Efficacy of One-Way Hare Structures in Woodland Areas

Megan L. Parker, BSc Forestry, MSc Ecology & Environmental Sustainability, MICFor

Jemma McLachlan, BSc (Hons) Environmental Science & Sustainability

Efficacy of One-Way Hare Structures in Woodland Areas

Summary

The forestry industry is currently limited as to how hares can be managed within fenced woodland enclosures to reduce damage to newly planted trees. Increased legal protection has also raised the profile of mountain hares and set the precedent for greater considered management of the species within woodland sites. However, understanding of hare behaviour within fenced woodland enclosures is limited, and more effective alternatives to current hare management strategies are needed. Therefore, this study aimed to investigate the effectiveness of one-way structures in allowing Brown hares (*Lepus europaeus*) and Mountain hares (*Lepus timidus*) to escape from fenced woodland enclosures, as well as to provide a greater insight into the behaviour of Brown hares and Mountain hares within fenced woodland sites. This was done through the creation of one-way gates and ramps and monitored through the implementation of motion-sensor camera traps. The findings indicate that hares will use one-way structures to exit enclosures. Both gate and ramp structures were found to be successful though ramps showed higher levels of use and provided additional benefits in areas where snow fall was high. All exits from the enclosure using these structures occurred at the corner location, indicating greater effectiveness in fenced corner locations. The successful use of the one-way structures suggests a degree of effectiveness suitable for further research, and these findings should be used to develop more effective strategies of hare management in future.

Introduction and Literature Review

Forestry Industry

In Scotland, forest and woodland areas now cover over 1.4 million hectares (see Fig. 1) (Scottish Government, 2019). Furthermore, the Scottish government aims to increase the country's forest cover from 18% to 21% by 2032 and 25% by 2050 for purposes such as timber supply security and carbon sequestration (White *et al*., 2013; Scottish Government, 2019). To attain this, the Scottish Government has set a target for afforestation of 18,000 hectares per year by 2025 (Scottish Government, 2022). To help achieve these ambitious targets, there is a clear precedent to ensure these newly planted trees establish both rapidly and successfully. This will involve the utilisation of effective and sustainable forest management techniques to mitigate any potential losses.

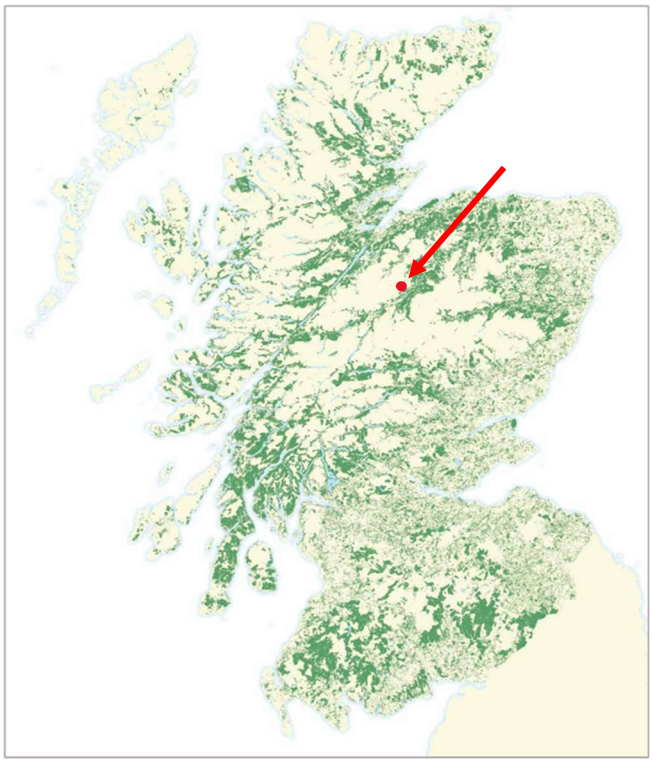


Figure 1: Scotland's forest and woodland cover (Source: Scottish Government, 2019). Area marked as red and indicated with arrow is approximate location of study area.

Hare Damage and Control

Herbivore damage is a chronic and widespread issue across the forestry sector. The two herbivore species considered to have the greatest impact on regeneration across Scotland are red deer and sheep, however several other species such as hares, roe deer, goats, rabbits, and voles can also significantly affect rates of tree regeneration (Andrews, Miller, and Armstrong, 2000; Rao *et al*., 2003). Damage levels are also noted to vary between regions. This can involve browsing on buds, shoots, and foliage, as well as bark stripping from main stems and branches through gnawing or rubbing (Rao *et al*., 2003; Forest Research, 2023). Young forestry plantations are particularly favourable, and these have been found to support high densities of herbivores such as hares (Hulbert and Iason, 1996; Newey *et al*., 2018; NatureScot, 2023a), with both mountain hares and brown hares browsing on young trees (NatureScot, 2023a). This can result in damage at several growth stages (Forest Research, 2023), and significantly affect the establishment of young trees. Mountain hare can generally be found on Scotland's upland areas above 300-400m (Newey *et al*., 2018; Hesford *et al*., 2020), with brown hares primarily preferring arable areas and grassland (NatureScot, 2023a). Estimations of mountain hare densities are said to be anywhere between 2-5 individuals to up to 200 individuals per sq km (Patton *et al*., 2010; Newey *et al*., 2018 NatureScot, 2023a). However, methods of accurately and reliably measuring abundance and density of hares have not yet been developed for land managers (Newey *et al.*, 2018; Hesford *et al.*, 2020), resulting in inadequate data on hare population numbers to inform effective hare control strategies.

Species	Age of trees affected	Typical signs of damage to trees
Hare (mountain & brown)	• Establishment • Thicket	• Often sporadic but widespread • May eat along a row of young trees • Damage up to 70cm

Table 1: Above right, main characteristics of damage from Hares (Forest Research,2023).

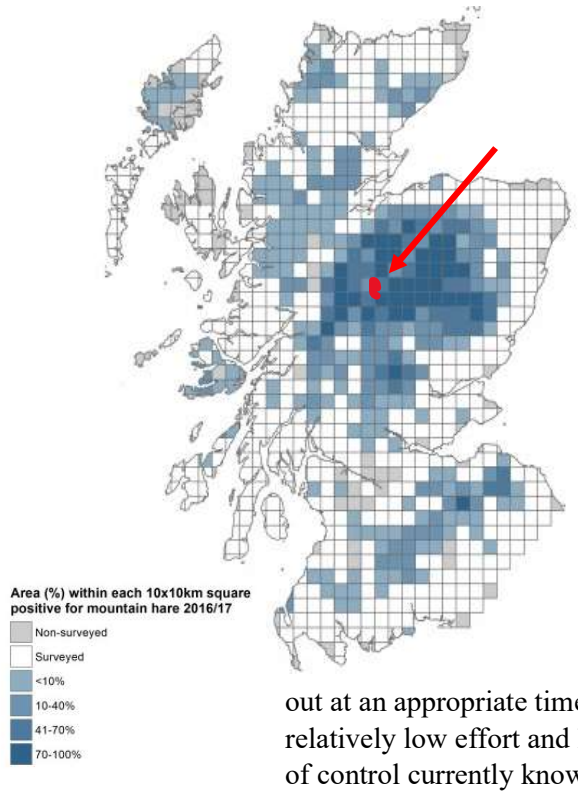


Figure 2: Left, reported percentage presence of mountain hare within each 10x10 km grid square in 2016/2017 (Hesford et al., 2020). Area marked as red and indicated with arrow is approximate location of study area.

Strategies to control hares within rabbit netted enclosures have formed an important part of the maintenance of young, afforested areas where hares are present (Rao *et al*., 2003). Lethal control through shooting and physical 'driving' or 'pushing' of hares through gates or openings are the most common practices used to remove hares from fenced enclosures. Lethal control of hares through shooting requires a suitably skilled and experienced controller and must be carried out at an appropriate time of year (GWCT, 2013; BASC, 2023). It is relatively low effort and low cost as well as being the most effective method of control currently known. Licensing rules apply to lethal control of hares,

and this must be agreed with and reported to relevant statutory bodies (BASC, 2023; NatureScot, 2023b). Driving hares or pushing hares out of an enclosure involves a coordinated effort and has limited effectiveness depending on the shape and size of the enclosure, the terrain and vegetation cover, and the number of people available to carry out the operation. Both strategies are labour intensive, and effectiveness can be particularly low in large enclosures.

