased rainfall run-off. In addition, the mob stocking of animals can increase the potential for rapid spread of disease in animal populations with the associated environmental and food safety risks - such as the *Salmonella brandenburg* problem in the lower South Island (Clark, 2000). The pastures used in this farming system are highly manipulated by man. Introduced pastures, especially with species such as red clover, white clover, chicory, and short rotation hybrid ryegrasses (Anon/Agricom1999), enhance deer production. These species were favoured by red deer in palatability studies (Hunt and Hay 1990). The idea of using a range of plant species and cultivars in pastures is in agreement with the concepts raised by Campbell (1990), who demonstrated the opportunities for development of additional cultivars to occupy particular niches in New Zealand pastures in general. The niche of one or more of these species may be to provide longer pasture cover identified as necessary for highest fawn survival (Thompson and Poppi 1990), without a marked reduction in palatability. The chicory, red clover and short rotation ryegrasses of the mixture recommended for intensive venison production, all have limited persistence in grazed pasture e.g. chicory 2-4 years (Barry et al. 1993), and pastures decline due to invasion by less palatable plant species on which deer productivity declines. A perceived difficulty of management then, is to maintain high feed quality and maintain species composition (Stevens et al. 1992; Barry et al. 1993).

4.8 Organic deer farming

The main issues regarding organic deer farming are extensively reviewed in a recent report by the Ministry of Agriculture and Forestry (2002). The main findings of this report are:

- A major issue for converting to organic deer farming is the control of lungworm, with extensive deer farming operations having a greater range of options to control lungworm than intensive operations.
- For the velveting operations there is a need to develop velveting techniques that do not require drugs.

- Better management of land resources, water courses and indigenous vegetation is needed.
- The control of woody weeds is also an very important issue for converting to organic production.
- Information on the market premiums is limited, but due to the consumer perception that deer farming is ‘natural’ and therefore close to organic, organic deer farming would command only a small premium.
- Extensive, low-stocked deer operations are close to complying with certification for organic supply.
- More intensive deer operations, will have to reduce stocking rates to remain viable.

4.9 Economic implications

The success of sustainable management practices for deer farming not only depends on a sound understanding of the biophysical resources and interactions, but also on the implementation and adoption of these practices by deer farmers. Although the deer farming community has already been very proactive in taking initiatives to adopt sustainable farming practices, the costs of new techniques or practices will be an important driver for their successful adoption. It is therefore important that the economic implications of such techniques or management practices are investigated. Not only the direct costs to the deer farmer, but also the total economic and resource costs (e.g. energy use, transport costs). Environmental Resource Accounting provides a mechanism for estimating these economic and resource costs, as it not only accounts for the direct resource costs of a process, but also considers resource costs and environmental impacts (S.F. Ledgard unpublished report). This could be of particular importance for the deer industry with the emerging concept of ‘food miles’. Resource Accounting could provide a mechanism to demonstrate the total resource costs and allows direct comparison of these costs from competing markets.

4.10 Research Capabilities

Most of the current deer research in New Zealand is carried out by AgResearch, and Massey and Lincoln University (Table 3). Research in the various environmental areas is carried out by a range of institutes, both CRIs and Universities.

Table 3. A summary of current research capabilities and expertise in deer research and/or environmental research at various institutions in New Zealand.

Institution	Capability
Crown Research Institutes	
AgResearch	AgSystems Deer Group – Forage quality, reproductive processes, breeding management, deer behaviour, and environmental impacts.
	AgSystems – deer farming systems, human decision making.
	Land & Environmental Research – Soil and water quality, nutrient budgeting, greenhouse gases, biodiversity, resource accounting.
Crop & Food research	Soil quality.
HortResearch	Bioremediation, tree research for soil conservation, shelter, fodder and riparian protection.
Landcare Research	Soil quality, soil erosion, climate change, greenhouse gases, biodiversity.
NIWA	Water quality, greenhouse gases.
Universities	
Massey	Deer Research – Nutrition, management and production, welfare and behaviour, diseases, forage species and management, grazing ecology, meat science, bioactive compounds, pharmacology, marketing and business, extension.
	Institute of Natural Resources – Soil and water quality, ecology, pastoral systems.
Lincoln	Deer Research – Animal production, health and behaviour, pregnancy scanning of deer embryo/transfer, public relations.
	Centre for Soil and Environmental Quality – Soil and water quality, greenhouse gases.
	Plant science – Biodiversity

