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Investigating wader breeding productivity in the East Cairngorms Moorland Partnership Area using collaborative methods

A report to the East Cairngorms Moorland Partnership

David Jarrett[1], John Calladine[1], Jos Milner[2], Chris Wernham[1] & Mark Wilson[1]

BTO Research Report 723

[1]BTO Scotland, University of Stirling Innovation Park, Stirling, FK9 4NF

[2]East Cairngorms Moorland Partnership, Cairngorms National Park Authority, Albert Memorial Hall, Station Square, Ballater, AB35 5QB

BTO Scotland, University of Stirling Innovation Park, Stirling, FK9 4NF
BTO, The Nunnery, Thetford, Norfolk IP24 2PU
Tel: +44 (0)1842 750050 Email: info@bto.org
Registered Charity Number 216652 (England & Wales), SC039193 (Scotland).

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EXECUTIVE SUMMARY

1. Breeding wader populations in Britain have declined markedly in recent decades. During this time, areas of moorland managed for grouse shooting and adjacent areas of rough pasture have been identified as persisting strongholds. Targets for forest expansion across Scotland can deliver conservation gains for woodland biodiversity and other environmental benefits but, in some areas, could also potentially further constrain breeding waders. Land management planning in the Cairngorms National Park (CNP) requires a balance between these and other competing objectives. Improved knowledge on the distribution, trends and breeding success of waders and the constraints they experience will help achieve a balance to the benefit of competing objectives.

2. This report describes two years (2018–19) of a project carried out collaboratively with the East Cairngorms Moorland Partnership (ECMP), which comprises six estates (Mar Lodge, Mar, Invercauld, Balmoral, Glenavon and Glenlivet) and the Cairngorms National Park Authority. The over-arching purpose of the partnership is to demonstrate a clear contribution to the aims of the CNP, including priority species conservation through sustainable moorland management. These estates contain a mix of farmland, woodland, moorland and montane habitat, with objectives including management for driven grouse shooting, deer stalking and woodland expansion. Predator control associated with management for grouse shooting is carried out across much of the partnership area.

3. Aims of the project included assessing how to increase the robustness of analyses, investigating associations of landscape configuration (notably woodland cover) and other covariates on wader breeding success, and to further consider possible strategies for ongoing monitoring of breeding wades.

4. A BTO staff member and ECMP project officer worked with estate staff (gamekeepers, rangers and ecologists) across the East Cairngorms Moorland Partnership (ECMP) area to train and encourage staff to monitor breeding waders using a variety of field methods. All project data were gathered by estate staff and a wildlife volunteer group.

5. Estate staff returned breeding wader transect survey data from 16 sites in 2018 and 17 sites in 2019 within the ECMP area, carrying out two or three survey visits at each site. There was variation in the sites covered (nine were covered in both years), with 156 apparent wader territories (ATs) identified in 2018, and 179 ATs in 2019. In 2019 Lapwing *Vanellus vanellus* (75 ATs), Oystercatcher *Haematopus ostralegus* (44 ATs), and Curlew *Numenius arquata* (45 ATs) were the most frequently recorded species.

6. A productivity index based on behaviour indicating breeding success from second or third visits on the transect surveys gives estimated proportions of pairs retaining young as 75% for Curlew, 69% for Lapwing, and 63% for Oystercatcher across both years of data, with lower productivity estimated in 2019 for each species. There was no apparent difference hatching success between years, suggesting the difference was likely due to higher chick mortality in 2019.

7. Across two years of the project, estate staff located and monitored 183 wader nests using temperature data loggers, with Lapwing (102), Oystercatcher (59) and Curlew (17) the most commonly monitored species. Hatching success of 54% for Lapwing, 65% for Oystercatcher and 75% for Curlew across the study area was estimated using the standard 'Mayfield method'.

8. Fifty-nine nests were also monitored with trail cameras over the two years, with the following nest predators identified: Common Gull *Larus canus* (two nests), Jackdaw *Corvus monedula* (one nest), Stoat *Mustela erminea* (three nests), Pine Marten *Martes martes* (three nests), Badger *Meles meles* (one nest), Sheep *Ovis aries* (one nest). Sheep were also recorded trampling one nest.

9. Participants demonstrated the ability to find and monitor Curlew nests in the second year of the project with 15 nests found and monitored (compared with two in the first year). Curlew are a high conservation priority, classed as 'near threatened' by the IUCN, and nests are challenging to find. In 2017 (the most recent year that data is available) data from only 16 Curlew nests were submitted to the BTO's Nest Record Scheme across the whole of Scotland.

10. Mixed models were not able to detect a significant effect of woodland cover on hatching success at any of a range of spatial scales. Power analysis suggests that we should be able to detect effects which change hatching success by 19% or greater with the sample size of nests monitored over two years. However the power to detect variation within the sampled nests, for example associated with proximity to woodland cover, was weaker.

11. Assessing wader breeding success from observations of adult behaviour showed a close match to measures determined more directly. This approach deserves further development as a cost effective means to assess breeding success and ultimately associations with landscape configuration.

12. Participating staff have committed significant time and resources to gathering data, while also demonstrating excellent field-craft and knowledge of wader species. Training estate staff in upland areas would prove an effective means of adding to the data needed to improve our understanding of wader breeding productivity across a range of landscapes.

1. INTRODUCTION

Scotland's breeding wader populations have declined markedly over recent years. According to the most recent BTO/JNCC/RSPB Breeding Bird Survey (Harris *et al.* 2019), the period between 1995 and 2017 saw Curlew decline by 61%, Lapwing by 55%, Oystercatcher by 38%, and Golden Plover *Pluvialis apricaria* by 10%. Snipe *Gallinago gallinago* has also experienced severe declines since the 1970s (Siriwardena *et al.* 2000), although more recently the population has stabilised or increased in Scotland (Harris *et al.* 2019).

Drivers of population change on wader breeding grounds include agricultural intensification, afforestation and increased levels of predation (Galbraith 1988, Hancock & Avery 1998, Evans 2004, Ottvall 2005, Smart *et al.* 2006, Eglington *et al.* 2010, Showler *et al.* 2010, Fletcher *et al.* 2010, van Dijk *et al.* 2015, Ainsworth *et al.* 2016, Franks *et al.* 2017). Lowland enclosed farmland has experienced the most severe declines (Baines 1990, O'Brien *et al.* 2002, Wilson *et al*. 2005, Shrubb 2007). In moorland areas where predator control is carried out for grouse moor management, waders have been found to breed at higher densities than in moorland without predator control (Tharme *et al.* 2001, Fletcher *et al.* 2010, Douglas *et al.* 2014, Franks *et al.* 2017). However, declines are unlikely to be driven by a single factor, and in many cases predation pressure, habitat change and disturbance associated with agricultural activities will be acting synergistically to make conditions less suitable for breeding waders (Eglington *et al.* 2009, van der Wal & Palmer 2008, Calladine *et al.* 2014).

In light of these declines in the lowlands and the effect of predation, upland areas of moorland and rough grassland where predator control is carried out are becoming increasingly important strongholds for breeding waders. In the East Cairngorms Moorland Partnership (ECMP) area (see Figure 1), predator control is carried out by all estates within the partnership, and there are also areas where habitat is actively managed for breeding waders (for example the Quoich/Dee floodplain near Braemar, and farmland around Tomintoul: Cunningham *et al.* 2017).

There are no published wader trends specific to the ECMP area (although Francis 1997 and 2008 provide some context), but breeding wader declines in north-east Scotland are thought to be broadly in line with trends elsewhere in the UK (Francis & Cook 2011). However, it is likely that declines in north-east Scotland have been greater on improved lowland farmland, where habitat is now less suitable and predator control less intensive or absent.

Breeding waders (especially Curlew) have become an increasing focus of conservation interest (Brown *et al*. 2015 for example). However, wader conservation can conflict with land management objectives related to afforestation (Calladine *et al.*2018), with policymakers and the wider public increasingly aware of the wider benefits of woodland including flood management, recreational opportunities and carbon sequestration. The Scottish Government aims to increase woodland cover from 17% to 25%, an addition of some 650,000 ha over the 21st century (Scottish Government 2009, WEAG 2012), with a shorter-term objective to increase cover by 15,000 ha per year from 2024 (Scottish Government 2017). Because of the high agricultural value of lowland farmland (WEAG 2012) and the prohibitive cost and lower suitability of planting at higher altitudes, marginal upland areas are likely to be favoured for this expansion. In the east Cairngorms, such areas are likely to hold significant populations of Curlew, Lapwing, and Oystercatcher, with Redshank *Tringa totanus* and Snipe also present at lower densities (Balmer *et al.* 2013). Dunlin *Calidris alpina* and Golden Plover are most abundant at higher elevations which may not be as suitable for planting so may be less likely to be affected immediately. In the ECMP area, existing woodland also supports a declining population of Capercaillie *Tetrao urogallus* (Wilkinson *et al.* 2018) and other Red- and Amber-listed bird species (Redstart *Phoenicurus phoenicurus*, Spotted Flycatcher *Muscicapa striata*, Tree Pipit *Anthus trivialis*, Willow Warbler *Phylloscopus trochilus*, Wood Warbler *Phylloscopus sibilatrix* for example) which would likely benefit from woodland expansion.

These conflicting conservation priorities make the east Cairngorms well suited to studies of the effect of landscape-scale habitat structure on breeding waders. Where woodland expansion takes place, the potential negative impacts on breeding waders can be divided into those resulting from direct habitat loss, and potential 'edge effects', where densities of breeding waders in open habitat are reduced in proximity to woodland (Stroud *et al.* 1990, Hancock *et al.* 2009, Wilson *et al.* 2014). This may be caused by increased levels of nest predation in proximity to woodland reducing breeding success, or by waders avoiding areas near woodland where perceived predation risk is higher, or through a combination of both (Wilson *et al.* 2014). However, analysis of wader nest data from the first year of this project (Jarrett *et al.* 2019) could not find evidence that the proportion of woodland cover near to the nest was associated with reduced nest success. While this may have been a result of insufficient statistical power to detect such an effect, an effect of the high intensity of predator control in the study area relative to other studies which have found an effect of woodland cover (Douglas *et al.* 2014) cannot be excluded.

The design of this project has followed a series of initiatives aimed at addressing the adversarial nature of the public discourse around moorland management (Thompson *et al.* 2016, Hodgson *et al*. 2018). The Understanding Predation project (Ainsworth *et al.* 2016) collected and reviewed information both from the scientific literature and stakeholders involved in land management. Subsequently the 'Working for Waders' initiative (www.workingforwaders.com) has been providing further support to collaborative projects. In 2017, the BTO trialled collaborative methods to survey waders, working with the Yorkshire Dales National Park Authority (YDNPA) and staff on a small number of estates in Wensleydale (Jarrett *et al.* 2017). The aim was to develop field methods for estate workers to monitor waders that: (a) were robust in providing useful information on breeding wader distribution, abundance and breeding success; and (b) could be used and applied effectively by gamekeepers and farmers. These approaches have been adapted and used in the current project. Fieldwork on the ECMP Wader Project began in the 2018 breeding season, with more than a hundred wader nests monitored (with cameras and/or data loggers) and data returned from transect surveys at 16 sites across the project area (Jarrett *et al.* 2019). Continued data collection will allow more robust conclusions to be made on factors affecting wader breeding productivity in the ECMP area which in turn can provide information which informs land management decisions.

1.1. Project Aims

The aims of the second year were as follows:

- To facilitate a feasible, cost-effective, longer-term wader monitoring approach within the ECMP area with the estates and the CNPA and engage more with those estates or beats that did not participate in the first year of the project.

- To increase the sample size of nests monitored across the six ECMP estates with nest cameras and temperature data loggers.

- To establish whether estate staff can find and monitor significant numbers of Curlew nests.

- To add to the growing body of evidence on factors which explain variation in wader breeding success, including the effect of landscape heterogeneity and woodland cover, and add to knowledge of the effect of individual predatory species on wader breeding productivity.