Current Legal Status of Hares

In recent years, increased legal status has raised the profile of mountain hares and set a precedent for a greater considered approach towards the management of hare species within woodland areas. From 1st March 2021 mountain hare were included on Schedule 5 of the Wildlife & Countryside Act 1981 (as amended) (Scottish Government, 2021; NatureScot, 2023b). This means that at any time of the year, anyone who intentionally or recklessly kills, injures, or takes a mountain hare without an appropriate licence will be acting unlawfully (Scottish Government, 2021). It is also an offence to possess or control, sell or offer for sale, or transport for the purpose of sale any living or dead mountain hare, or any derivative, giving mountain hare full protection under this Act (NatureScot, 2023b). Furthermore, mountain hares are also a species of 'Community interest' listed on Annex V of the Habitats Directive and thus have additional protection under the Habitats Regulations 1994 (as amended) (Newey *et al*., 2018; Hesford *et al*., 2020). Mountain hares are the only hare species native to Scotland, and it is believed that numbers of this native species have declined in recent years (Hesford *et al*., 2020; The James Hutton Institute, 2023). Therefore, it is hoped that increased protection will help ensure healthy and sustainable populations of mountain hares in upland and mountainous regions (Scottish Government, 2021).

Brown hares may be legally controlled through lethal control methods during the open season but are protected in the closed season under the Wildlife and Countryside Act 1981 (as amended) (NatureScot, 2023b). The closed season for brown hare is from 1st of February to the 30th of September. It is an offence to intentionally or recklessly kill, injure or take a brown hare in its closed season without a licence (NatureScot, 2023b). It is also an offence to possess or control, sell or offer for sale, or transport for the purpose of sale any living or dead brown hare, or any derivative of such an animal, which has been killed without a legal right to do so (NatureScot, 2023b). Although this species is given less legal protection compared to the native mountain hare, brown hares are classified as a priority species in the UK Biodiversity Action Plan (JNCC, 1994), meaning management strategies which alleviate the need for lethal control are valuable.

Rational for Study

The forestry industry is currently limited as to how hares can be managed within fenced woodland enclosures to reduce hare caused damage to young trees. As afforestation projects continue to increase in scale to meet government woodland creation targets, the level of effort required to ensure suitable hare control is increasing. Upland areas are particularly problematic in terms of hare damage to young trees as high snow levels allow hares to overtop fencing, leaving them trapped inside fenced areas once snow melts. Furthermore, increased legal protection has raised the profile of mountain hares and set the precedent for greater considered management of the species within woodland sites. However, understanding of hare behaviour within fenced woodland enclosures is poor. As a result, more effective alternatives to augment or replace current hare management strategies are needed. The implementation of one-way structures, allowing hares to exit fenced enclosure and not re-enter the enclosure, could provide a valuable passive strategy to reduce numbers of hare requiring control within fenced woodland enclosures.

Aims and Objectives of Study

Aims

This project aims to investigate the effectiveness of one-way structures in allowing hares to escape from fenced woodland enclosures. This will be done through implementing innovative one-way exit structures to allow for the safe passage of hares, and to subsequently monitor the use of the structures by hares through the implementation of camera traps. This will allow for a greater insight into the behaviour of hares, and into the practicality of exit structures in reducing numbers of hares within enclosures and thus reducing hare damage to young trees. Furthermore, the authors hope this will encourage and focus greater research into more effective or non-lethal alternatives for hare management within the forestry industry.

Objectives

Project objectives:

1. To implement innovative one-way hare structures within fenced woodland sites
2. To monitor the use of one-way structures by Brown hare (*Lepus europaeus*) and Mountain hare (*Lepus timidus*) through the utilisation of camera traps
3. To analyse the effectiveness of one-way hare structures in allowing escape from within fenced woodland enclosures
4. To observe the behaviour of Brown hare (*Lepus europaeus*) and Mountain hare (*Lepus timidus*) within fenced woodland sites

Methodology

Site Description

Located in the Monadhliath mountains above Loch Alvie near the town of Aviemore, this site was selected for large-scale environmental improvements. This site includes afforestation of native woodlands to aid in combating the climate emergency predominantly through carbon sequestration. The proposal covers a gross area of 645 hectares, of which approximately 400 hectares was found suitable for new planting and natural regeneration. A new perimeter deer fence with rabbit netting was installed over the duration of this study to fully enclose the afforestation area.

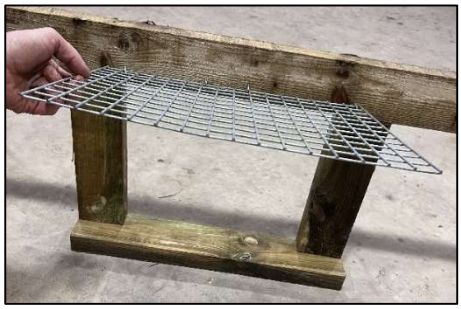
This site was once part of a much larger ancient Caledonian pinewood of which only sparse veteran trees remain scattered on the hillside. It was historically used for sporting and sheep grazing, and for many years underwent regular muir burning to maintain a diverse heathland. The site remains largely dominated by heathland habitats with some areas of wet ground, blanket bog, deep peat, along with remnant ancient woodlands (of semi-natural origin dating from the 1860s) on lower ground as well as other broadleaf woodlands. The study area is situated within the higher ground of the afforestation area between 350m and 550m in elevation in areas which have been planted with upland birch woodland in 2022 and 2023.

A resident population of hares are present in what is believed to be high numbers around the site area. Throughout the study area well-used hare runs, burrows, resting places, droppings, and evidence of hare browsing can be found frequently. Historically hares have been culled on site though this ceased in 2021 following a land ownership change. Hare culling was thought to have been linked to sporting interests. A number of other protected species occur on site along with sensitive habitats and landscapes which are of national importance. The property sits amongst a dense concentration of designated sites which reflect the importance of these species, habitats and landscapes including Cairngorms National Park, Craigellachie Site of Special Scientific Interest, Craigellachie National Nature Reserve, Kinveachy Forest Site of Special Scientific Importance, Kinveachy Forest Special Area of Conservation, Kinveachy Forest Special Protection Area, and River Spey Special Area of Conservation. Red and roe deer are present within this landscape and the proposal falls within the catchment of the Monadhliath Deer Management Group. Herbivore pressure, such as deer and hares, plays a significant role in limiting natural regeneration within this proposal area.

Structure Design and Implementation

With the aim of providing a safe passageway for hares to escape fenced woodland enclosures, four predetermined exit structures were installed within the chosen woodland site. The first design consisted of a one-way hare gate. This comprised of wire mesh with a hinged one-way flap which allows hares to pass through. The simple wire mesh flap design overlapping the frame prevents ingress from outside of the enclosure.

Image 1. Below left, photograph showing hare gate prototype used in study.



The second design mirrored deer ramps, which are currently used in forestry to allow deer to jump out of fenced enclosures, but were modified to consider the smaller dimensions of hares. The structure consisted of a wooden rail retaining wall sitting flush with the rabbit netting rising to approximately 1.2m with a built up steep earthen ramp covered in turf. Ramps were pyramidal to allow hares to travel up the ramp from three sides and exit the fenced

enclosure through the deer netting, with a drop on the outer side to discourage re-entry of hares back into the fenced woodland area.

Image 2. Below left, showing installation of upper camera location prior to fences being in place, author Megan Parker on left, forest manager Jaeger Lamont on right. Below Centre, showing construction wooden retaining wall being constructed for the ramp using posts and rails. Below right, showing the buildup of turf material in progress.