Although there is no current research into the environmental impacts of deer farming, researchers at AgResearch, Massey and Lincoln University all have applied for research funding in this area. To date, none of these applications have been successful (J. C. Pollard, P.R. Wilson, S.D. Morriss, M.J. Keeley pers. comm.)

5 Future Projections

Future trends in deer farming (T. Pearse pers comm.) and some of the potential impacts on the environment include:

- Increased winter feeding on brassicas, and feedlots on sacrifice paddocks or wintering pads. This is likely to increase the risk of soil damage, contamination of waterways and N_2O emissions. The increased use of wintering pads will require better effluent disposal and drainage systems on deer farms.
- Continued expansion of deer farming in Canterbury, Otago and Southland.
  This will increase the pressures on the natural resources in these regions, in particular if deer farming expands into areas with higher risks of soil erosion.
- Increase in hill country farming.
  If stocking rates are higher than about 0.5 SU/ha, there will be an increased risk of losses of slow growing grass species. Risks of soil damage will also increase, particularly on steeper slopes.
- Increase of deer farming close to urban areas.
  This is likely to increase deer disturbance and results in more fence line pacing and treading damage.
- Increase in intensive systems for finishing off weaners.
  This generally involves grazing of large mobs on borderdyke land and an increase in N fertilisation to boost autumn growth. This could increase the risks of nitrate leaching to waterways and N_2O emissions.

6 Knowledge Gaps

6.1 Soil and water quality

As shown in section 4, very little research has been carried out to date, to quantify the impacts of intensive deer farming on soil and water quality. To assess these impacts, rates of sediment and nutrient (especially P) transfer on deer farms need to be quantified, as well as the effect of farm management, topography, soil type and climate conditions on these rates. Although the effect of deer tracking and deer farming on soil conditions, has been studied in one pilot study (Pollard et al. 2002b), the full extent of this problem and its environmental and economic impact is unknown.

Similarly, the loss of soil through wind- and/or water-generated erosion has been measured in only one preliminary survey (Thorrold and Trolove, 1996), and more detailed studies are required in order to develop management practice to reduce erosion losses. E.g. determining behavioural aspects of deer pacing, mob size and shelter provision that may decrease erosion problems. Deer behaviour such as fence pacing and wallowing enhance the risks of faecal contamination or water ways. However, very limmited data exists to quantify the extent of this problem.

6.2 Nutrient budgets and greenhouse gas emissions

Nutrient budgets are a powerful tool for monitoring soil fertility for optimum production and to identify potential environmental risks. Although a nutrient budgeting model is available (OVERSEER®), the current equations are largely based on nutrient cycling research on sheep, beef and dairy farms, and more work is required to refine them for deer farming if they were to be applied extensively to deer farming systems.

Although the contribution of the deer industry to New Zealand's agricultural greenhouse gas emissions is relatively small, they have doubled since 1990 and this trend is expected to continue over the next decade. With the pending ratification of the Kyoto Protocol, quantification of methane and nitrous oxide emissions from deer farming will become increasingly important. Direct measurements of methane emissions from deer not been carried out and the impact of soil compaction on deer farms on nitrous oxide emissions is also unknown. In addition, deer farmers need more clarification on the financial implications of adopting management practices aimed at reducing greenhouse gas emissions.

6.3 Biodiversity

The extent to which biodiversity on different types of deer farms can be increased is unknown. In particular, the effect of biodiversity on improving the viability of the deer farming operation, reducing possible environmental damage, and increasing indigenous plant and animal biodiversity.