2. METHODS

Either a BTO staff member or the ECMP project officer met with staff from the ECMP estates to discuss the project prior to each breeding season to establish the capacity of each estate to participate in the project. Estate staff (gamekeepers, rangers and ecologists) and volunteers from a local wildlife group were responsible for all data gathered. In both 2018 and 2019, participants carried out the following fieldwork:

- Monitoring a sample of wader nests across the ECMP estates, using nest cameras and temperature loggers.

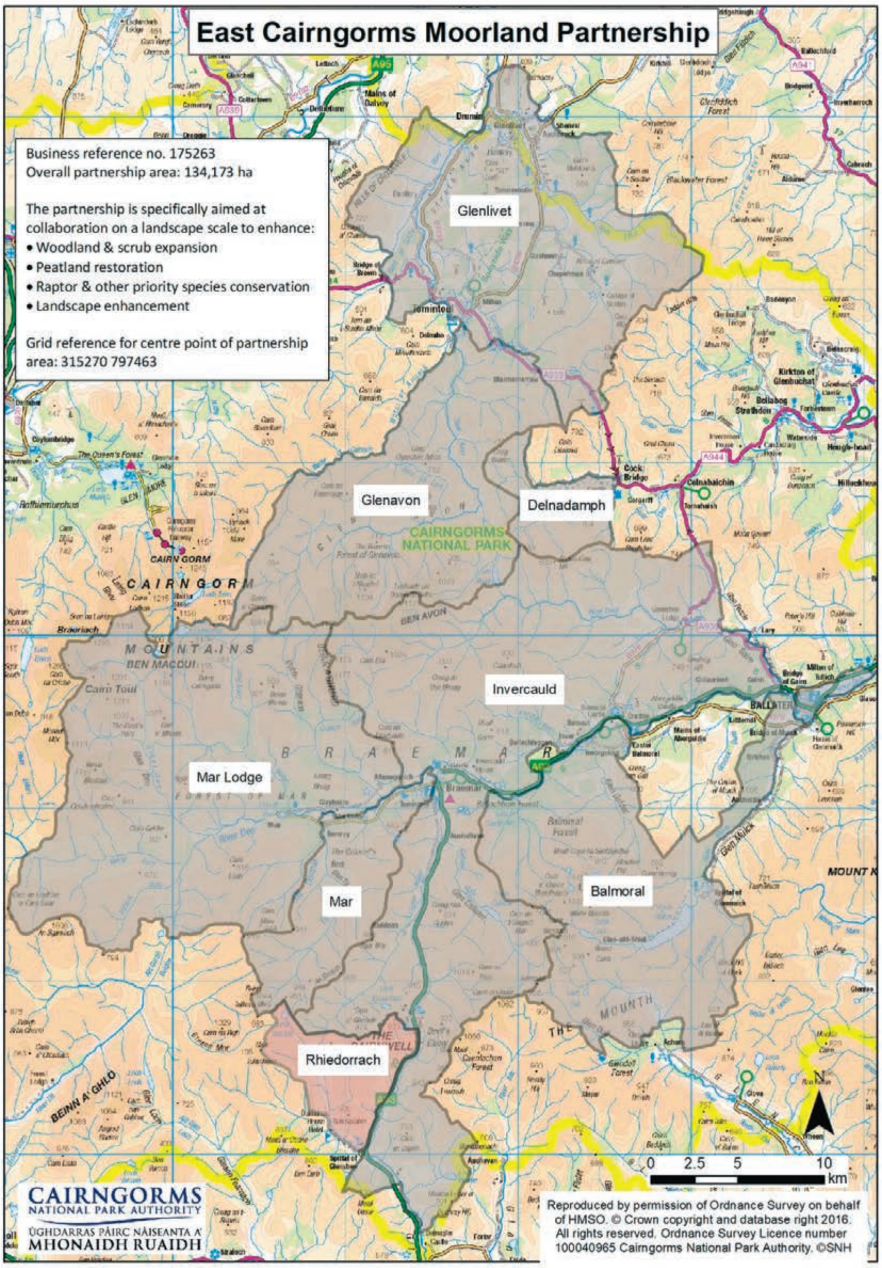
- Carrying out systematic surveys of the numbers and behaviour of breeding waders at a selection of sites.

In 2018, participants were also asked to trial two other methods; 'post-breeding flock counts', a means of assessing productivity by counting the number of juveniles in wader flocks in summer, and mammal monitoring using baited trail cameras. These methods are described in more detail in the report of the first year of the project (Jarrett *et al.* 2019).

2.1. Study Areas

In 2019 wader transect surveys and nest monitoring were carried out on Balmoral, Glenavon, Invercauld, Mar and Mar Lodge (Figure 1). Areas where wader surveys were carried out and where nests were monitored were largely selected by estate staff. The aim was to assess the compatibility of activities associated with wader monitoring with other estate activities. Participants were encouraged to select areas covering a range of different elevations, habitats, and distances from woodland.

Figure 1: The East Cairngorms Moorland Partnership area (grey) showing the participating estates' boundaries. Part of Invercauld Estate was sold prior to the wader monitoring project commencing, and participated in 2018 as Rhiedorrach Estate (pink). Delnadamph is one of Balmoral Estates.



2.2. Wader Transect Surveys

Estate staff were given guidance on carrying out wader transect surveys, and it was confirmed through informal discussions on waders and a walk around suitable wader habitats on the relevant estates (where possible) that they had sufficient knowledge of wader identification and behaviour to carry out effective surveys. Participants were then advised to choose a survey route of approximately 2–3 km (but if longer or shorter routes were preferred this was not discouraged). Following site selection, estate staff were provided with concise instructions, survey forms and maps (Appendix 3). Estate staff who participated in the first year of the project were encouraged to do repeat visits to the same transect routes in the second year. The methodology for estate staff carrying out wader surveys followed the approach set out in Jarrett *et al.* (2019), with a target of three survey visits across the breeding season (Calladine *et al.* 2009). On each survey visit, the recorder followed their chosen route, which was marked onto the survey form. All waders seen and heard were recorded and mapped on each survey visit, with associated behavioural codes for 'displaying', 'calling', 'alarm calling' and 'aggressive encounter' to capture territorial behaviour. On second and third visits, juveniles were recorded when encountered. Flights were also mapped to help identify territory boundaries. Survey visit information was interpreted according to the rules described by Brown & Shepherd (1993). On an individual survey visit, where multiple individuals of the same species were present in an area and it was difficult to determine the number of breeding pairs they represented, individuals of all species were conservatively deemed to represent different pairs only if the distance between them was greater than 500 m. These distances broadly reflect the distances over which individuals may be observed to move (e.g. when mobbing intruders) during a single survey visit. When the three visits were complete, observations of pairs on different visits were considered to be separate only if at least 1000 m apart (Brown & Shepherd 1993). These distances reflect the distance that pairs, especially with young, might move between survey visits. Where possible the surveys were carried out between 08:30 and 18:00 to avoid the periods when bird activity is more variable.

All surveys were carried out in relatively calm and dry conditions. For all surveys, precipitation (none, drizzle, rain), wind (calm, breeze, windy), and visibility (clear, moderate, poor) were recorded. Adult alarm calling or the presence of juveniles on the third survey visits (or second visits where juveniles were encountered) were taken to indicate breeding success. Other observations associated with territory occupation, such as display behaviour, non-alarm calling or presence of pairs on third visits were not taken to indicate breeding success. An index of breeding productivity was calculated for those sites where three visits were carried out by dividing the number of alarm calling pairs (and pairs seen with juveniles) on the third survey visit by the maximum number of pairs recorded on any of the three survey visits.

An estimate of the percentage of habitat covered was also recorded across three categories: 'heather', 'tussocky grassland'/'white ground' and 'enclosed grazing'. The elevation of the centre-point of each transect was also obtained using a Digital Elevation Model (Pope 2017) on QGIS (version 3.2.1).

2.3. Nest Monitoring

Advice was provided on methods for finding wader nests, along with training on how to deploy temperature loggers and cameras for all participants. Each estate was also given forms to record information on monitored nests including grid references, and time and date of deployment and recovery of the data logger (see Appendix 3). Nests were either monitored with temperature data loggers and wildlife 'trail' cameras, or only data loggers.

The temperature loggers used were Thermochron ibuttons. Each logger was programmed to record temperature every 20 minutes, sealed in plastic and placed below the eggs within the nests. Each logger has space for 2,048 temperature records, meaning that approximately 28.5 days-worth of data can be stored on each logger. The loggers were programmed to overwrite earlier data to increase the likelihood of capturing the cessation of incubation, given that loggers would not be immediately deployed once handed out to participants. All loggers were anchored by garden wire and screwed into the soil at the base of the nests to reduce incidences of birds displacing loggers from nests. The relocation of loggers was facilitated by use of high-precision hand-held GPS units and, where necessary, a metal detector. Three copies of the software used to download the data from the temperature loggers were provided and used by estate staff, volunteers and the ECMP project officer. Because the data loggers were programmed to overwrite, the prompt downloading of data from loggers following the end of the incubation period was very important. The temperature traces downloaded from the loggers were used to identify the date and time when incubation ceased. The end point of incubation was taken as when a clear diurnal cycle of temperature variation commenced.

Motion-triggered video cameras (Bushnell Trophycams), with night-vision capabilities, were mounted on stakes and placed overlooking wader nests across the study areas (Table 2); 36 camera units were shared amongst the participating estates, some of which were redeployed to different nests after being recovered from the first deployment. Images and video captured were used to specifically identify nest predators and to confirm successful hatching. Using one or more of: (a) captured video and images; (b) the examination of nest contents and shell remains when retrieving temperature loggers; (c) the temperature pattern recorded by the temperature logger and (d) direct observations, the outcomes of monitored clutches were recorded as: (i) hatched; (ii) predated; (iii) lost to agricultural activities; (iv) otherwise failed; or (v) unknown.

Generalized Linear Mixed Models (GLMMs; all statistical analyses used the statistical program R using the lme4 package, Bates *et al.* 2015) were used to test for variables which affected the probability of nests being predated across the study area. Note that alternative analyses for nest survival that considers other causes of nest failure are described in Section 2.4. We used an adaptation of Mayfield's (1975) method as a logistic model with a binomial error term, in which nest success (predated or not) was the dependent (or response) variable, with the number of days which a nest was actively monitored by the temperature logger as the binomial denominator (Aebischer 2009, Laidlaw *et al.* 2015). Explanatory variables (independent factors) in the model were: wader species (n = 5); habitat (n = 3); the start date of nest monitoring (annual Julian date as a continuous variable); whether the nests were monitored using cameras or not (n = 2) and measures of woodland cover (see below). Nests from both the 2018 and 2019 breeding season were combined for analyses, with 'Estate' included as a random effect in the model (to account for potential non-independence between nests within an estate associated with where that estate is within the landscape and potentially individual aspects of how they are managed). Models were run for nests of all species together, and also for Lapwing, Oystercatcher and Curlew individually.

The habitat classes included were 'heather' (areas where *Calluna vulgaris* was dominant) 'rough grassland/white ground' (areas where tussocky grassland was dominant) and 'enclosed/well-grazed' (where ground was fully enclosed and there were signs of livestock grazing). These were assessed either at the time by participants deploying the camera/data logger or by subsequent use of aerial images of the nest site grid reference. Because the likelihood of predation might be influenced by the date at which the loggers were first placed in nests, monitoring start date was included in the models to account for such variation. Inclusion of whether or not nest cameras were deployed aimed to assess whether the marking of nests (with a visible camera and stake) had a measurable influence on clutch survival.

Because we did not know the spatial scale at which woodland cover might influence predation likelihood, we ran multiple models to test the effect of different measures of woodland. The alternative woodland variables tested were i) the distance, in metres, from the location of the monitored nest to the nearest mature tree using satellite images of the area surrounding the nest. This was a continuous variable. We also tested the proportion of total woodland cover within a ii) 300 m, iii) 1 km and iv) 5 km buffer of the nest location, and the proportion of only coniferous woodland cover within a v) 300 m, vi) 1 km, and vii) 5 km buffer of the nest location. These were also continuous variables. The National Forestry Inventory Scotland database (Scottish Government Spatial Data Infrastructure) was used to calculate these variables using QGIS (version 3.2.1).