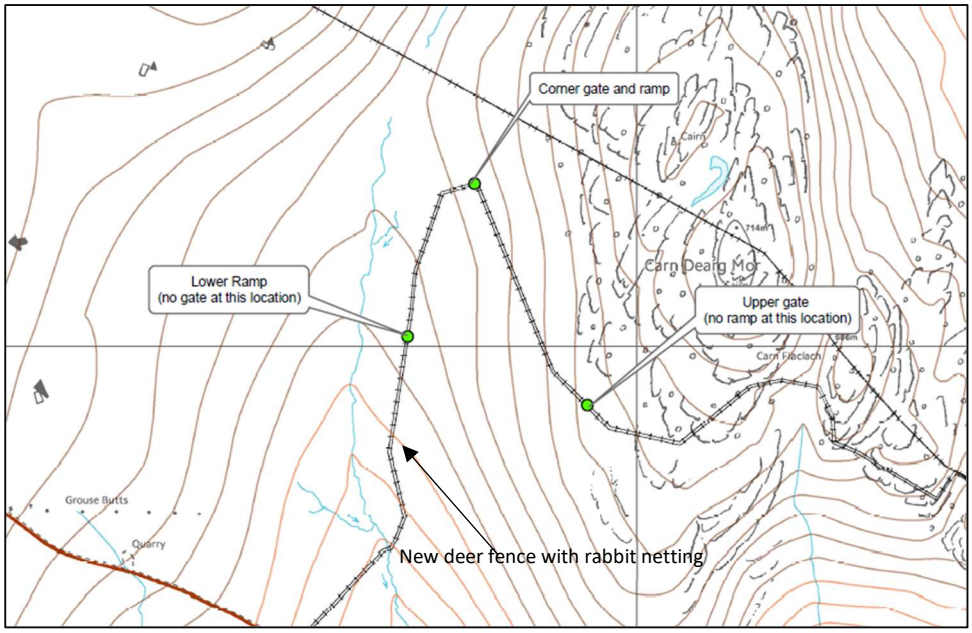
Image 3. Below, photograph showing constructed ramp at corner location. Note height matches that of the rabbit netting.

Each structural design was duplicated, making a total of four one-way passageways made from the two designs. The one-way structures were strategically placed in locations where hare presence was expected to be greatest or where hare presence was thought to be concentrated. This involved a walkover of the site to detect visible hare runs, and then marking the location where the detectible hare runs would pass under the constructed deer fence.

Image 4: Left, photograph of hare run prior to fence construction showing marked upper location for installation of structure following fence construction.

Following construction of the deer fence and rabbit netting, the fencing contractors assembled the one-way gates and ramps in the pre-determined locations. This involved a ramp being installed on the lower location of the deer fence, a gate being placed in the upper location of the deer fence, and both a ramp and gate being installed in the corner location of the deer fence to allow for greater comparative data (see Map).

Figure 3: Below, this map image shows the orientation and layout of the three study locations along route of new deer fence. Not to scale. Reproduced under licence, Crown copyright and database rights 2023 Ordnance Survey 100030835.



A total of seven motion-sensor camera traps were set up to monitor their effectiveness. All cameras were located within the enclosure and provided visibility inside the fence while also providing views through the enclosure to activity on the outside of the fence. These were checked regularly to gather data from the cameras and to assess any defects. Throughout the study period, footage from the cameras were thoroughly reviewed to allow for an insight into the level of use, structural stability, and any limitations of the one-way exit structures. The table below outlines the three locations, cameras set up at each location, and the types of structure installed.

Table 2. Study site details.

Location	No.	Camera Name	Structure
Lower	1	LF (Lower focused view)	Ramp
		LL (Lower long view)	
Corner	2	CF (corner focused view)	Gate
		CLD (corner long view downhill)	Ramp
		CLU (corner long view uphill)	
Upper	3	UF (upper focused view)	Gate
		UL (upper long view)	

Project Timings

Due to delays in operations, the one-way exit structures were not completed until 2023, though camera trapping to identify behaviour patterns began prior to fence construction in early September 2022. The camera monitoring continued from installation through to late December 2022 when significant snow fall necessitated removal of the cameras. The cameras were re-installed and monitoring re-commenced at spring snow melt in March 2023, and one-way structures were installed on 11th May 2023 with monitoring continuing until 16th August 2023.

Actual project timings

- 5th September 2022 cameras installed; start of monitoring
- 7th – 11th September fence constructed (hares provided ingress and egress)
- 22nd December 2022 cameras removed for winter; monitoring paused
- 1st March 2023 cameras re-installed; monitoring restarted
- 11th May 2023 one-way structures installed (hare ingress prevented)
- 16th August 2023 cameras removed; end of monitoring

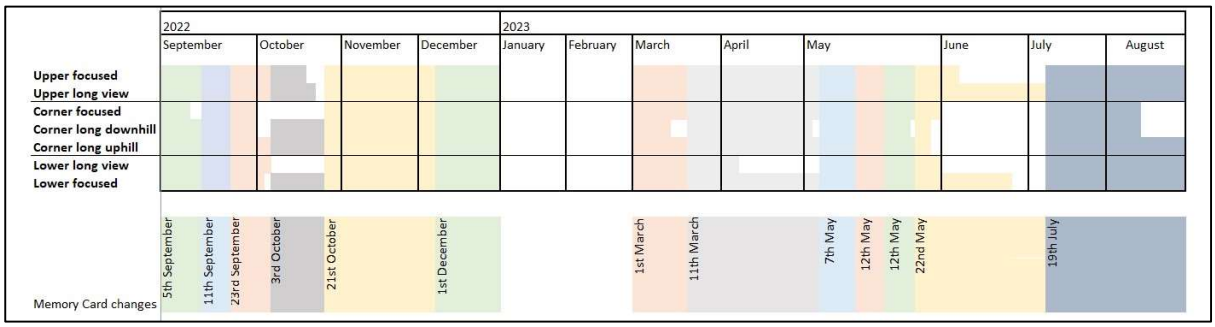


Figure 4: Above, representative timeline showing coverage of recording indicated by shaded colouring. Periods where recording did not occur are shown with no shading. Memory card changes are noted by colour.

Data Collection

This project adopted a primary research approach involving the collection and analysis of raw photographic data, allowing us to gather specific data suitable for this research. Qualitative data was collected by utilising an empirical research approach through the implementation of camera traps. This included a total of seven camera traps which were utilised for in-situ monitoring; two placed around the upper location, two at the lower location and three placed around the corner location. The cameras used were 'GardePro A3 Wildlife Camera', 24 megapixel 1080P waterproof trail cameras with 100ft infrared night vision and 0.1 second motion activated triggers. The seven cameras were set up for a total of eight months with a two-month winter gap. This allowed for the study to record use of one-way exit structures for approximately three months and a longer period of behavioural monitoring for a period of eight months. It is noted that there were regular gaps in monitoring records at times when batteries died, memory cards became full, snowfall or rain prevented triggering, or heavy fog limited visibility. Cameras were set to record a static burst of five photographs at 0.1sec intervals when triggered by motion. At each structure, at least one camera was positioned facing along the fence boundary, with a wide viewing angle, to collect data on hare behaviour along fenced woodland enclosures, and at least one other camera was positioned more specifically towards the one-way structure to collect data on the effectiveness of exit structures in allowing hares to escape fenced woodland sites. The use of multiple cameras per structure also improved chances of capturing behavioural data should one camera fail to trigger. Throughout the trial period, regular checks were made on the cameras to assess their condition, check for any defects, renew batteries, and retrieve data. Data was collected from the cameras through the regular replacement of memory cards, and subsequently downloaded for analysis to take place.

Data Analysis

Data collected was reviewed, and all camera images which were evidently triggered by void features, for example wind, were removed from the sample. Photographs were then stratified. Categories for stratification of photographs included; a) photographs taken before installation of one-way structures, b) photographs taken after installation of one-way structures showing hares outside of the enclosure, c) photographs taken after installation of one-way structures showing hares inside of the enclosure. The photographic files containing the latter category 'c' were renamed using the following format: 'YYYYMMDD TIME CAMERA-ID feature FILENAME' and carried forward for further statistical analysis. Other categories of photographs were viewed in sequence and observations were noted for qualitative discussion.

Statistical analysis of photographs was visualised using Microsoft Excell and R version 4.3.1 (R Core Team, 2023) using 'ggplot2' (Wickham, 2016). This sample of data was analysed by reviewing each image and recording the date, time, location (1-lower, 2-corner, 3-upper), structure (1-gate, 2-ramp), type of interaction (1-near structure within 5 metres, 2-physical interaction with structure, 3-exit from enclosure), and day/night of each data point. The location, structure, interaction, and day/night were all given numerical values to allow for statistical analysis to take place.

Stacked bar charts and pie charts were used to illustrate the number of interactions and types of interactions the hares had with the gate and ramp structures in each of the three locations. The number of hare interactions with both gates and ramps combined was plotted by hour of the day on a stacked bar plot. A stacked histogram was used to visualise the number of hare interactions of different types with both gates and ramps combined over time. This histogram was overlaid with a smooth local regression trendline fitted to the count of the total number of interactions of all types per day for each of the locations. This allowed for comparisons to be made between the four structures, and between the two designs, accounting for structure design, location and time.