A sound understanding of best management techniques to maintain indigenous plant biodiversity within existing and developing deer farming systems is also lacking, especially on farming systems on hill and high country. This would require an audit of native plants (most relevant to the property, as browse species, or to conservation; absence of species relevant to conservation interests).

Best management techniques to maintain indigenous plant biodiversity also requires expansion of the knowledge of attractiveness of species as deer browse, and of practical methods to protect plants. The possible role of deer as control agents of invasive weeds in extensively grazed landscapes is also unknown.

Although it is generally accepted that increased biodiversity in grassland systems can help deter potential environmental and animal welfare impacts, the specific needs require investigation (e.g. what is required to reduce soil erosion and animal disturbance; to provide shelter, alternative browse reserves for drought years and possibly alternative herbs in intensive pastoral systems; or to extend the persistence of favoured species in intensive pastoral systems?)

6.4 Organic deer farming

The main issues for organic deer farming are the control of lung-worm, the need to develop an alternative method for velveting, and the need to control woody weeds. Information on the market premiums is limited, but due to the consumer perception that deer farming is ‘natural’ and therefore close to organic, organic deer farming would command only a small premium.

6.5 Economic implications

The costs of new techniques or management practices for sustainable deer farming will be an important driver for their successful adoption. It is therefore important that both the direct costs to the deer farmer, and the total economic and resource costs of such techniques or management practices are investigated. This could be of particular importance for the deer industry with the emerging concept of ‘food miles’. Resource Accounting could provide a mechanism to demonstrate the total resource costs and allows direct comparison of these costs from competing markets.

7 Research priorities

7.1 Soil and water quality

- Rates of sediment and nutrient transfer (especially phosphorus) and feacal contimination of waterways due to deer farming, over a range of farm conditions, managements, topography, and sources
- Effect of deer tracking on soil conditions
- The environmental impact of changing management practices to prevent soil, nutrient and faecal losses, and soil damage
- Above research priorities particularly in sensitive/erosion prone soil areas, e.g., southern South Island sedimentary soils with high rainfall.
- The impact of nutrient and faecal contamination of waterways on New Zealand’s clean green image.
- Behavioural aspects of deer pacing, mob size and shelter provision, which may help to reduce erosion problems.

7.2 Nutrient budgets and greenhouse gas emissions

- Rates of N excretion by deer as effected by management practices, such as different diets and grazing management.
- Refinement of nutrient budgeting model OVERSEER® to account for differences in N utilisation and excretion between deer and sheep.
- Direct measurements of CH_4 emissions from deer.
- Effect of soil compaction due to deer tracking on N_2O emissions.

7.3 Biodiversity

Evaluate the extent at which deer pacing behaviour is reduced on hill farms by:

- physical barriers, including trees to provide visual barriers between paddocks.
- planting of trees within blocks (i.e. not at the fences) to offer greater range of habitat, cover for young etc.
- measure effects on changes in ground cover with vegetation, or of soil erosion.
- deer behaviour related to age, sex, breed type and the strong seasonal influences of the biology of production.

Determine the extent of, and monitor changes in, biodiversity on:

- the game reserves and extensive hill and high country breeding units where there is increasing need to retain native forested areas and native tussock grassland landscapes.
- more intensively managed pastures to determine the rate of natural nitrogen inputs into pastoral systems through legumes, and the success or lack of it in maintaining a variety of selected herbaceous plants which are both preferred by browsing deer and enhance productivity

Investigate the role of deer to control of spread of invasive weeds notably *Hieracium lepidulum* and *H. pilosella*. The preference of deer for herbaceous browse plants indicates the animal could be an agent of biological control of the weeds.

7.4 Organic deer farming

- Development of management practices to control lungworm.
- Development of velveting techniques that do not require the use of drugs.
- Development of techniques or management practices for controlling wood weeds.

7.5 Economic implications

- Determine the total economic and resource costs of New Zealand deer farming products and compare with competing products.
- Determine the total economic impact of changing management practices to prevent soil, nutrient and faecal losses, and soil damage.
- Cost/benefit analysis of ‘action’ versus ‘inaction’ with respect to reducing greenhouse gas emissions.