2.4. Nest Survival Probability

For species where more than five nests were monitored, daily survival rates were transformed to nest survival probability rates over the incubation period by raising the daily survival rate to the power of the species incubation periods (taken from Ferguson-Lees *et al.* 2011). Note that this calculation was based on nest survival, while the modelling in section 2.3 was based on predation events.

2.5. Power Analysis

Power analyses were carried out using the pwr R Package (Champely, 2018) to assess the suitability of our sample size of nests to detect effects causing variation in nest success. We set power to 80% (the probability of detecting an effect if it exists) and 0.05 as the significance level, and specified the number of variables tested in the model. A range of effect sizes were specified corresponding to reductions in nest success (calculated using the Mayfield method calculation) at 5% increments, down to a 50% reduction in nest success. The analysis produces a range of sample sizes needed to detect these different sizes of effects.

3. RESULTS

3.1. Wader Transect Surveys

In 2019 participants carried out 17 wader survey transects across the project area, nine of these transects were also carried out in 2018, while eight were new sites. Following analyses of surveys using the approach described in Section 2.2, 179 apparent wader territories (ATs) were identified across the 17 transects covered in 2019 (Table 2). The most numerous species recorded was Lapwing (75 ATs). First visits were carried out between 18 April and the 2 May, second visits between 13 May and 28 May, and third visits between the 10 June and the 30 June (see Appendix 1). All surveys were carried out in dry weather with good visibility and low wind. Maps with wader territories for each site are presented in Appendix 2. Data are summarised from both years across all sites in Table 1. An estimate of the number of successful territories based on third visit activity is shown in parentheses for those transects where three visits were completed (12 transects in 2019). The sites surveyed were intended to cover a range of habitats of varying suitability for breeding waders, and sites surveyed represent a small sample of the study area, so the data presented in Table 1 are not intended to facilitate comparison between estates or with other areas. The productivity index for Curlew, Lapwing, and Oystercatcher suggests lower productivity in 2019 compared to 2018 (with declines from 93% to 69%, 100% to 58%, and 79% to 53% respectively).

3.2 Nest Monitoring

Across both years of the project (2018 and 2019), participants found and monitored 183 wader nests, of which outcomes and incubation periods were known with a reasonable degree of certainty for 166 nests, based on data from cameras, data loggers or observation of the nest site. The models (GLMMs; Table 4) and nest survival calculations (Table 5) are based on this sample of 166 nests.

Locations of all monitored nests across the project area are shown in Figures 2 and 3. Additionally, 59 nests were also monitored with cameras over the two years of the project, allowing identification of six different nest predators (Tables 2 & 3). Pine Marten and Stoat (three nests each) were the most frequently recorded nest predators. Figure 4 summarises the nest monitoring data by year, estate, species and three woodland cover variables.

In the GLMMs for all species combined (Table 4), and also for individual models for Lapwing, Curlew and Oystercatcher (not shown), there were no significant or marginally non-significant effects with any of the four different woodland variables tested in the model or for the other variables tested (camera used/not used, nest habitat, or date monitoring commenced).

Figure 2: Location of monitored nests in 2018 and 2019 in the south of project area. Oystercatcher are shown in black, Lapwing in green, Curlew in blue, Golden Plover in yellow, Redshank in red, Snipe in pink and Common Sandpiper in grey.

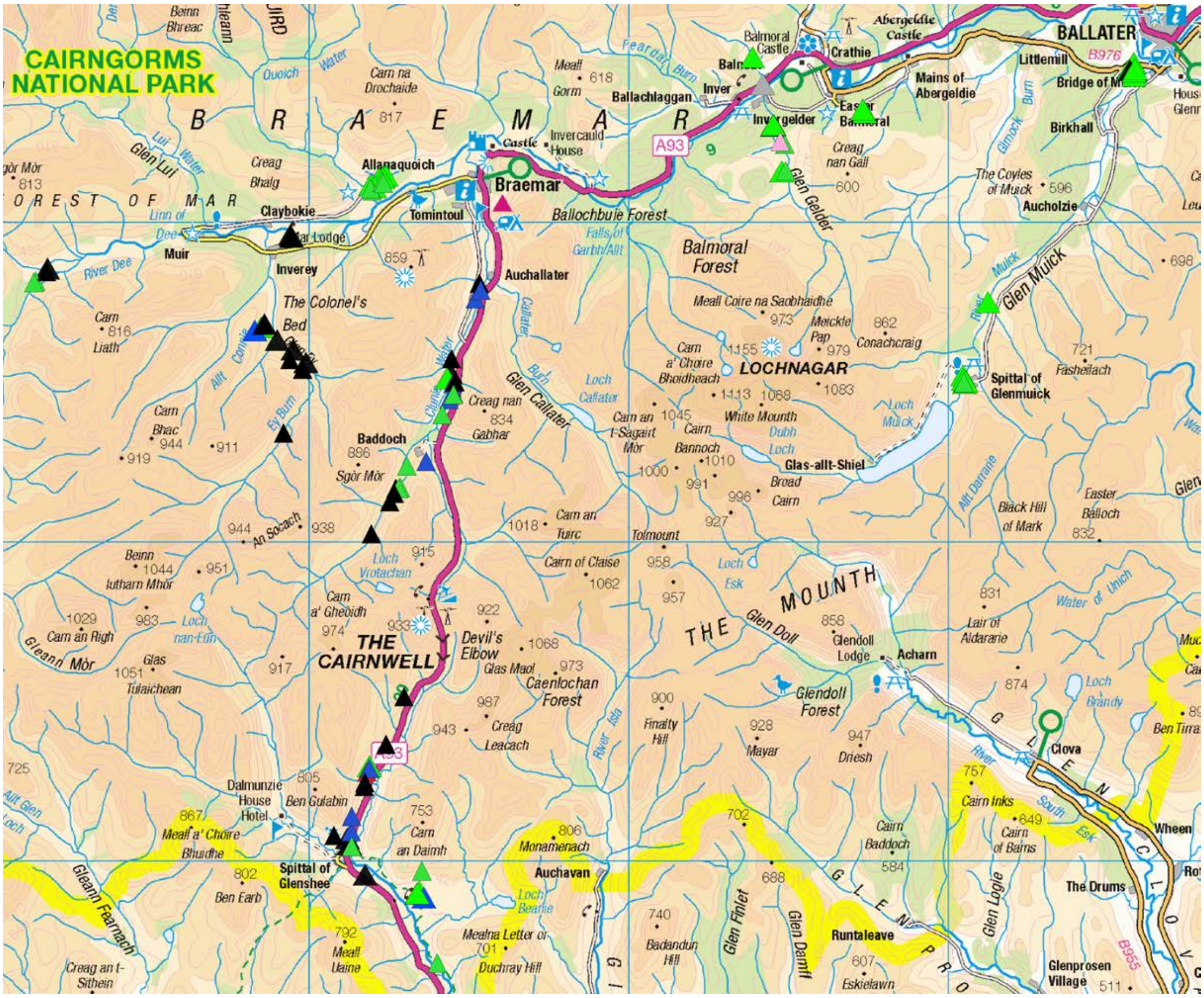
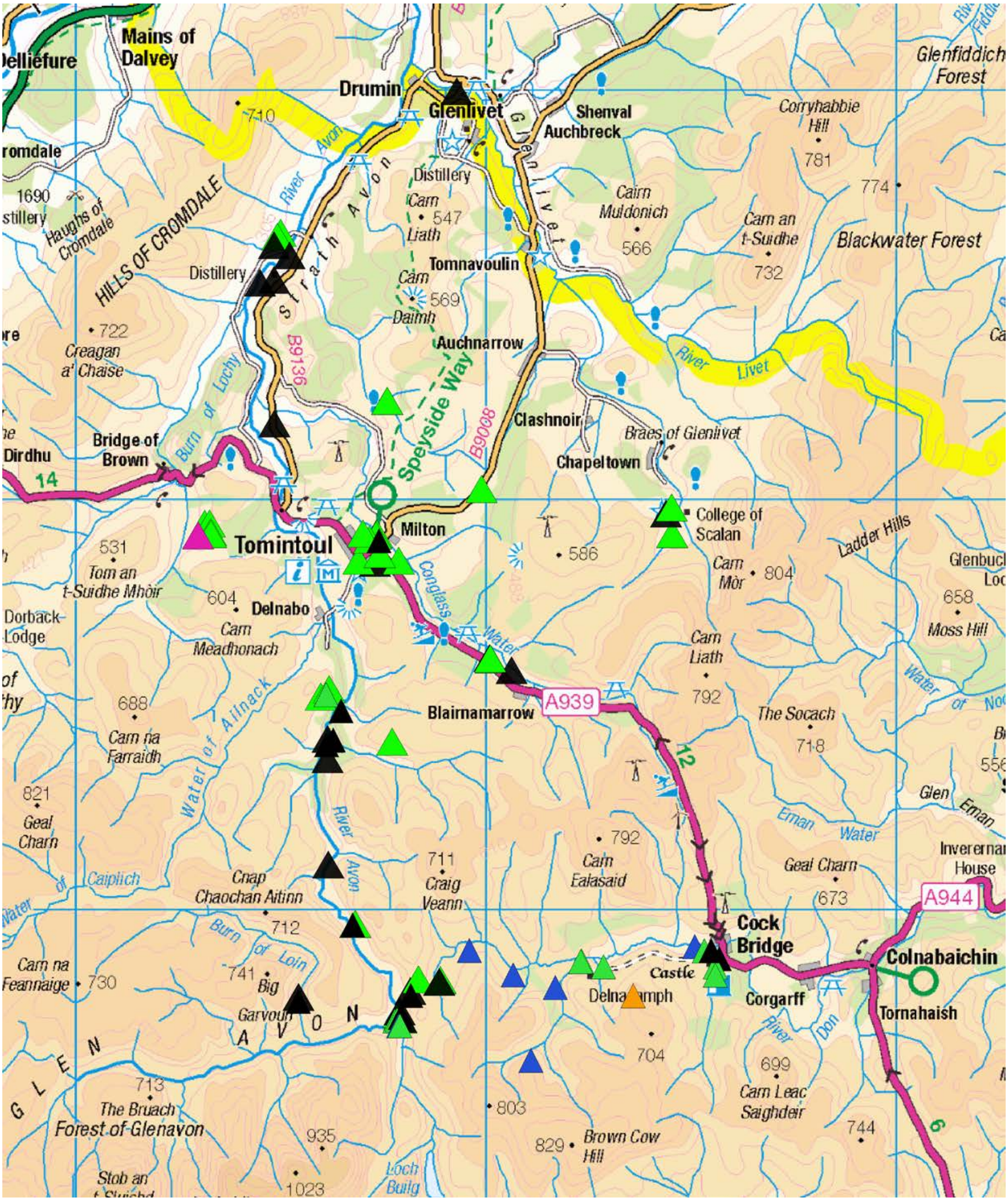


Table 1. Summary of data from 2018 and 2019 recorded from each wader transect survey carried out by estate staff. Numbers are estimates of territorial pairs based on the Brown & Shepherd (1993) methodology described in Section 2.2; NS – no survey. For survey sites where three visits were carried out, estimates of successful pairs based on third visit activity is shown in brackets.