For clarification, an 'interaction' was defined as a recorded hare displaying a behaviour fitting into one of the following three types: near structure within 5 metres (i.e. hare is visible within 5m of the gate or ramp), physical interaction with structure (i.e., touching, pushing, biting, climbing on, resting against, etc.), exit from enclosure (i.e., hare is visible physically leaving the enclosure). In many instances hares spent an extended period of time near gates and displayed more than one behaviour. Multiple behaviours were recorded as unique data points, and a behaviour was deemed to be 'stopped' once the hare physically turned away from the structure either by body movements or by head movements and restarted once the hare began a new behaviour. Due to the occurrence of multiple cameras potentially capturing the same hare displaying the same behaviour, there was likely risk of double counting. This could not be eliminated, and any double counting was consistently double counted throughout the study.

Qualitative analysis was utilised to allow for an explorative and descriptive insight into the effectiveness of one-way structures in allowing Brown hare and Mountain hare to escape from fenced woodland enclosures. This analytical approach was also undertaken to examine the behaviour of Brown hare and Mountain hare along fenced boundaries, for example allowing for an insight into whether hares run along or avoid fence lines, providing useful information in developing more effective strategies to hare management. For this broader qualitative behavioural analysis, photographs were viewed in sequence to allow observations of all behaviours on a given day/night and compared between different site conditions over time. Important condition changes included erecting of deer fencing, installation of rabbit netting, winter/seasonal change, and installation of one-way exit structures. Behavioural patterns were noted and changes between patterns then considered and discussed.

Limitations

There are several limitations involved with this study approach:

- Sample size- The study was based around a small sample size, as there was only a total of four one-way structures being trialled as well as an unknown hare population size inside the enclosure. This resulted in a small dataset, meaning comparability of data was unable to prove significant correlations.
- Locations- Variations between structure locations, including varying territories of hares, locations of burrows, and differing forage available adversely affected the comparability of data, as hare population density may have varied between structure locations.
- Double Counting- There was also a lack of independence between detections due to an inability to distinguish the number of individual hares recorded, resulting in a risk of possible repeat detections within the data collected.
- Timings- Time constraints surrounding winter snowfall and delayed fence/structure construction to 2023 affected structure and camera implementation, adversely affecting the duration of data collection during the project.
- Hardware- As with any hardware, there is risk of malfunction. On multiple occasions batteries died, camera cards filled with photographs resulting in gaps in recording, and weather impaired camera function. There were also two instances of dates being reset resulting in date and timestamps on photographs being incorrect. There was also a single camera displacement following a deer rubbing and pushing over the post upon which a camera was fixed.
- Photography production- Quantities of photographs recorded was estimated to be over 400,000 which all required visual assessment to determine whether the subject matter was to be recorded into the study. Sensitivity to windblown vegetation was problematic and tens of thousands of photographs were captured of grasses swaying in windy conditions. As such additional analysis of behavioural characteristics beyond simple observations was not

possible due to limitation in available hours of the authors to screen through the photographs produced.

- Species identification- Individual species of hares were not differentiated between within this study and no efforts were made to distinguish brown hares from mountain hares within camera trap data due to a lack of differentiation in identifiable features, as most observations were taken during night mode.

These limitations unfortunately resulted in the degree of variance being high and confidence being low. Nevertheless, despite the limitations, the project demonstrates a commitment of the forestry industry in contributing time and resources into developing non-lethal alternatives to hare control and sets a precedent for greater research into more effective alternatives for hare management.

Ethical Considerations

The utilisation of untested structures raises uncertainty surrounding potential welfare issues regarding hares. This includes ethical considerations surrounding these protected species becoming trapped or separated from their litter, particularly in varying weather conditions. Frequent monitoring, by both in person visits and motion-sensor camera traps, was undertaken to identify any ethical concerns. There were no recorded instances of welfare concerns during the study period. Furthermore, consultation with NatureScot regarding the proposed research took place and, in agreement with their species specialists, it was stated that no species licences would be required for the undertaking of this project as it was not intended to harm, take, or kill any hares, nor was it intended to disturb or interfere with places of rest.

Further research into breeding season impacts is recommended and would provide information which could be used to limit use of one-way structures to certain periods of the year if found to pose welfare issues if, for example during the breeding season, one-way structures contributed toward separations from litters.

Results

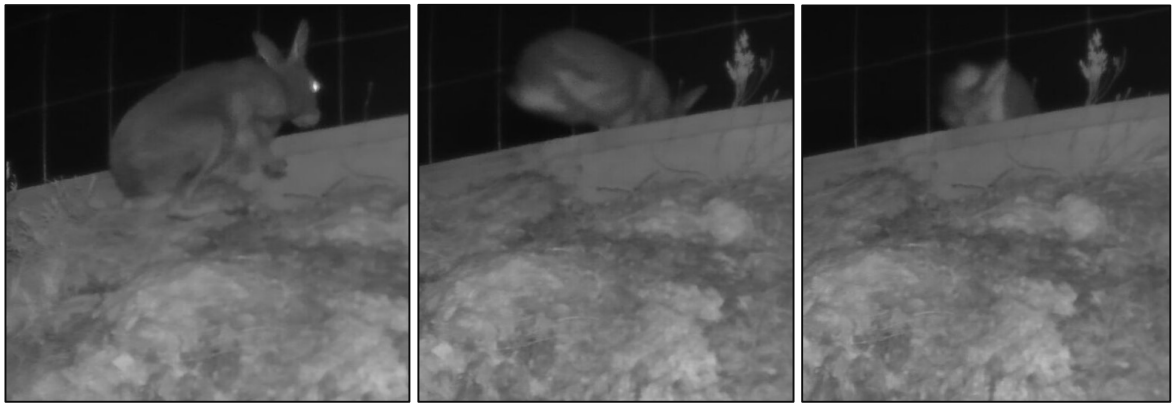
Numbers of interactions recorded following installation of one-way structures totalled 557 over the period 11th May – 16th August 2023. In total four hares were confirmed to have left the enclosure using the one-way structures. One hare exited through the gate on the 14th of May 2023 while three hares exited through the ramps on the 26th of May 2023, 22nd July 2023, and the 23rd of July 2023.

Images 5-7. Below, photo sequence showing a hare exiting the one-way gate on 14th May 2023 in the corner location.

Images 8-10. Below, photo sequence showing a hare exiting the one-way ramp on 26th May 2023 in the corner location.

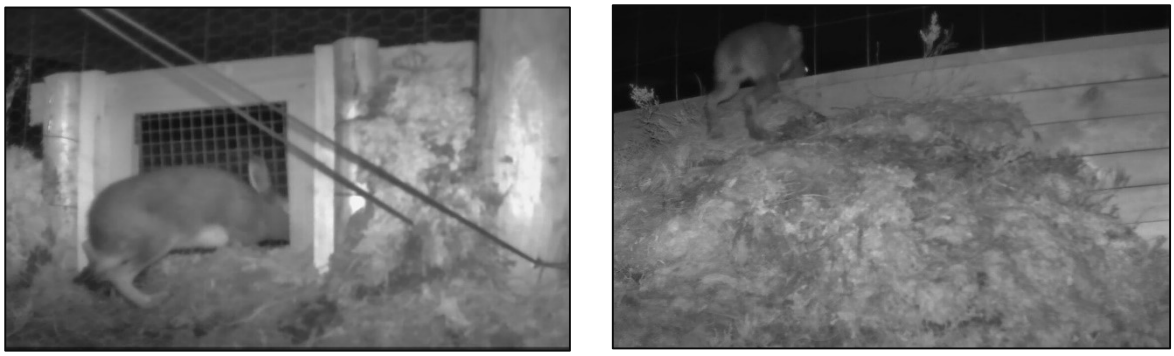
Images 11-13. Below, photo sequence showing a hare exiting the one-way ramp on 22nd July 2023 in the corner location.

Images 14-16. Below, photo sequence showing hare exiting one-way ramp on 23rd July 2023 in corner location.