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9 Appendices

Appendix 1: A three-way classification of the available data on the dietary preferences of ungulates (deer and goats) for some commonly occurring woody plants, ferns, and graminoids in New Zealand native forests. The two-letter codes preceding species names indicate whether the plant is typically a canopy dominant (CD), a seral tree species (SE), a subcanopy tree >5 m (SC), a shrub <5 m (SH), a climber (CL), a fern (FE), or a graminoid (GR). (Reproduced from Nugent at al. 2001).

Highly preferred	Moderately preferred	Not preferred or avoided
CD *Weinmannia racemosa*[1]	CD *Metrosideros umbellata*[1]	CD *Dacrydium cupressinum*[1]
SC *Carpodetus serratus*[1]	CD *Metrosideros rubusta*[2]	CD *Dacrycarpus dacrydioides*[1]
SC *Griselinia littoralis*[1]	CD *Elaeocarpus dentatus*[2]	CD *Prumnopitys ferruginea*[1], *taxifolia*[1]
SC *Myrsine australis*[1]	SC *Elaeocarpus hookerianus*[1]	CD *Nothofagus fusca*[1], *menziesli*[1]
SC *Pseudopanax crassifolius*[1]	SC *Pennantia corymbosa*[1]	CD *N. solandri var. cliffortioides*[1]
SC *Raukaua edgerleyi*[1]	SC *Raukaua simplex* [1]	CD *Beilschmiedia tawa*[2]
SC Large-leaved *Coprosma* spp. [1]	SC *Sophora microphylla*[2]	CD *Lepidothamnus intermedius*[1]
SC *Coprosma lucida*[1]	SC *Myrsine salcina*[2]	CD *Quintinia serrata*[2]
SC *Hedycarya arborea*[1]	SC *Pittosporum tenuifolium*[3]	CD *Phyllocladus* spp.
SE *Schefflera digitata*[1]	SE *Geniostoma rupestre*[2]	CD *Nestegis cunninghamii*[2], *lanceolata*[2]
SE *Cordyline australis*[2]	SH *Myrsine divaricata*[1]	SC *Myhoporum laetum*[2]
SE *Cordyline indivisa*[2]	SH *Alseuosmia pusilla*[2]	SC *Kunzea ericoides*[2]
SE *Hoheria glabrata*[3]	SH *Corokia cotoneaster*[2]	SH *Pseudowintera colorata*[1]
SE *Carmichaelia egmontiana*[2]	SH *Lophomyrtus obcordata*[2]	SH *Dracophyllum menziesii*[1], *longifolium*[1]
SE *Carmichaelia grandiflora*[3]	SH *Pseudopanax lineare*[3]	SH *Dracophyllum uniflorum*[3], *traversii*[3]
SH *Alseuosmia macrophylla*[2], *turneri*[2]	SH Small-leaved *Coprosma* spp.[a]	SH *Leptospermum scoparium*[1]
SH *Brachyglottis rotundifolia*[2]	SH *Coriaria sarmentosa*[3]	SH *Cyathodes juniperina*[1]
SE *Aristotelia serrata*[1]	SH *Oleria lacunosa*[3]	SH *Gaultheria antipoda*[1]
SE *Fuchsia excorticata*[1]	SH *Brachyglottis buchananii*[3]	SH *Hebe stricta*[2]
SE *Melicytus ramiflorus*[1]	CL *Clematis* spp.[2]	SH *Leucopogon fasciculatus*[2]
SE *Pseudopanax arboreus*[1]	CL *Metrosideros diffusa*[2]	SH *Olearia ilicifolia*[2]
SE *Pseudopanax colensoi*[1]	CL *Rubus* spp. [1]	SH *Melicope simplex*[2]
CL *Ripogonum scandens*[2]	CL *Muehlenbeckia australis*[2]	SH *Rhabdothamnus solandri*[2]
FE *Asplenium bulbiferum*[1]	FE *Dicksonia squarrosa*[1]	SH *Pittosporum crassicaule*[3], *divaricatum*[3]
FE *Asplenium flaccidum*[2]	FE *Polystichum vestitum*[1]	SH *Archeria traversii*[3]
FE *Phymatosaurus pustulatus*[2]	FE *Asplenium oblongifolium*[2]	CD *Podocarpus hallii*[1]
GR Nil	FE *Asplenium polyodon*[2]	SH *Raukaua anomalus*[3]
	FE *Blechnum fluviatile*[2]	SH *Neomyrtus pedunculata*[1]
	FE *Blechnum penna-marina*[2]	CL *Parsonsia* spp.[2]
	FE *Blechnum procerum*[2]	FE *Blechnum discolor*[1]
	FE *Rumohra adiantiformis*[2]	FE *Blechnum chambersii*[2], *colensoi*[2]
	FE *Timesipteris* spp.[2]	FE *Cyathea smithii*[1], *dealbata*[2]
	FE *Cyathea colensoi*[3]	FE *Histiopteris incisa*[1]
	GR Nil	FE *Ctenopteris heterophylla*[2]
		FE *Hypolepis* spp.[2]
		FE *Cardiiomanes reniforme*[2]
		FE *Leptopteris* spp. [1]
		FE *Pteridium esculentum*[2]
		FE *Grammitis* spp.[2]
		FE *Hymenophyllum* spp.[2]
		GR *Uncinia* spp.[2]
		GR *Microlaena avenacea*[2]
		GR *Carex* spp.[2]
		GR *Gahnia procera*[3]