	LENGTH OF TRANSECT (KM)	ELEVATION (MID-POINT)	HEATHER %	WHITE GROUND (%)	ENCLOSED GRAZING (%)	COMMON SANDPIPER		CURLEW		GOLDEN PLOVER		LAPWING		OYSTER-CATCHER		REDSHANK		SNIPE	
						2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Balmoral – Gelder Burn 1	2.3	370	50	0	50	1	0	1	0	0	0	2	3	1	0	0	0	0	1
Balmoral – Gelder Burn	2.3	335	75	0	25	0	0	1	0	0	0	2	1	0	0	0	0	1	0
Balmoral – Gelder Burn	2.3	320	10	40	50	1	0	0	0	0	0	1	0	1	1	0	0	0	0
Balmoral – Inchmore Delnadamph	2.1	460	60	40	0	NS	0	NS	6 (3)	NS	0	NS	1 (0)	NS	0	NS	0	NS	0
Blamoral – Corgaff Castle, Delnadamph	1.1	450	30	70	0	NS	0	NS	0	NS	0	NS	4 (4)	NS	2 (2)	NS	1 (1)	NS	0
Balmoral – River Don Flats, Delnadamph	2.3	420	25	25	50	NS	0	NS	5 (5)	NS	0	NS	5 (4)	NS	4 (2)	NS	0	NS	0
Glenavon – Blairnamarrow	3.2	455	50	50	0	0	NS	1 (1)	NS	1 (0)	NS	1 (1)	NS	0	NS	0	NS	0	NS
Glenavon – Carn na t-Sleibhe	2.3	475	50	50	0	0	0	5 (5)	3 (2)	1 (0)	1 (1)	5 (5)	4 (2)	1 (0)	1 (0)	0	0	0	1
Glenavon – Glen Loin	2.2	480	60	10	30	1 (1)	1 (1)	1 (1)	1 (0)	0	0	0	0	3 (2)	2 (1)	0	0	0	0
Glenavon – Inchrory	1.4	460	30	10	60	0	0	2 (1)	3 (1)	0	0	4 (4)	5 (1)	3 (1)	3 (3)	0	0	0	2
Glenlivet – Distillery	3.8	240	0	20	80	0	NS	0	NS	0	NS	4	NS	5	NS	0	NS	0	NS
Glenlivet – Inchnacape	2.4	395	0	30	70	0	NS	3	NS	0	NS	5	NS	2	NS	1	NS	0	NS
Glenlivet – Tombreck	2.8	460	15	35	50	0	NS	2	NS	0	NS	4	NS	1	NS	0	NS	1	NS
Glenlivet – Lagganvoulin	1.3	340	10	20	70	0	NS	2	NS	0	NS	5	NS	2	NS	0	NS	0	NS
Invercauld – Baddoch Burn	5.2	450	35	60	5	NS	0	NS	4 (3)	NS	0	NS	5 (4)	NS	5 (3)	NS	0	NS	0
Invercauld – Corndavon	4.9	410	45	50	5	NS	0	NS	3 (2)	NS	0	NS	7 (7)	NS	2 (1)	NS	0	NS	1
Invercauld – Glen Feardar	1.3	400	50	50	0	NS	0	NS	1 (1)	NS	0	NS	4 (3)	NS	0	NS	0	NS	1
Invercauld – Gleann Beag	4.1	370	10	80	10	1	0	8	9	0	0	8	10	9	8	1	4	0	1

(CONTINUED)	LENGTH OF TRANSECT (KM)	ELEVATION (MID-POINT)	HEATHER %	WHITE GROUND (%)	ENCLOSED GRAZING (%)	COMMON SANDPIPER		CURLEW		GOLDEN PLOVER		LAPWING		OYSTER-CATCHER		REDSHANK		SNIPE	
						2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Mar – Glen Eye (N)	3.6	445	20	80	0	1 (1)	2 (0)	6 (6)	7 (5)	1 (1)	1 (1)	4 (4)	4 (1)	8 (8)	4 (0)	0	0	0	1
Mar – Glen Eye (S)	2.5	475	20	80	0	5 (5)	4 (1)	0	0	0	1 (0)	3 (3)	6 (1)	4 (4)	5 (3)	0	0	0	2
Mar Lodge – Quoich Fields	2.6	330	0	0	100	NS	0	NS	1	NS	0	NS	13	NS	3	NS	1	NS	1
Mar Lodge – White Bridge	2.4	405	60	40	0	NS	0	NS	2 (2)	NS	0	NS	3 (1)	NS	4 (2)	NS	0	NS	1
Rhieddorach – Carn Mor	3.0	840	80	20	0	0	NS	0	NS	7	NS	0	NS	0	NS	0	NS	0	NS
Rhieddorach – Gleann Taitneach	5.8	385	20	65	15	0	NS	6	NS	0	NS	0	NS	6	NS	0	NS	0	NS
Totals (all sites)						**10**	**7**	**38**	**45**	**10**	**3**	**48**	**75**	**46**	**44**	**2**	**6**	**2**	**12**
Productivity index (sites with 3 visits)						**–**	**–**	**0.93**	**0.69**	**–**	**–**	**1.0**	**0.58**	**0.79**	**0.53**	**–**	**–**	**–**	**–**
Averaged across both years						**–**		**0.75**		**–**		**0.69**		**0.63**		**–**		**–**	

Figure 3. Location of monitored nests in 2018 and 2019 in the north of the project area. Oystercatcher are shown in black, Lapwing in green, Curlew in blue, Golden Plover in yellow, Redshank in red, Snipe in pink and Common Sandpiper in grey.



Tables 2. Nest outcomes of monitored nests in 2019.

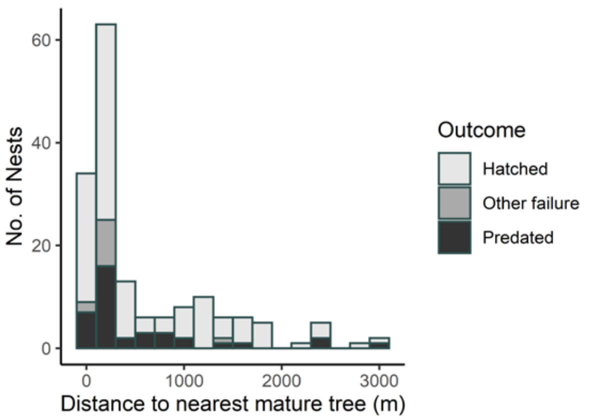
	OUTCOME				CAUSE OF FAILURE										
SPECIES	Total	Hatched	Failed	Unknown	Unattributed (diurnal)	Unattributed (nocturnal)	Abandoned/ weather	Agricultural operations	Sheep (predated)	Sheep (trampled)	Badger	Stoat	Pine Marten	Jackdaw	Common Gull
Common Sandpiper	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Curlew	15	11	4	–	1	–	1	–	–	–	–	–	1	–	1
Golden Plover	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Lapwing	30	24	5	1	1	1	2	–	–	–	–	–	1	–	–
Oystercatcher	28	21	6	1	2	–	1	–	1	–	1	–	1	–	–
Redshank	1	–	1	–	1	–	–	–	–	–	–	–	–	–	–
Snipe	1	–	1	–	–	–	1	–	–	–	–	–	–	–	–
Total	**76**	**57**	**17**	**2**	**5**	**1**	**5**	0	**1**	**0**	**1**	**0**	**3**	–	**1**

Tables 3. Nest outcomes of monitored nests in 2018 and 2019 combined.

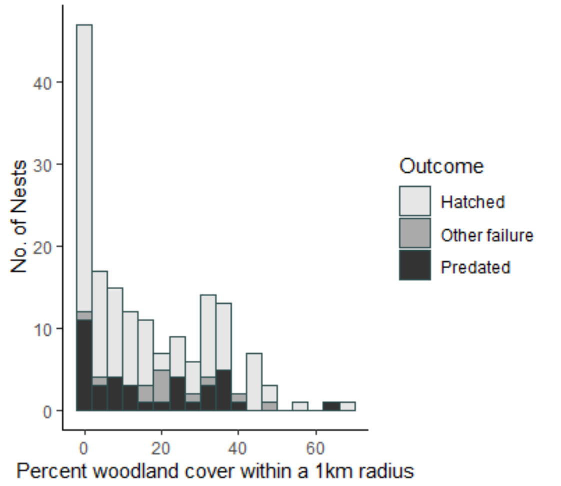
	OUTCOME				CAUSE OF FAILURE										
SPECIES	Total	Hatched	Failed	Unknown	Unattributed (diurnal)	Unattributed (nocturnal)	Abandoned/ weather	Agricultural operations	Sheep (predated)	Sheep (trampled)	Badger	Stoat	Pine Marten	Jackdaw	Common Gull
Common Sandpiper	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Curlew	17	12	4	1	1	–	1	–	–	–	–	–	1	–	1
Golden Plover	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Lapwing	102	56	34	12	17	4	5	3	–	–	–	2	1	1	1
Oystercatcher	59	44	14	1	4	3	1	1	1	1	1	1	1	–	–
Redshank	1	–	1	–	1	–	–	–	–	–	–	–	–	–	–
Snipe	2	1	1	–	–	–	1	–	–	–	–	–	–	–	–
Total	**183**	**115**	**54**	**13**	**23**	**7**	**8**	4	**1**	**1**	**1**	**3**	**3**	1	**2**

Figure 4. Number of nests that hatched, were predated or otherwise failed for (a) Distance to nearest mature tree, (b) woodland cover within a 1 km radius, (c) a 5 km radius, (d) by species, (e) by estate, and (f) by year. Species: L = Lapwing. OC = Oystercatcher, CU = Curlew, GP = Golden Plover, RK = Redshank, SN = Snipe, CS = Common Sandpiper.

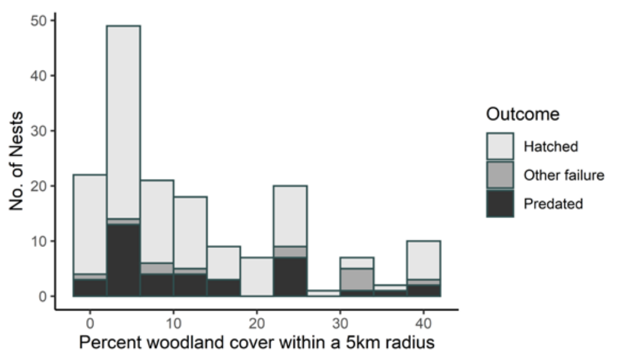
(a) Distance to nearest mature tree



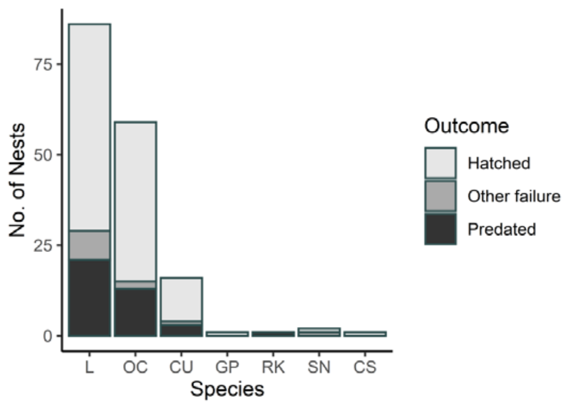
(b) woodland cover within a 1 km radius



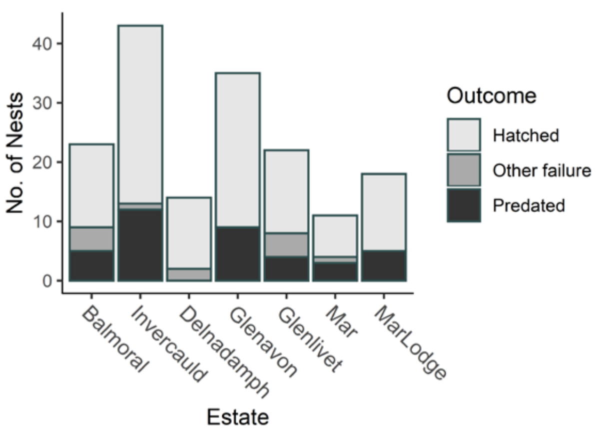
(c) a 5km radius,



(d) by species,



(e) by estate



(f) by year

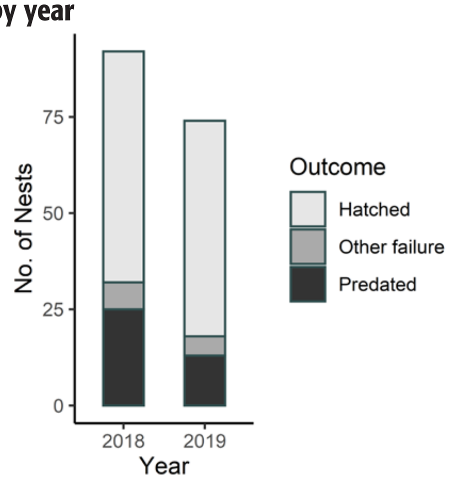


Table 4. Model outputs for fixed effects from GLMMs that examine associations between explanatory variables and wader nest success. Models were run with four different woodland cover variables; distance in metres to the nearest mature tree, and woodland cover within a radius (300 m, 1 km and 5 km) of the nest site. 'Estate' was the random effect in the model. All variables which were tested in the original model are shown, and those variables which were statistically significant (p < 0.05) or marginally non-significant (0.05 < p > 0.10) are shown in bold text.