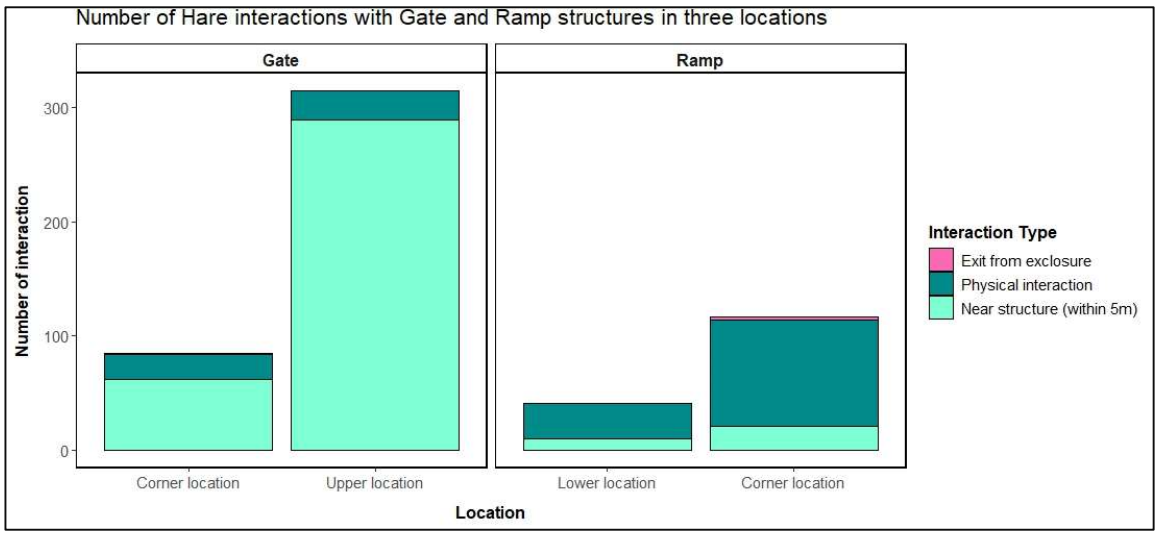
There were also two instances of near-exits: one for the gate and one for the ramp. This involved one hare pushing on the gate slightly on the 24th of May 2023, and one hare leaning over the edge of the ramp on the 28th of July 2023, but neither fully exiting the enclosure via the structures.

Images 17-18. Below left, hare investigating the one-way gate with a slight push but remaining within the enclosure. Below right, hare leaning over the one-way ramp with head through deer netting but remaining within the enclosure. Both were located in the corner location.



All four instances of hare exits occurred within the corner location, with no exits within the lower or upper locations. Both instances of near-exits also occurred within the corner location, with no near-exits being observed in the lower or upper locations. Of the corner exits, one involved the utilisation of the one-way gate, and three involved the utilisation of the one-way ramp.

Figure 5: Below, showing the number and type of interactions in each location of the different structures. This illustrates one interaction with the gate in the corner location, and three with the ramp in the corner location.



Findings show that 3% of interactions with the one-way ramp in the corner location resulted in successful exits from the enclosure, whereas 0% of interactions with the one-way ramp in the lower location resulted in exits from the enclosure.

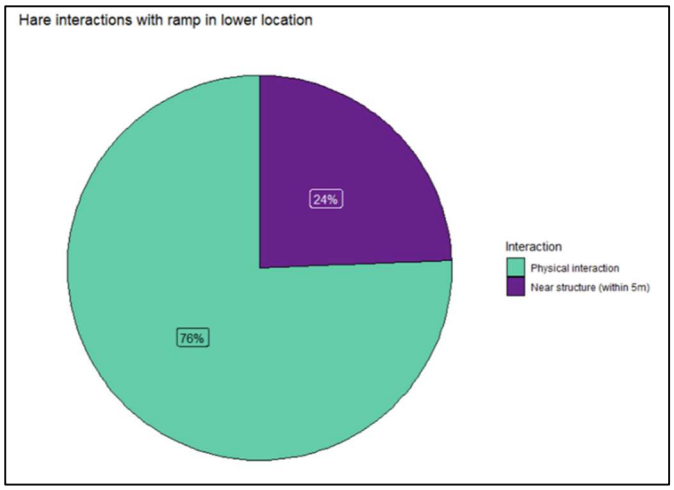
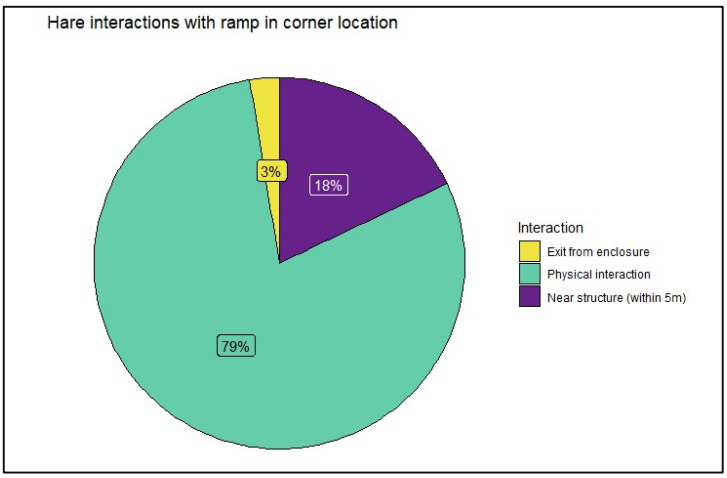


Figure 6: Left, illustrating percentage of each type of interaction with the ramp in the lower location. This shows that 76% of interactions were 'physical interaction' and 24% were 'near structure (within 5m)'.

Figure 7: Below, illustrating percentage of each type of interaction with the ramp in the corner location. This shows that 79% of interactions were 'physical interaction',18% were 'near structure (within 5m)', and 3% were exit from enclosure.



Results show that 1% of interactions with the one-way gate in the corner location resulted in successful exit from the enclosure, whereas 0% of interactions with the one-way gate in the upper location resulted in exits.

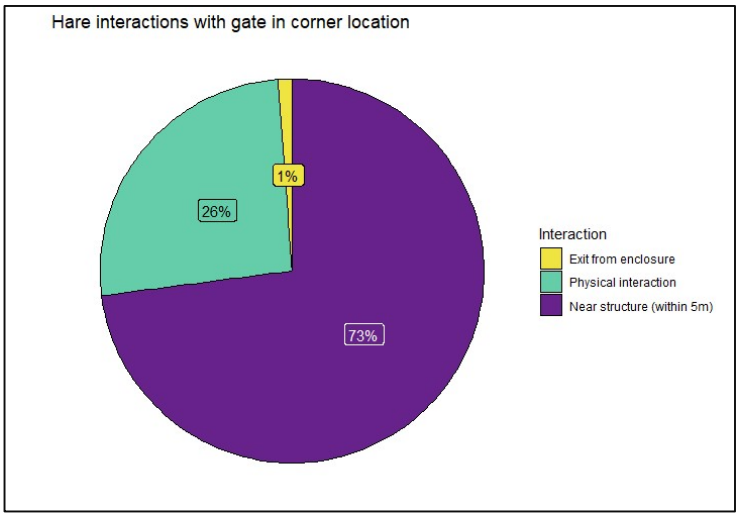


Figure 8: Left, illustrating percentage of each type of interaction with the gate in the corner location. This shows that 73% of interactions were 'physical interaction',26% were 'near structure (within 5m)', and 1% were exit from enclosure.

Figure 9: Right, illustrating percentage of each type of interaction with the gate in the upper location. This shows that 92% of interactions were 'physical interaction', and 9% were 'near structure (within 5m)'.