[1] Deduced from both preference and browse index data; [2] deduced only from preference data; [3] deduced only from browse index data; Adapted from Forsyth et al.(2000).

[a] *Coprosma* species: *foetidissima*[1], *propinqua*[1], *rhamnoides*[1], *ciliata*[3], *colensoi/banksii*[3], *parviflora*[3], *pseudocuneata*[3], *rotundifolia*[3], *macrocarpa*[3], and *rugosa*[3]

Appendix 2: Browsing susceptibility of plants; headwaters of Grey River, North Westland (source: Wardle 1991)

Trees				Shrubs and herbs			
High	**Medium**	**Low**	**Selected against**	**High**	**Medium**	**Low**	**Selected against**
Fuschia excorticata	Schefflera digitata	Notofagus fusca	Podocarp spp	Asplenum bulbiferum	Coprosma foetidissima	C.colensoi	Pittosporum divaricatum x
Griselinia littoralis xx	Pseudopanax colensoi	N. truncate	Dacrydium cupressinum	Polystichum vestitum	Olearia ilicifolia	Astelia nervosa	Chionochloa spp
Hoheria glabrata	Pseudopanax crassifolius	Quintinia acutifolia	Dracophyllum spp	Leptopteris superba	C. ciliata	O. lacunose	Dracophyllum spp x
Aristotelia serrata x	Carpodetus serratus	N solandri var cliffioides		Cyathea colensoi		Cyathodes fasciculata	Psedowinterii colorata x
Prumnopitys ferruginea	Pseudopanax linearis	N menzii				Podocarpus nervalis	
Brachyglottis buchananii	Pseudopanax simplex	Metrosideros umbellata				Blechnum discolour	
Melicytus ramiflorus	Weinmannia racemosa	Dicksonna squarrosa				C. banksii	
						C. aff. parviflora	
						C. pseudocuneata	
						Neomyrtis pedunculata	

Appendix 3 Summary of Deer browse in Urewera study (Wardle 1991)

Species preferred by red deer	**Species not palatable to red deer**
Weinmannia racemosa x	Phyllocladus glaucus
Pseudopanax spp x	Dracophyllum traversii
Large leaved coprosmas x	Dicksonia lanata
Small leaved coprosmas x	Astelia nervosa
Ixerbia brexioides	Quintinia acufolia x
	Nothofagus menzii
	N fusca x
	Pseudowinteri colorata x
	Podocarpus spp
	Cyathodes fasiculata