VARIABLE / MODEL	ESTIMATE	STANDARD ERROR	Z-VALUE	P
a) Distance to nearest tree model				
Intercept	**-4.40**	**0.55**	**-8.047**	**<0.001**
Distance to tree	0.0006	0.003	0.214	0.83
With camera	0.05	0.35	0.148	0.88
Date	0.019	0.017	-1.102	0.27
Habitat – heather	0.09	0.57	-0.149	0.88
Habitat – white ground	0.27	0.40	0.702	0.48
b) 300 m woodland buffer model				
Intercept	**-4.38**	**0.59**	**-7.48**	**<0.001**
Woodland cover	0.0002	0.011	0.018	0.99
With camera	0.05	0.35	0.16	0.88
Date	-0.02	0.02	-1.01	0.31
Habitat – heather	0.0003	0.58	0.001	1.00
Habitat – white ground	0.34	0.40	0.87	0.39
c) 1 km woodland buffer model				
Intercept	**-4.36**	**0.60**	**7.32**	**<0.001**
Woodland cover	-0.004	0.011	-0.37	0.72
With camera	0.03	0.35	0.09	0.93
Date	-0.02	0.02	-1.02	0.31
Habitat – heather	0.0009	0.58	0.02	0.99
Habitat – white ground	0.35	0.40	0.87	0.39
d) 5 km woodland buffer model				
Intercept	**-4.40**	**0.54**	**-8.11**	**<0.001**
Woodland cover	0.0009	0.02	0.06	0.96
With camera	0.05	0.35	0.14	0.89
Date	-0.02	0.02	-1.06	0.29
Habitat – heather	0.04	0.56	-0.07	0.94
Habitat – white ground	0.31	0.39	0.82	0.42

3.3 Nest Survival Probability

The Mayfield Method (1975) allows the conversion of survival rates measured between two known times to a probability of nesting success. For waders, as nidifugous species, this typically relates to hatching success only. In this study, only those nests where the outcomes were known are included in the determination of Mayfield estimates of hatching success, giving hatching success rates of 75% for Curlew, 65% Oystercatcher, and 54% for Lapwing (Table 5). These figures compare favourably to indices of breeding success determined from observations of adult behaviour during the transect surveys for Curlew and Oystercatcher and gave a lower estimate for Lapwing (Table 5).

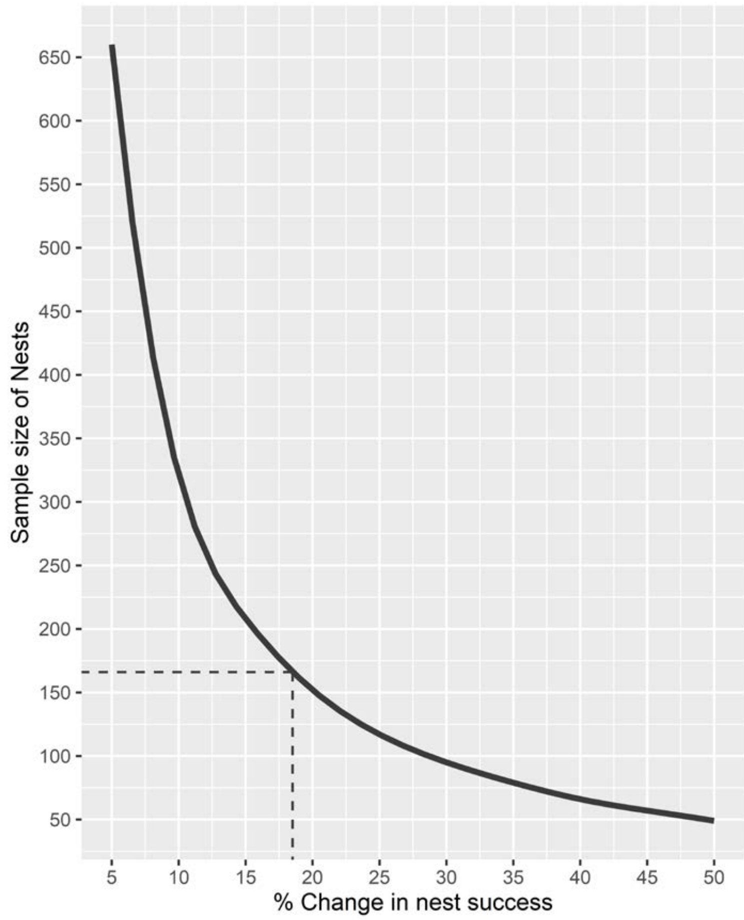
3.4 Power Analysis

With a sample size of 166 nests, we expect to be able to detect statistically significant ($p < 0.05$) differences in nesting success of 19% or more (Figure 6). The differences could either spatially in response to land management or landscape differences, or else in time in response to some changing conditions. With a greater sample of monitored nests, there would be the statistical power to detect smaller changes. For example, were the sample size doubled to 332, we would expect to be able to detect a statistically significant change of 10%.

Table 5. Nest success estimates using the Mayfield Method for those nests with known outcomes, assuming an incubation period of 29 days for Curlew, 26.5 days for Lapwing and 25.5 days for Oystercatcher. Nest success is compared to breeding success indices from the transect surveys described in Section 3.1.

Species	Daily survival rate	Implied nest success rate	Breeding success based on third visit activity
Curlew (n=16, 29 days)	0.990	75%	75%
Lapwing (n=86, 26.5 days)	0.977	54%	69%
Oystercatcher (n=59, 25.5 days)	0.983	65%	63%

Figure 5. The relationship between our sample size of nests and the size of the effect on nest success that we are likely to be able to detect.



4. DISCUSSION

The objectives of the two-year project included assessing the feasibility of a cost-effective, long-term approach to wader monitoring through engagement with estate staff. Specific objectives for the second year of the project also included: (i) to increase the sample size of nests to assess the statistical power to detect influences and potentially produce more robust findings; (ii) to engage with those estates that were less involved in the first year of the project; and (iii) to establish whether more Curlew nests could be found and monitored by estate staff.

4.1. Nest Monitoring and Breeding Success

The sample size of nests (for which outcomes were reasonably certain) increased to 166 nests after the second year of monitoring. In our models, no statistically significant influences on hatching success were detected. Power analysis (Figure 5) demonstrates that with our sample size of nests we would expect to be able to detect differences or a change in hatching success of 19%. To assess what level of variation might be detected within that sample, consider the simplest scenario of two strata (e.g. one potentially influenced by woodland cover and one not) with an equal sample of nests within each (i.e. 83 nests in each). From figure 5, there is an expectation to be able to detect a statistically significant difference of about 40% between two such samples of 83 nests. Studies on hatching success by waders using comparable methods (data loggers and nest cameras) on the Uists showed that in areas with contrasting predation pressure (the presence or absence of introduced Hedgehogs *Erinaceus europaeus*), hatching success differed by 39% between the two strata (Calladine *et al.* 2017).

With the current sample size of monitored nests in the East Cairngorms area, there might be a reasonable chance of detecting a comparable difference associated with any variables should the distribution of nests be conveniently spread between two strata (for example, one with a high level of proximate woodland cover and one with a low level). However, the distribution of nests within the landscape will be more complex than an even split between two distinct strata. Assuming the distribution of nests monitored during the two years of the project is representative of the wider distribution of nests within the landscape of the east Cairngorms, with more in areas with lower scores of proximate woodland cover (as shown in Figure. 4), then the power to detect a statistically significant affect would be lower and perhaps unlikely without a considerable increase in the number of nests monitored.

Nest predators recorded on the nest cameras, included Pine Marten (at three nests), Stoat (three nests), Badger (one nest), Common Gull (two nests), Sheep (one nest), and Jackdaw (one nest). Agricultural operations were associated the failure of five nests and abandonment associated with weather or other uncertain causes was recorded for eight nests. Other studies have indicated that mammals may be the more likely predators of nests, and birds more likely predators of chicks (Teunissen *et al*. 2008, Langgemach & Bellebau 2005, Bolton *et al.* 2007), however, there has been less work on nest predation in areas where generalist predators (particularly Fox, Stoat, Weasel, Carrion Crow) are controlled under general licence. In this study, mammalian predation (either attributed directly to a mammal species, or implied due to nocturnal nest failure) was responsible for a minimum of only 14 out of 54 known nest failures. While in the first year of the project, Pine Marten were not recorded predating a nest, in the second year there were three instances of Pine Marten nest predation recorded. Annual variation in predator pressure on ground-nesting birds in response to vole abundance has been identified in Scandinavia (Marcstrom 1988), where bad vole years result in predators switching to ground-nesting birds. More research is needed to understand if similar effects might drive variations in predation pressure on waders in the UK uplands. It is worth noting, however, that nest survival probabilities found during this study (Curlew 75%, Lapwing 54%, Oystercatcher 65%) are at the higher end of the range (30%–60%) commonly reported for breeding waders (Berg *et al.* 2002, Seymour *et al.* 2003, Bolton *et al.* 2007).

Comparisons of hatching success assessed directly using nest temperature loggers and cameras with indices of productivity index assessed from the presence and behaviour of waders during later transect surveys over the two years of the project show they were broadly similar but with the greatest difference for Lapwing (Curlew 75% using both methods; Lapwing 54% from direct measures and 69% using observations from transect surveys; and Oystercatcher 63% using both methods). Lapwing nest earliest of these three species and are the most likely to relay (Shrubb 2007, Ferguson-Lees *et al.* 2011) and the resulting differences in timing of breeding could potentially explain why there is a greater difference between productivity inferred from nest success and from assessing productivity on later visits than the other species. The productivity index from the transect data also showed a difference between 2018 and 2019, with lower apparent productivity recorded in 2019 for Oystercatcher, Lapwing and Curlew. However, hatching success assessed directly using nest temperature loggers were very similar between the two years. It is likely that the difference in productivity between years was driven by chick mortality, perhaps due to wetter weather in 2019. The monitoring of breeding waders and therefore understanding of constraints that limit them would benefit from the further development of repeatable indices of overall breeding success.

4.2. Other Methods Trialled in the Project

In the first year of the project we trialled mammal monitoring with camera traps as an initial test of their efficacy for assessing of mammalian predator distribution and also post-breeding flock counts of waders to assess the proportions of adults and juveniles present towards testing the efficacy of that approach to deliver an index of overall breeding success. Details of these modules are given in the report for work undertaken in 2018 (Jarrett *et al.* 2019). These different methods vary in terms of the resources required and it is relevant to note that monitoring of mammals with camera traps following the breeding season in July was considered too time consuming at a time of year when estate staff are preparing for the start of shooting seasons.

4.3. The feasibility of long-term wader monitoring to inform conservation management

The repeatability and validity of transect surveys undertaken by estate workers has been demonstrated (this study, Jarrett *et al.* 2017, 2018). How data collected can be collated, archived and analysed to assess temporal changes and spatial variation to inform trends and ultimately management requires further attention and development. Similarly how such data can be integrated with other ongoing monitoring schemes to their mutual benefit should be explored.