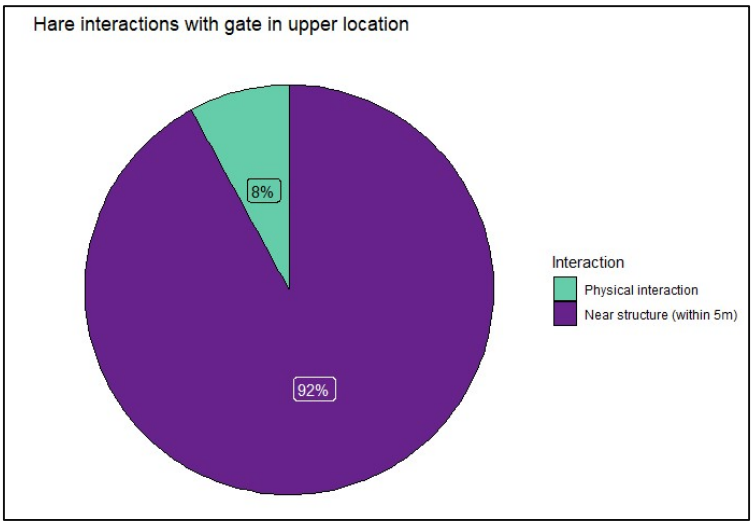


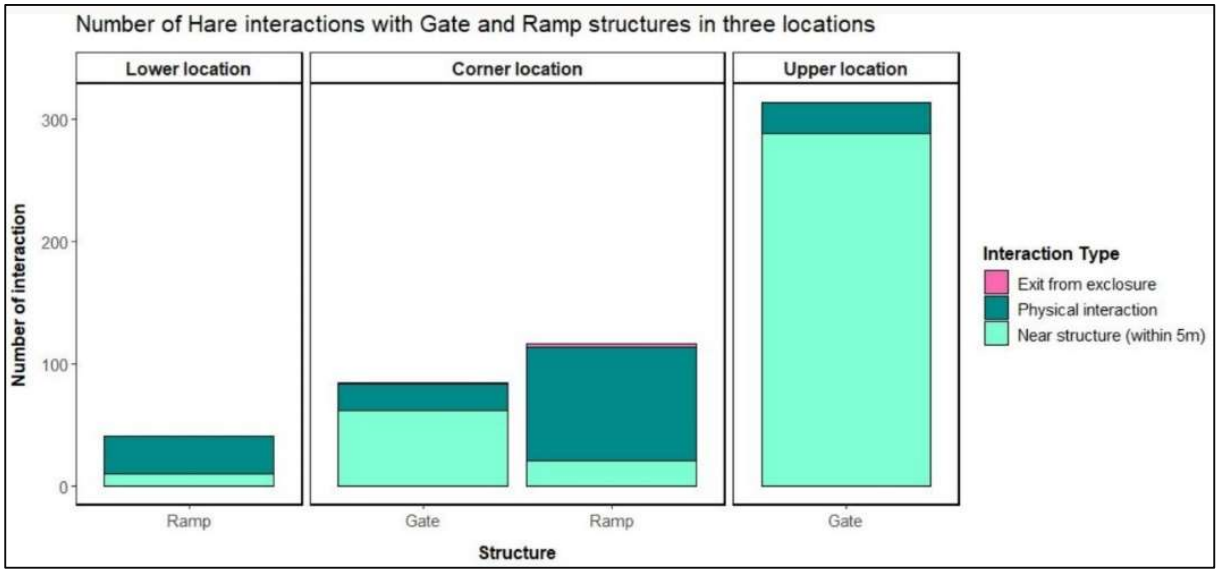
Image 19. Below, hare rising on hind legs attempting to enter enclosure.

It appeared that hares which exited the enclosures carried out multiple attempts to re-enter the enclosure. No ingress of hares occurred during the study period though hares on the exterior of the enclosure were recorded attempting to bite through the gate location, including pulling on the wire. They were also recorded attempting to rise onto their hind legs and gain access onto ramps or climb above gates, there were no successful attempts to re-enter the enclosure.

The upper location registered the most activity of hares, with the lower location registering the lowest levels of activity. Although the corner location did not have as high a level of activity as the upper location, interactions in the corner location consisted of more 'physical interactions' and 'exits from enclosure' compared to the upper location, which consisted primarily of 'near structure (within 5m)' interactions. Furthermore, it is also evident that, when making comparisons between the ramps and

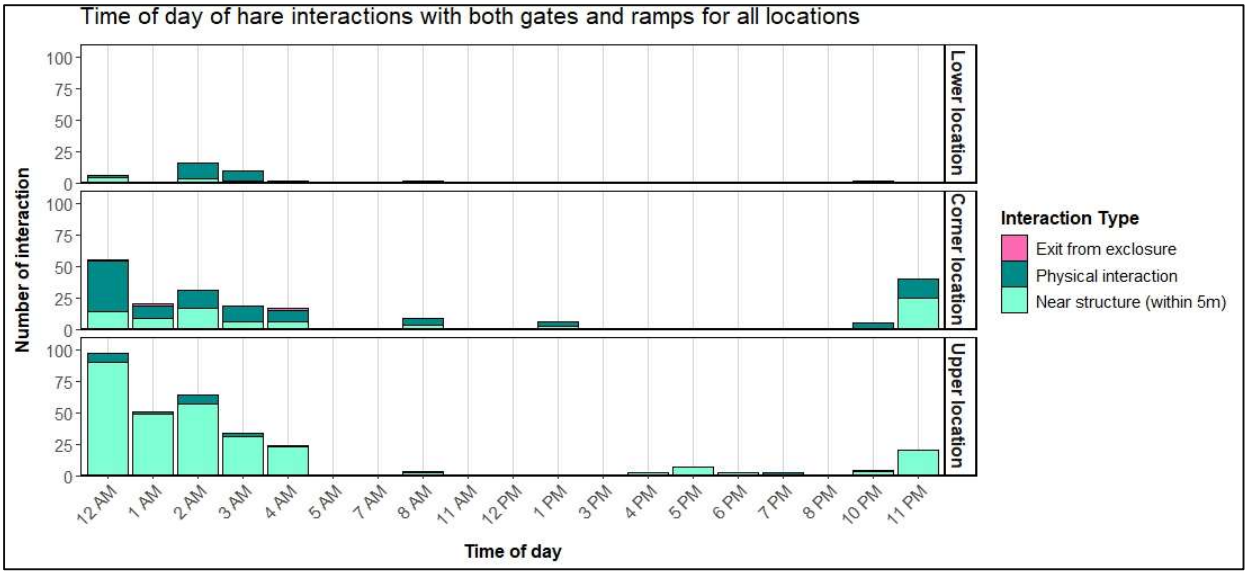
the gates, the ramps have a significantly higher percentage of 'physical interactions' and 'exits from enclosure' compared to the gates, which primarily consist of 'near structure (within 5m)' activity. For the corner location, where most significant interactions took place, the ramp consisted of 79% 'physical interaction' and 3% 'exit from enclosure', whereas the gate only had 26% 'physical interactions' and 1% 'exit from enclosure'. This indicates that hare spend more time around the ramps than they do with gates. This is also supported by observed use of the ramps as vantage points. The higher percentage of physical interactions with the ramp perhaps contributed to a higher number of exits compared to the gate.

Figure 10: Below, showing the number and type of interaction with both the gate and the ramp in each location. Exits occurred once at the corner gate and three times at the corner ramp.



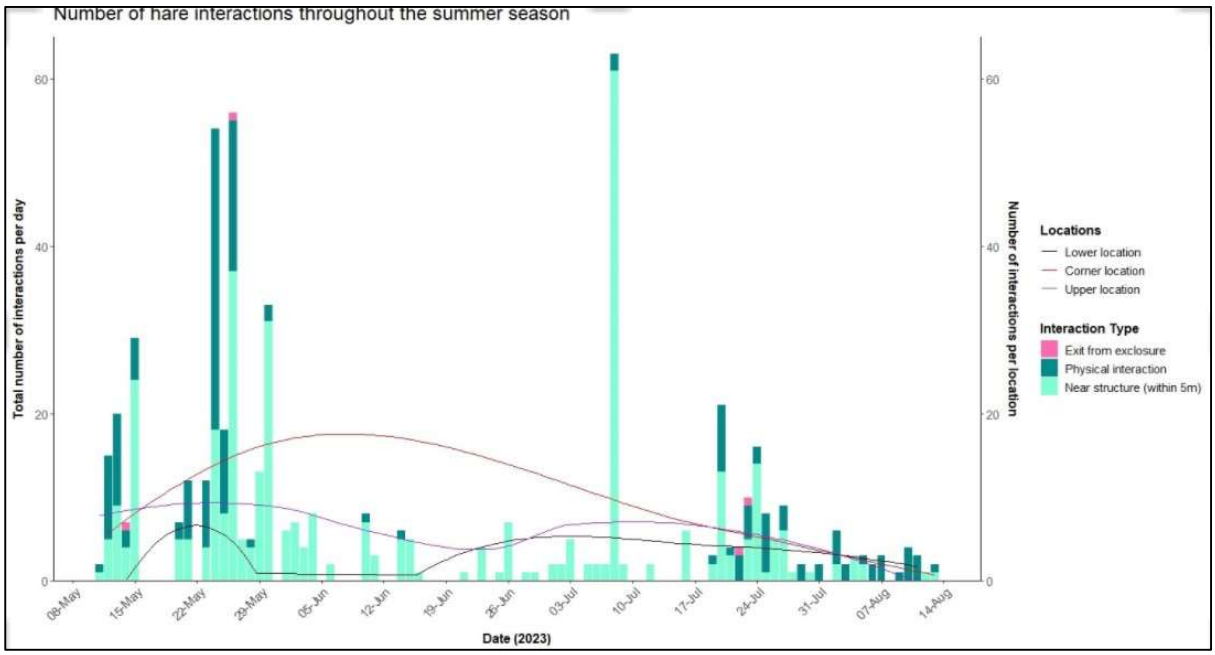
Hares were, unsurprisingly, most active during hours of darkness, though summertime activity occasionally occurred during daylight hours given the longer periods of daylight. The times of day in which hares were most active were between 11pm to 4am, with activity peaking around 12am.