Waders are relatively long-lived birds and response to any change in conditions can take time to be detected as changes in population densities. A time-lag between changes in conditions and the effects being detected by monitoring population sizes of waders could potentially hinder adaptive management aimed to benefit those bird assemblages. Monitoring of breeding success has the potential to detect changes within shorter timescales and could prove more amenable for adaptive management purposes; any needs for change in management (or else assessing the effectiveness of management) could be achieved in a timely manner. Participants of this work in the ECMP and other similar studies have demonstrated considerable success in nest finding and monitoring, however the statistical power to detect changes or differences in hatching success from those nests directly has proven to be quite limited. However assessing breeding success from observations of wader behaviour during transect surveys could prove to be useful and relatively easier (cost-effective) alternative to the time-consuming finding of nests and use of specialist equipment such as cameras and loggers.

The use of behavioural observations has the additional potential advantage of providing a measure of overall breeding success. While measures of hatching success can be obtained, knowledge of fledging success and the limitations for waders at that time remain poorly understood because of the mobility of their nidifugous young. The behavioural observations derived from the latest transect surveys in this study demonstrate considerable potential of the method to deliver a proxy for breeding success but the methods requires further development to assess their repeatability (to provide a robust index of breeding success) and ultimately calibration against more direct methods. The uses of nest cameras and temperature loggers still have much potential to identify nest predators and times of predation events but will require careful design in their deployment across different landscapes to better understand how landscapes and land uses interact to influence levels of predation.

The two-year study in the east Cairngorms demonstrates the capabilities of estate workers to monitor breeding waders and associated with that, their capacity to contribute to a wider understanding of how land management can offer opportunities and limitations for that group of birds. Participants have committed significant time and resource to data gathering data, while also demonstrating excellent field-craft and knowledge of wader species. Training estate staff in upland areas may prove an effective means of gathering the data needed to improve our understanding of wader breeding productivity across a range of landscapes. A larger related project on breeding waders (CNP-wide or larger) involving a wide range of stakeholders (statutory bodies, farmers, gamekeepers, birders, hill-walkers etc.) and including the monitoring methods used this project is an attractive longer-term option. Interest is growing in methods which involve local stakeholders in wader monitoring through initiatives such as ‘Working for Waders’ (www.workingforwaders.com). Resulting data will prove most insightful if comparisons can be made between different landscapes, habitats and predator assemblages, with data on habitat management, and predators gathered concurrently. Spreading this approach across other areas has the potential to significantly increase our understanding of how different landscapes and associated managements affect wader populations.

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6. APPENDICES

APPENDIX 1. VISIT DATES FOR 2019 WADER TRANSECT SURVEYS.

ESTATE	SITE	VISIT 1	VISIT 2	VISIT 3
Balmoral	Gelder Burn 1		13/05	26/06
	Gelder Burn 2		13/05	26/06
	Gelder Burn 3		13/05	26/06
	Inchmore, Delnadamph	18/04	16/05	17/06
	Corgaff Castle, Delnadamph	18/04	15/05	20/06
	River Don Flats, Delnadamph	18/04	17/05	19/06
Mar Lodge	Quoich Fields	18/04		30/06
	White Bridge	22/04	21/05	10/06
Mar	Glen Ey North	25/04	17/05	13/06
	Glen Ey South	25/04	17/05	13/06
Invercauld	Gleann Beag, Glen Shee	23/04		
	Baddoch Burn	02/05	28/05	26/06
	Cordavon	20/04	20/05	25/06
	Gled Feardar	18/04	20/05	17/06
Glenavon	Inchrory	02/05	28/05	27/06
	Glen Loin	01/05	27/05	27/06
	Carn na t-Sleibhe	02/05	02/06	10/07

APPENDIX 2. TRANSECTS SURVEYED IN 2019. THE RED LINES SHOW THE ROUTES WALKED. STARS INDICATE THE CNTRES OF TERRITORIES IDENTIFIED FROM MULTIPLE VISITS (OYSTERCATCHER ARE SHOWN IN BLACK, LAPWING IN GREEN, CURLEW IN BLUE, GOLDEN PLOVER IN YELLOW, REDSHANK IN RED, SNIPE IN PINK AND COMMON SANDPIPER IN GREY).