Figure 11: Below, showing the number and type of interaction for both ramps and gates with each location over different times of the day.



Prior to installation of the fences, it was evident that hare movements followed well established runs. No activity was registered at the lower location, occasional hare movements were recorded at the corner cameras, and regular nightly records were captured at the upper camera prior to the rabbit netting being installed. Following installation of the rabbit netting, gaps were left at the three locations to allow continued movement for a period of eight months. During this period, increased activity was recorded at the lower and corner locations while levels of activity recorded at the upper location remained relatively high. Following installation of one-way structures, levels of activity generally decreased over time at the corner location, decreased at a much slower rate at the upper location, and remained low at the lower location. This trend, as displayed using regression curves, is thought to be related to the fact that hares left the enclosure over time using the one-way structures, though this could not be tested in analysis.

Figure 12: Below, a smooth regression trendline showing the total number and type of interactions per day with each location over the period 11th may 2023 – 16th August 2023.



Hare movements parallel to fences, referred to as 'running the fence', changed over time. When the fence was first erected with only deer netting, hare quickly learned how to pass through the fence wires. However, this took several attempts as the initial approach was to not cross the deer fence.

Image 20. Left, hare passing through an open gap in the deer fence.

Once habituated to passing through the deer netting, runs were utilised religiously. Once rabbit netting was in place, a gap was left open for passage at the future structure location and hares used this gap without running the fence line (running parallel). Once the gap was closed there was an initial period of not running the fences but rather approaching the access point along the well-used run and stopping at the fence before returning along the run in the direction they originated from. After some time, hares began to run the fence line though this appeared to be influenced by hare movements on the outside of the fences. Hares on outside of fences ran along fence lines to find new routes to access lower ground, presumably for feeding. This is presumed to have contributed to higher levels of hare activity outside of the fence at the corner location.

Images 21-26. Below, photographic series showing hares running the fence line on the outside of the enclosure.

It was evident that hares located on the outside of the enclosure significantly affected the behaviour of hares inside the enclosure. On the 8th of July 2023, there were 54 data points of activity between 00:26am – 03:32am due to a hare on the inside of the enclosure relentlessly running the fence and attempting to exit the enclosure to reunite with a hare on the outside of the enclosure.

Images 27. Below, showing hares on either side of the fence 'kissing' through rabbit netting.

Discussion

Summary of Discussion points:

- Hares will use one-way structures
- Hares used ramps more than gates
- Hares exited at the corner location on four occasions even though activity levels were highest near the well-used hare run at the upper location
- Hares use vantage points, particularly on the ramps
- Hares inside the enclosure remained relatively dedicated to their runs once fences were installed and did not in general run the fence lines unless hares outside the fence were running the fence
- Hare behaviour was heavily influenced by hares outside of the enclosure
- Leaving gaps open for passage prior to installation of one-way structures may have habituated hares to the opening points where gates/ramps were later installed and used

Successful use of both types of one-way structures suggests there is potential for some form of structure to be incorporated into future best practice guidance for forestry fencing where rabbit netting is installed. A structure such as the ramp may have added benefits in areas where winter snows allow hares to enter enclosures and spring melts result in entrapment within enclosures. One-way gates pose higher risk in terms of malfunction and ingress of hares as well as limited functionality during periods of snow which may prevent the gates from operating. Gates would require maintenance to keep vegetation cleared from around the structures whereas ramps would be relatively maintenance free for a number of years. Ramps are likely the most feasible structure to include in future research.

It is possible that more than four hares have left the enclosure and on multiple occasions camera records showed hares in a position poised to leap from the ramp with the next photographs showing an empty ramp, but these could not be conclusively determined as exits, and further research should take this into account to ensure more reliable methods of recording are implemented to improve confidence. Being able to identify and track individual hares would have been advantageous.

Based on these limited results, installation at fence corners may be suitable for exit structures as 100% of exits in this study occurred at the fence corner location which had been relatively inactive prior to fence installation. In the upper location only a gate was installed along the most well-established hare run, it is therefore unclear whether a ramp at this location would have been successfully used by hares to exit the enclosure. Further research into optimum placement of structures is recommended.

Over time activity levels increased at the lower and corner locations and this is thought to be caused by the hares need to access areas outside of the enclosure which had been cut off from them due to the new fences. It is thought that hares became habituated to the gaps left in the fences and following closure of the gaps, hares were more likely to spend time at these locations which may have contributed towards their usage of one-way structures. It is unclear if the level of use would occur had gaps not been left and hares habituated to these three locations.

Social interactions of hares were changed following fence construction, and this may have impacted on how and when hares exited the enclosures. Of the four successful exits from the enclosures, hares inside the enclosure were aware of and interested in hares moving around the outside of the enclosures at the same time which perhaps compelled them to push through the gate and to leap off the ramp at various times. Cameras recorded multiple occurrences of hares running along the fence for short periods in synchrony with hares running on the outside of the fences. This is also the only time hares on the inside of the fence were seen running the fence lines. When hares inside enclosures approached the fence in isolation, they did not appear to be running the fence lines, whereas hares

outside the enclosures were found to run the fence lines. There are also several instances where hares have pulled at the rabbit netting in an attempt to exit the enclosure when hares have been positioned on the other side of the fence. There is no evidence that hares have behaved this way unless encouraged by the presence of hares on the outside of the fence.

Image 28. Below, showing hares inside the enclosure pushing at the rabbit netting in an attempt to exit, with another two hares located directly outside the enclosure.

Hares used the ramps as vantage points on multiple occasions and this may have increased likelihood of hares to use these types of structures to exit as they appear to be instinctively drawn to the higher vantage points. It is widely known hares are nocturnal, however the use of vantage points at night may be less well evidenced in research, this study provides clear evidence of use of vantage points by hares at night. Gate locations were often found to be associated with resting behaviours of hares while the ramps were commonly used for viewing from higher vantagepoints.

Image 29. Right, hare using top of the ramp as a vantage point.

During a period of heavy snowfall, before the one-way structures were implemented, recordings for the Upper Focussed camera stopped from 5th December 2022 – 19th December 2022 due snowfall accumulating up to the height of the rabbit netting. This resulted in hares being unable to pass through the deer fence during this period. The Upper Long camera continued to capture hare behaviour when snow coverage was significant, and this shows hares habitually returning to the same runs to attempt to pass through the deer fence.

Images 30-31. Below, hares habitually using runs and attempting to pass through the deer fence during a period of heavy snowfall.

As the number of hares within the enclosure was never determined, and with every hare leaving the enclosure fewer hares remained within the fenced woodland, it is unclear what significant conclusions can be made from this data. No statements can be made as to whether the structures were effective in reducing damage to young trees nor about whether the need to cull hares was impacted as a result. That said, with four hares successfully leaving the enclosure, four fewer hares would require culling and four fewer hares would be damaging trees within the enclosure so there is strong evidence to encourage further research.

Further study into welfare impacts is needed, all four hare exits occurred during typical breeding seasons and there is no way of knowing the gender or reproduction status of these individuals. No conclusions can be made as to whether their exit from the enclosure resulted in any welfare concerns for offspring.

Some notes on implementation of the structure themselves, local fencing contractors used to build the new deer fence also fabricated and installed all structures used in the study. It took the fencing crew around 1 day and another half day to build and complete installation. All work was done by hand, and it would have been more efficient if the structures had been installed at the same time as other activities, such as fence construction or ground preparation, when an excavator was on site, making the ramp turfing less labour intensive. Over the period of the study some of ramp material settled and some maintenance may be required to maintain height over time. It was also noted that turf and moss used on the corner ramp also seemed to have an added benefit of blocking views adjacent to this gate location, leaving only the gate area for hares to view out of the enclosure, this may have contributed toward hares using the gate at this location. It may be worth further study to determine if gate design can include visual screening along the fence on either side or some shelter element as hares were observed sheltering near the gate structures and posts installed at the upper location. It may also be worth noting that during period of heavy wind the gates would swing slightly, increasing risk of ingress and over time vegetation growth may risk gates swinging and becoming stuck on vegetation also allowing ingress.