Figure 6: Mar Lodge – Quoich Fields

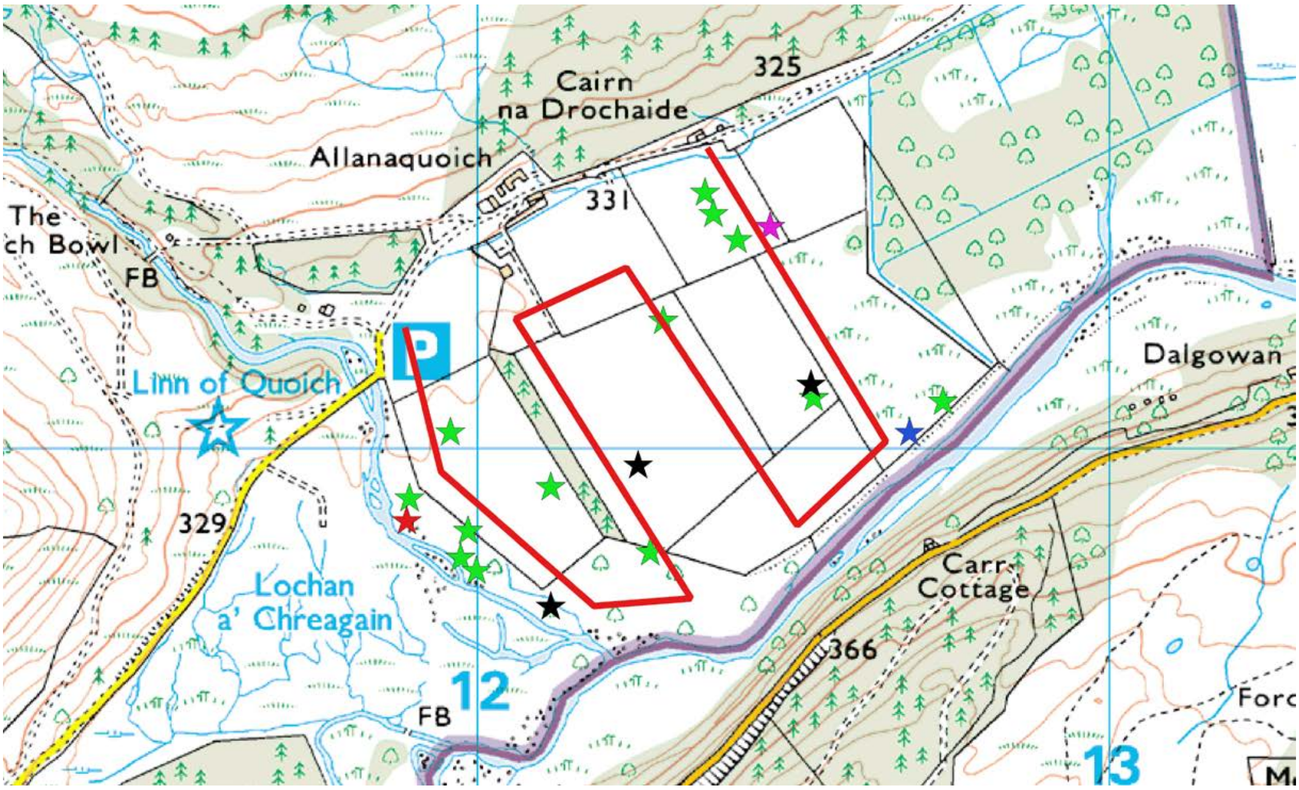


Figure 7: Mar Lodge – White Bridge

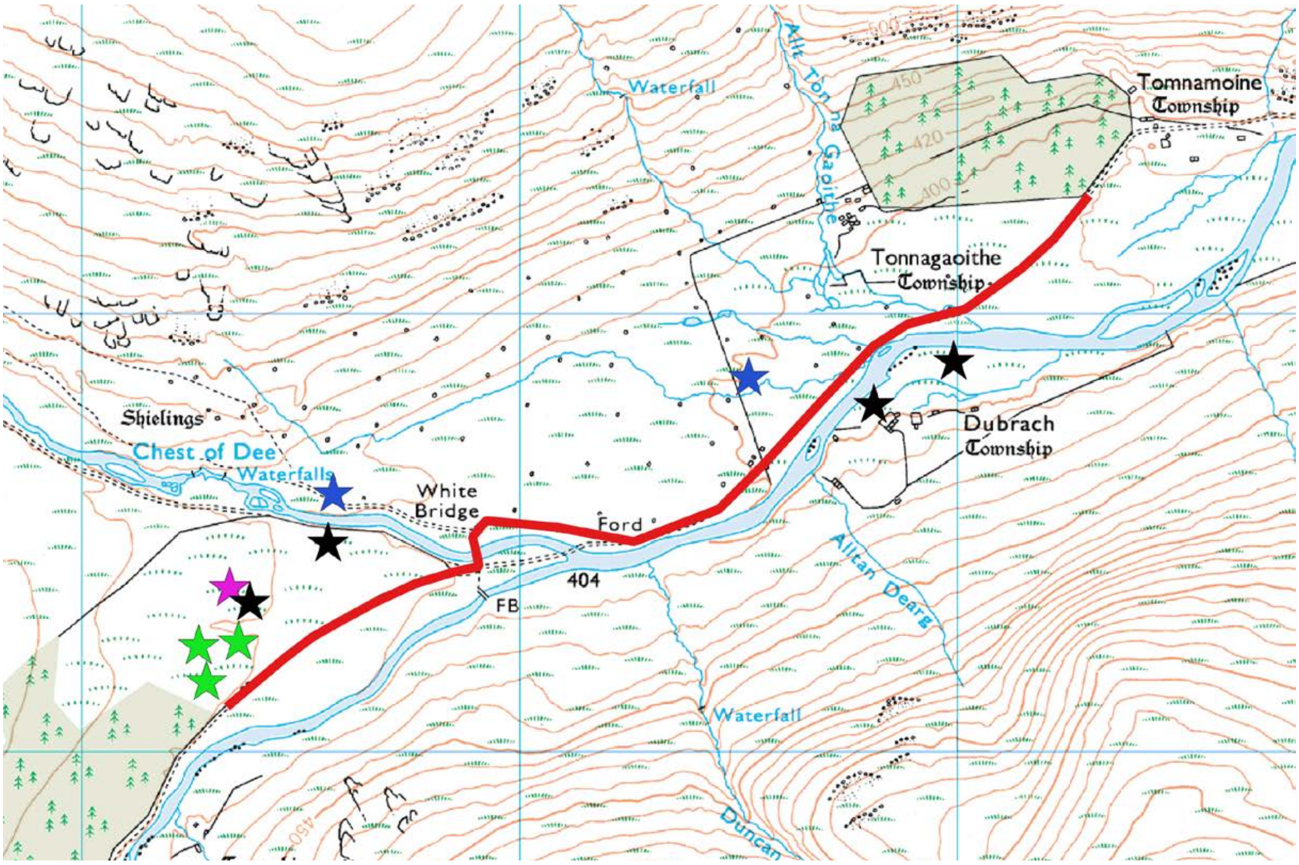


Figure 8: Invercauld – Corndavon Lodge, Corndavon

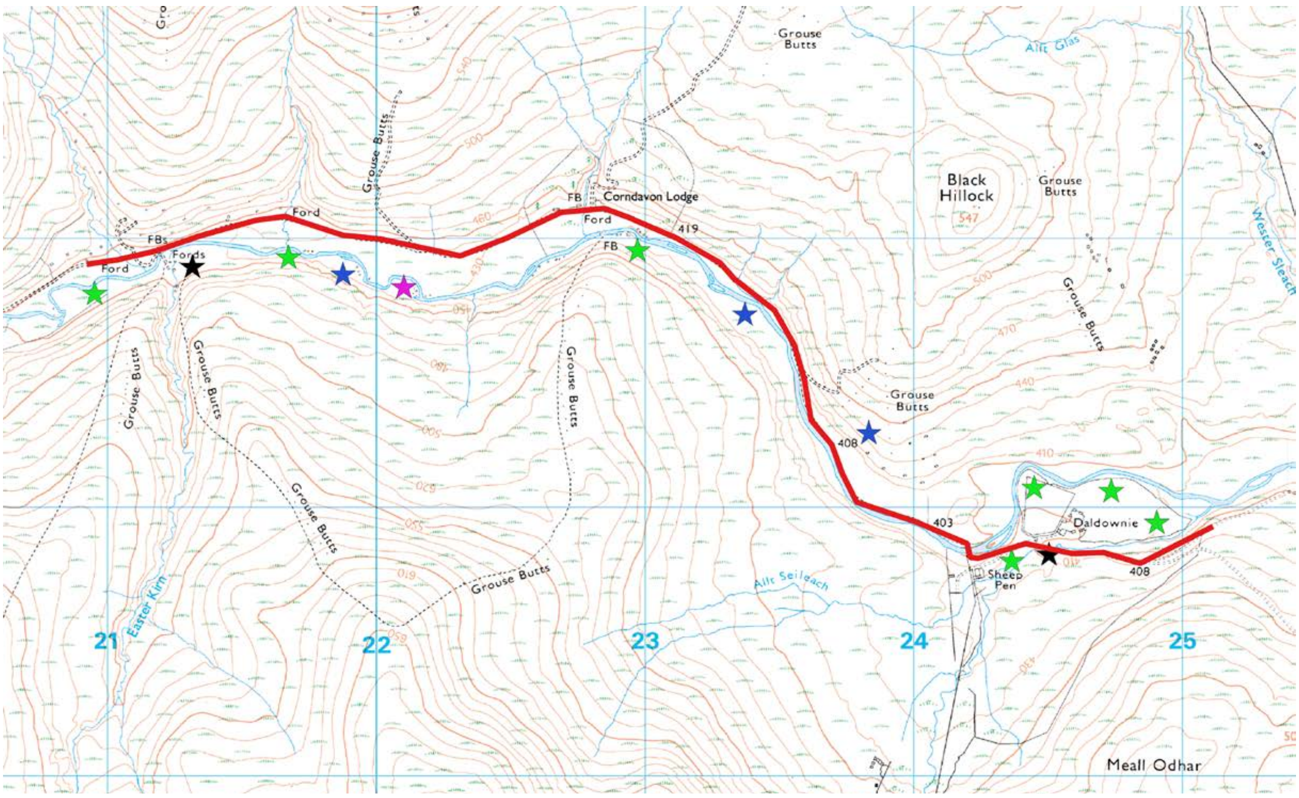


Figure9: Invercauld – Glen Feardar, Corndavon

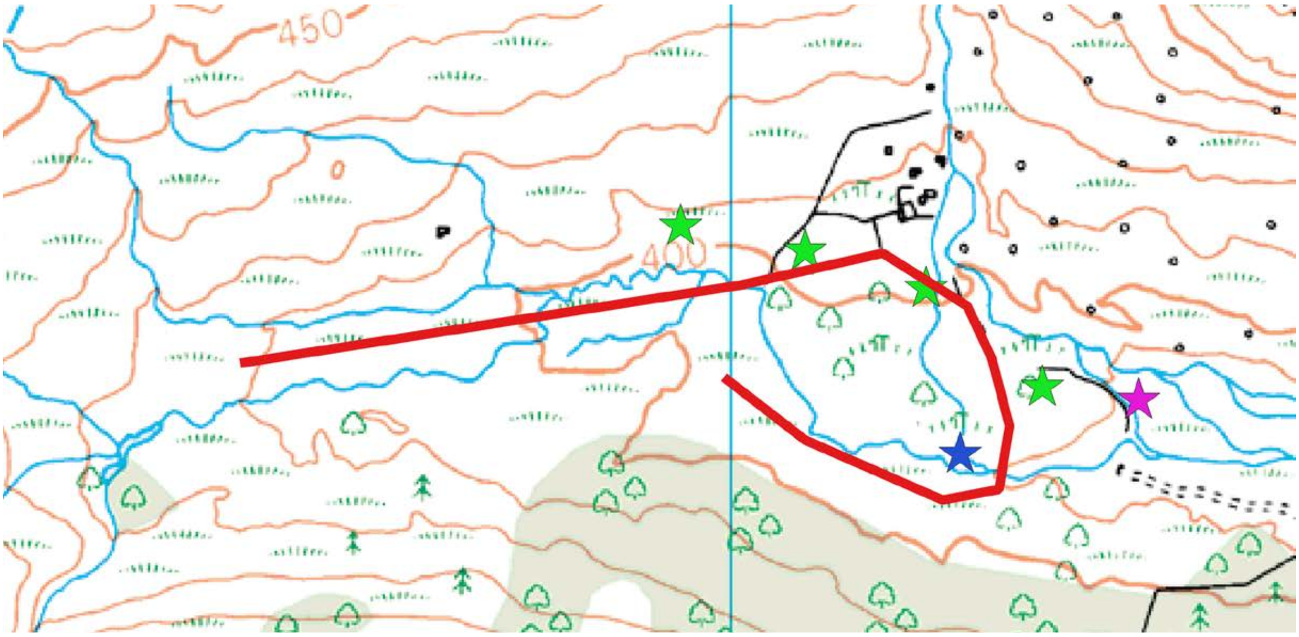


Figure 10: Invercauld – Baddoch Burn

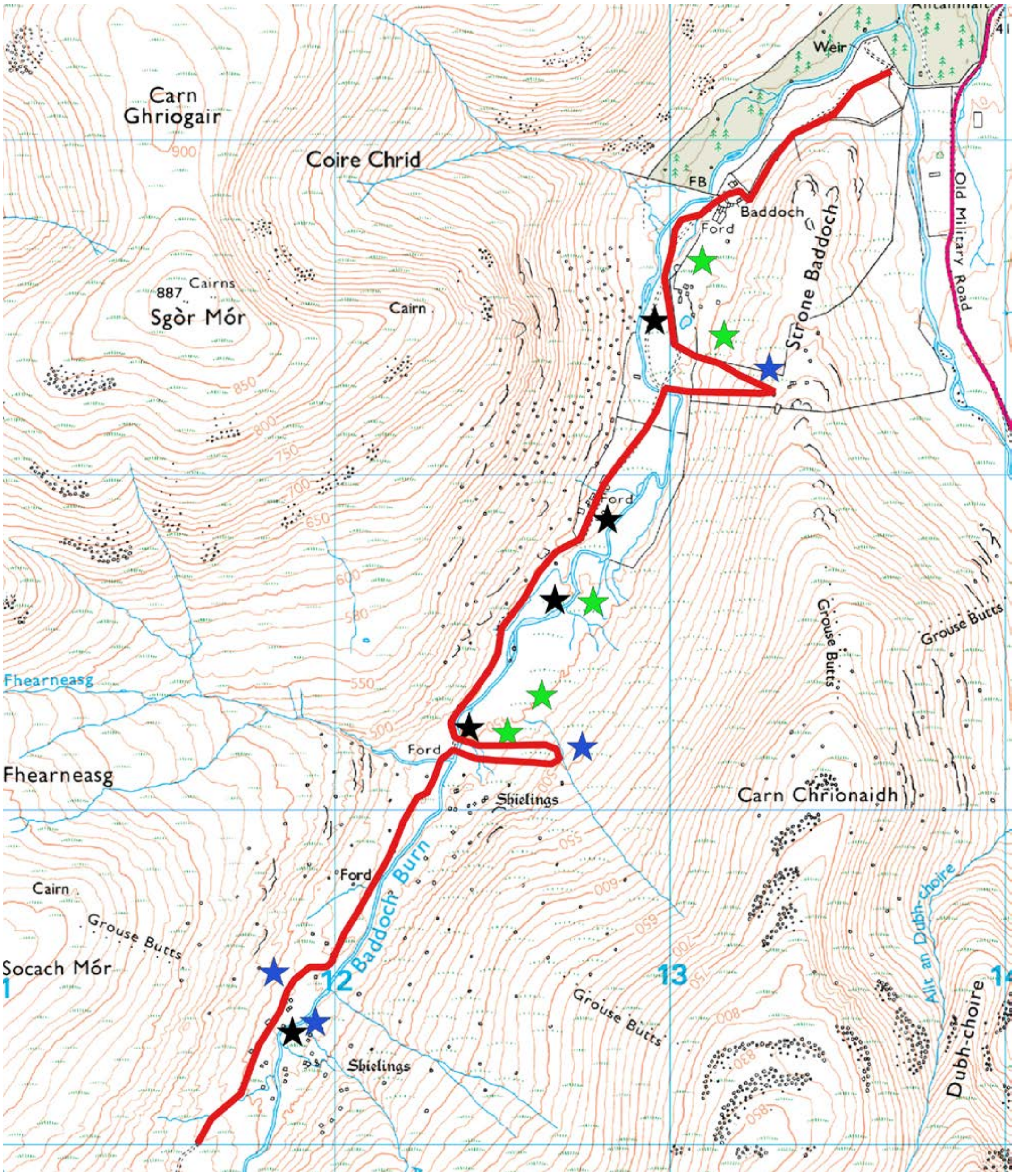


Figure 11: Invercauld – Gleann Beag, Glen Shee

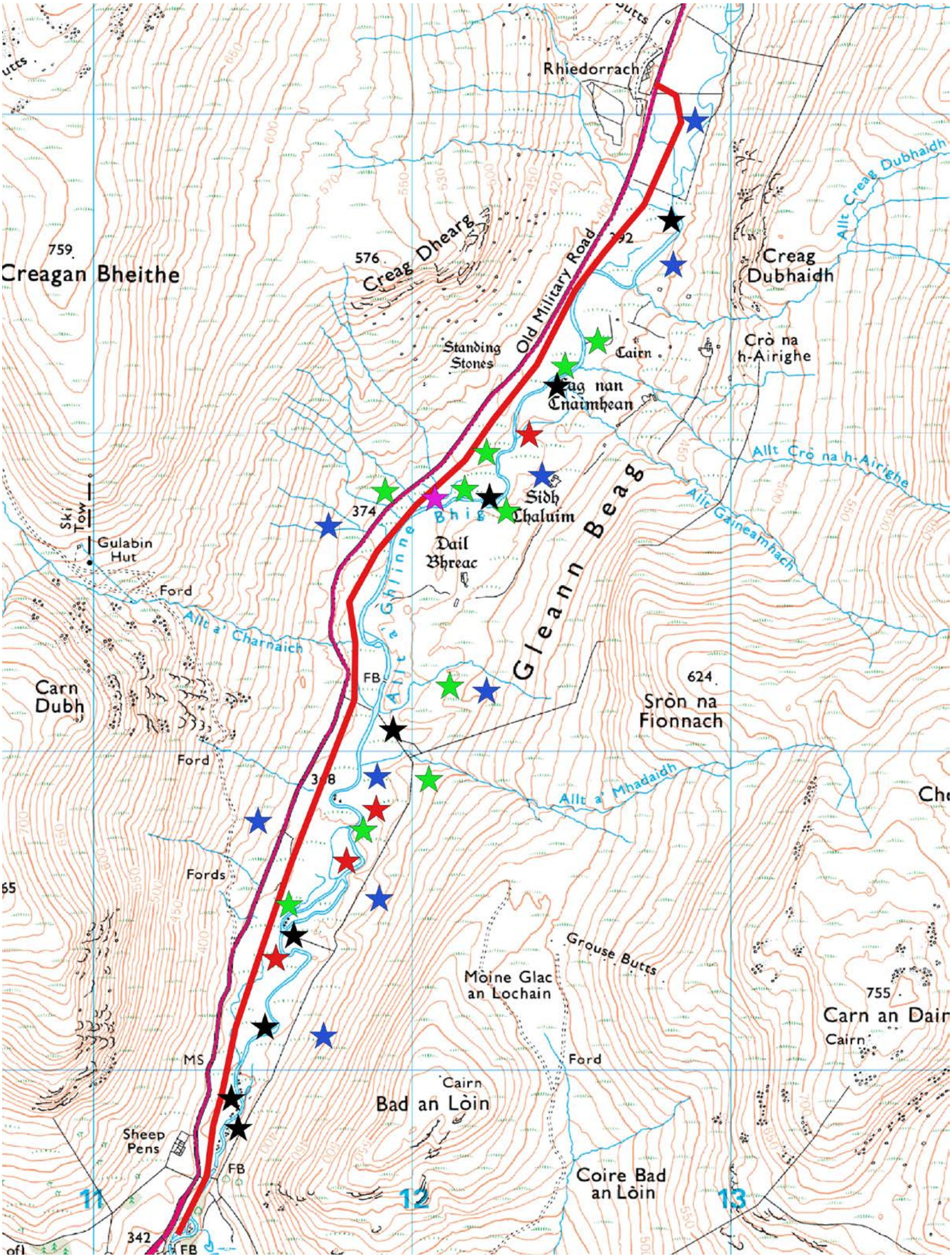


Figure 12: Balmoral – Gelder Burn North