A number of questions were raised following the end of this study which may be suitable for further consideration and research;

- → How much damage to young trees was prevented through use of one-way structures?
- → What percentage of the hare population within the fence exited using the one-way structures?
- → How far will hares travel from territories within fenced enclosures? Is there a potential for a geotagging study?
- → How many structures, and at what density or spacing, are needed to reduce hare numbers within enclosures to the greatest extent possible?
- → Is there a location where structures would be used the most (i.e., at corners, along well used runs, at high points, at low points, etc.)?
- → How many hares enter enclosures during winter snows (overtop fences) and then become trapped inside, and of this sample how many use ramps to continue to pass in and out of structures as snows recede?
- → How long would hares continue to visit unused structures before abandoning interest (particularly gates)?
- → Will hares trapped inside enclosures reproduce within the first breeding season? Would hares with litters use structures and what welfare risk does this pose at a population level?

Conclusion

Findings indicate that hares will utilise one-way structures to exit fenced woodland enclosures. Both gate and ramp structures were found to be successful, however ramps showed higher levels of use and provided additional benefits in areas where snow fall was high. All exits from the enclosure using these structures occurred at the corner location, indicating implementation of one-way structures in fenced corner locations may be more effective. The successful use of the one-way structures suggests a degree of effectiveness suitable for further research. Although it is unlikely to replace the need to manually remove hares from enclosures through driving or shooting, the success of the study suggests that some hares will escape via these structures, requiring less effort to remove remaining numbers of hares and therefore reducing costs involved with hare management. These findings should be used to develop more effective strategies of hare management in future. Further research should assess the correlation between use of structures and hare damage on newly planted trees to determine whether the numbers of hares able to escape enclosures using these structures would result in measurable decreases in tree damage. There is also potential for the use of ramps to be incorporated into best practice guidance for deer fencing in areas with high hare presence, however this can only be achieved following longer term larger scale studies.

References

Andrews, J., Miller, G.R. & Armstrong, H.M. (2000). The effects of mammalian herbivores on natural regeneration of upland, native woodland. *Scottish Natural Heritage Information and Advice Note No. 115*. Scottish Natural Heritage, Battleby, Perthshire.

Forest Research (2023). Recognising types of mammal damage to trees and woodland. *Forest Research*. [Online]. Available at: Recognising types of mammal damage to trees and woodland - Forest Research [Accessed 26 October 2023].

Game and Wildlife Conservation Trust (GWCT) (2013). Code of Practice for Brown Hare Management and welfare in England. Game and Wildlife Conservation Trust. [Online]. Available at: Layout 1 (gwct.org.uk) [Accessed 26 October 2023].

Hesford, N., Baines, D., Smith, A. A., Ewald, J. A. (2020) Distribution of mountain hares Lepus timidus in Scotland in 2016/2017 and changes relative to earlier surveys in 1995/1996 and 2006/2007, *Wildlife Biology*, 10.2981/wlb.00650, 2020 (2).

Hulbert, I.A.R. and Iason, G.R. (1996), The possible effects of landscape change on diet composition and body weight of mountain hares Lepus timidus. *Wildlife Biology*, 2: 269-273. https://doi.org/10.2981/wlb.1996.030

Joint Nature Conservation Committee (JNCC) (1994). *The United Kingdom Biodiversity Action Plan*. HMSO, London.

NatureScot (2023a). Hares and Rabbits. *NatureScot*. [Online]. Available at: Hares and rabbits | NatureScot [Accessed 25 October 2023].

NatureScot (2023b). Protected species: hares. *NatureScot*. [Online]. Available at: https://www.nature.scot/professional-advice/protected-areas-and-species/protected-species/protected-species-z-guide/protected-species-hares [Accessed 25 October 2023].

Newey, S., Fletcher, K., Potts, J. & Iason, G. (2018). Developing a counting methodology for mountain hares (Lepus timidus) in Scotland. *Scottish Natural Heritage Research Report* No. 1022.

Newey, S.; Potts, J.; Aebischer, A.; Wilson, M.W.; Newson, S.E. (2020) Designing a monitoring scheme for mountain hare (Lepus timidus) in Scotland. *Scottish Natural Heritage Commissioned Report No. 1076*, pp.1-30.

Patton, V., Ewald, J.A., Smith, A.A., Newey, S.J., Iason, G.R., Thirgood, S.J., & Raynor, R. (2010). Distribution of mountain hares Lepus timidus in Scotland: results from a questionnaire. *Mammal Review*, 40: 313-326.

R Core Team (2023). _R: A Language and Environment for Statistical Computing. *R Foundation for Statistical Computing*. Vienna, Austria.

Rao, S.J., Iason, G.R., Hulbert, I.A.R., Elston, D.A. and Racey, P.A. (2003), The effect of sapling density, heather height and season on browsing by mountain hares on birch. *Journal of Applied Ecology*, 40: 626-638. https://doi.org/10.1046/j.1365-2664.2003.00838.x

Scottish Government (2019). Scotland's Forestry Strategy 2019–2029. *Scottish Government*. [Online]. Available at: Scotland's Forestry Strategy 2019-2029 [Accessed 24 October 2023].

Scottish Government (2020). Scotland's Forestry Strategy: Implementation Plan 2020-2022. *Scottish Government.* Available at: Layout 1 (forestry.gov.scot) [Accessed 24 October 2023].

Scottish Government (2021). Greater Protection for Iconic Scottish Mountain Hares. Scottish Government. [Online]. Available at: Greater protection for iconic Scottish mountain hares - gov.scot (www.gov.scot) [Accessed 25 October 2023].

Scottish Government (2022). Scotland's Forestry Strategy Implementation Plan 2022-2025. *Scottish Government.* [Online]. Edinburgh: The Scottish Government. Layout 1 (forestry.gov.scot) [Accessed 24 October 2023].

The British Association for Shooting and Conservation (BASC) (2023). Brown Hares Code of Practice England. *The British Association for Shooting and Conservation*. [Online]. Available at: Brown Hares Code of Practice - BASC [Accessed 26 October 2023].

The James Hutton Institute (2023). Estimating mountain hare numbers. The James Hutton Institute. [Online]. Available at: Estimating mountain hare numbers | Ecological Sciences | The James Hutton Institute [Accessed 25 October 2023].

White, P.J., Warren, P. and Baines, D. (2013). Forest expansion in Scotland and its potential effects on black grouse Tetrao tetrix conservation. *Forest ecology and management*, 308, pp.145-152.

Wickham. H. (2016). ggplot2: Elegant Graphics for Data Analysis. *Springer*. Verlag New York, 2016.

Special Thanks

Although small in scale this study was made possible by the support of many people. The following people and businesses helped carry out this study and the authors offer many thanks to them for their time and efforts:

Scottish Forestry Trust, for providing funding for this study and the support of Amanda Bryan during our application process.

Taiga Upland, Fencing contractors who helped refine the design of the swing gate , build prototypes (special thanks to Rab Robertson), and the crew on site for building and installing all of our structures used in the study.

James Macpherson-Fletcher, Forest Manager for Scottish Woodlands who made the trek up to our camera traps on multiple occasions to collect memory cards for us.

Amauta Halvorsen, Assistant Environmental Forest Manager (Graduate) for Scottish Woodlands who helped screen hundreds of photographs and run statistics on the data.

Beth Scott, Assistant Environmental Forest Manager (Graduate) for Scottish Woodlands who helped run statistics and produce our wonderful graphs for the study.

Scott Newey, previously of the James Hutton Institute who provided his wealth of research experience and understating of hares in the Haglands to help us shape our study and add context.

Stuart Wilkie, Certification & Environment Manger for Scottish Woodlands who encouraged us to approach the Scottish Forestry Trust and thus lock in our commitment to the project and his encouragement along the way.

Ralland Browne, ex-director of Scottish Woodlands for proposing the idea of a hare jump as a possible structure type to use in the study.

Jaeger Lamont, Forest Manager for Scottish Woodlands who made implementation on site possible.