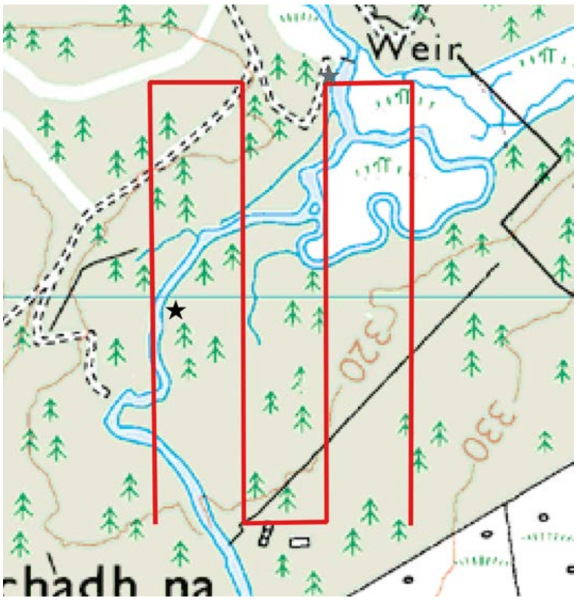


Figure 13: Balmoral – Gelder Burn Mid

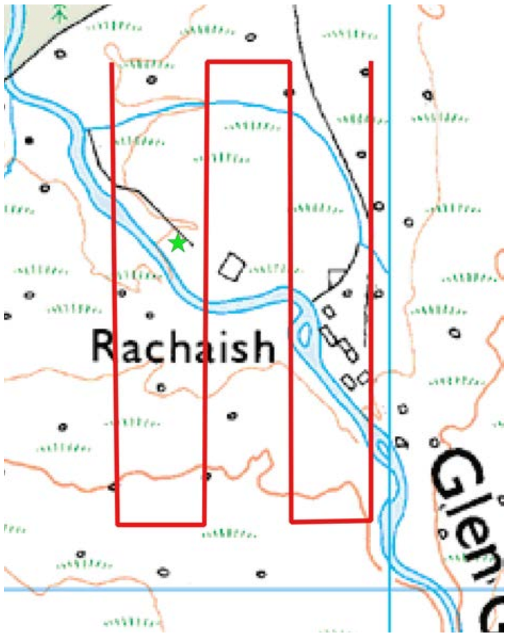


Figure 16: Balmoral – Corgaff Castle, Delnadamph

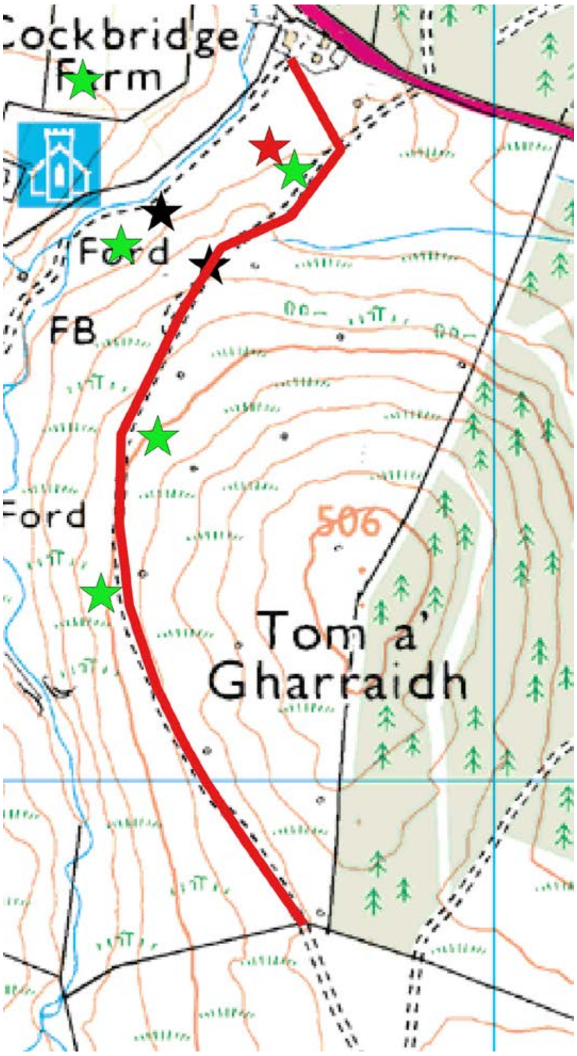


Figure 14: Balmoral – Gelder Burn South

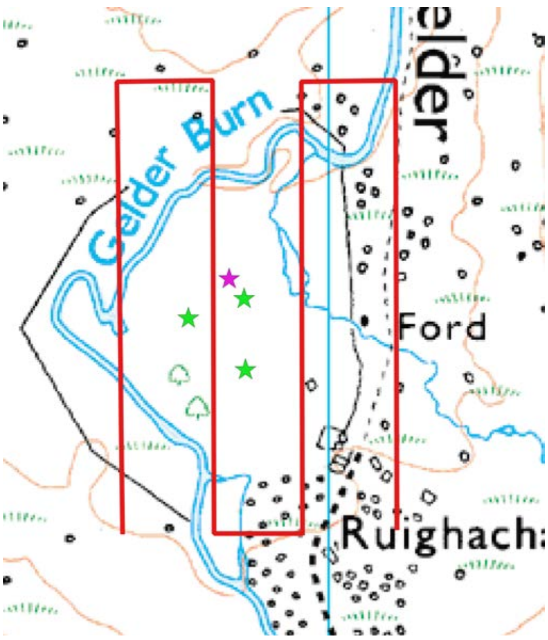


Figure 15: Balmoral – Inchmore, Delnadamph

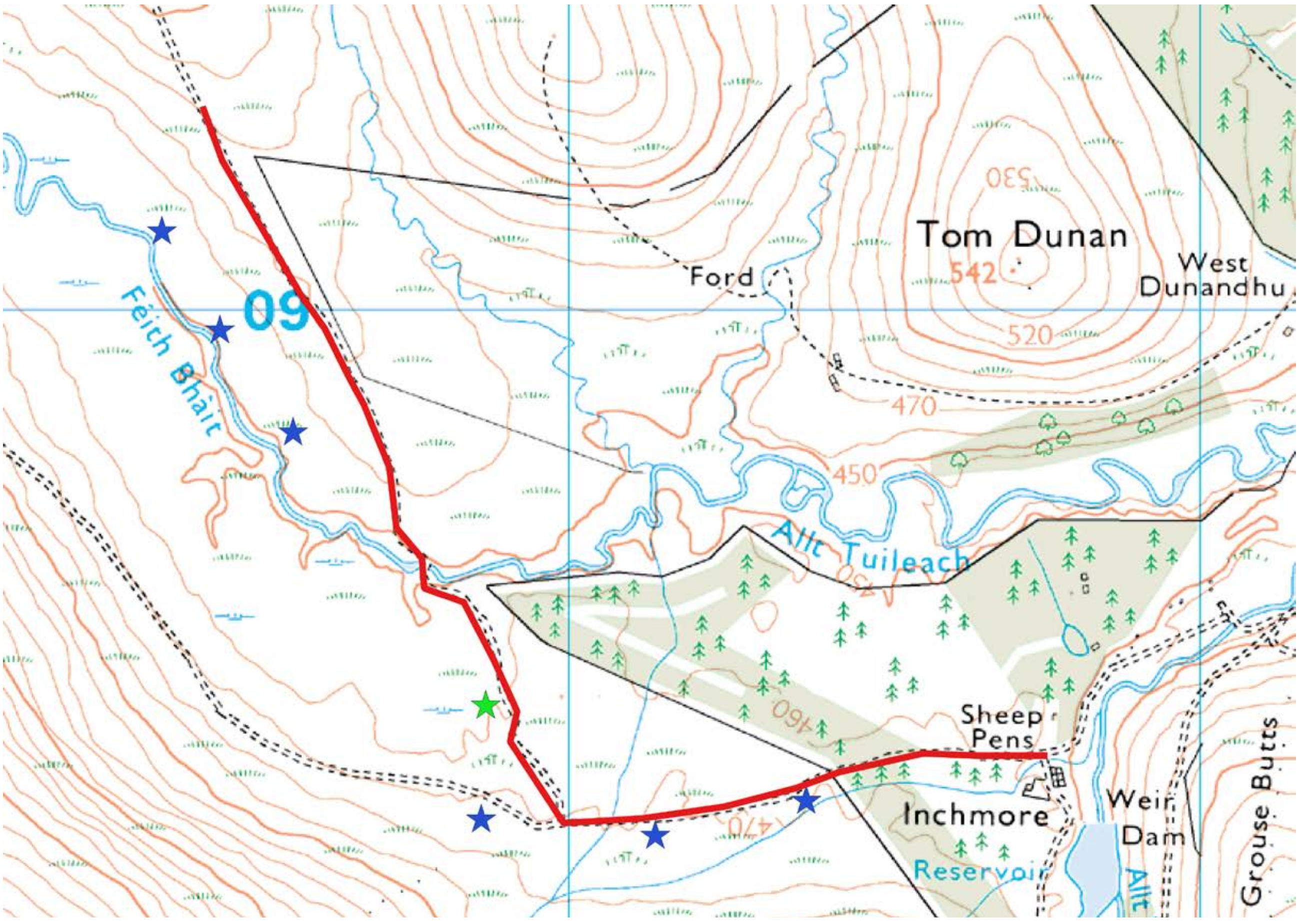


Figure 17: Balmoral – River Don Flats, Delnadamph

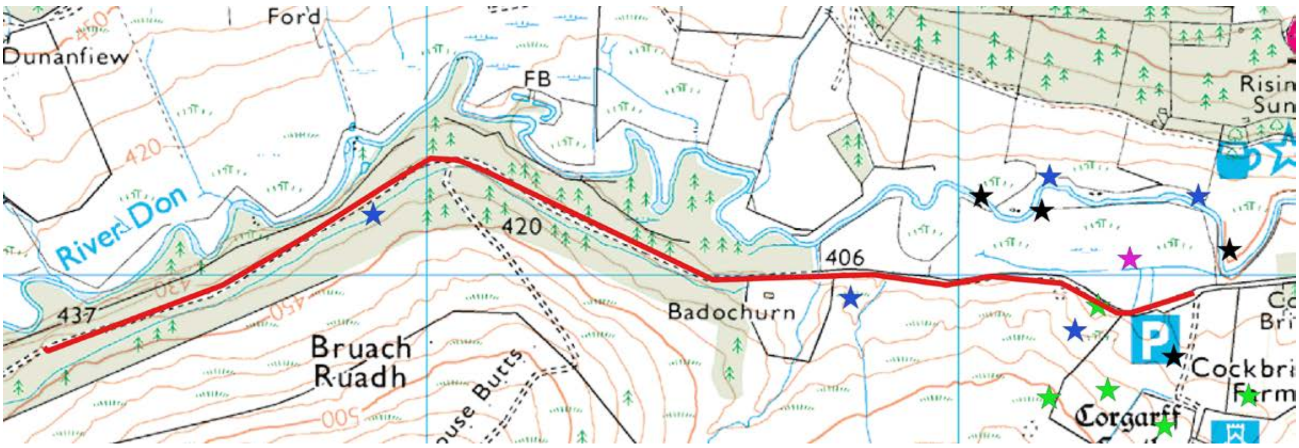


Figure 18: Glenavon – Carn an t-Sliebhe

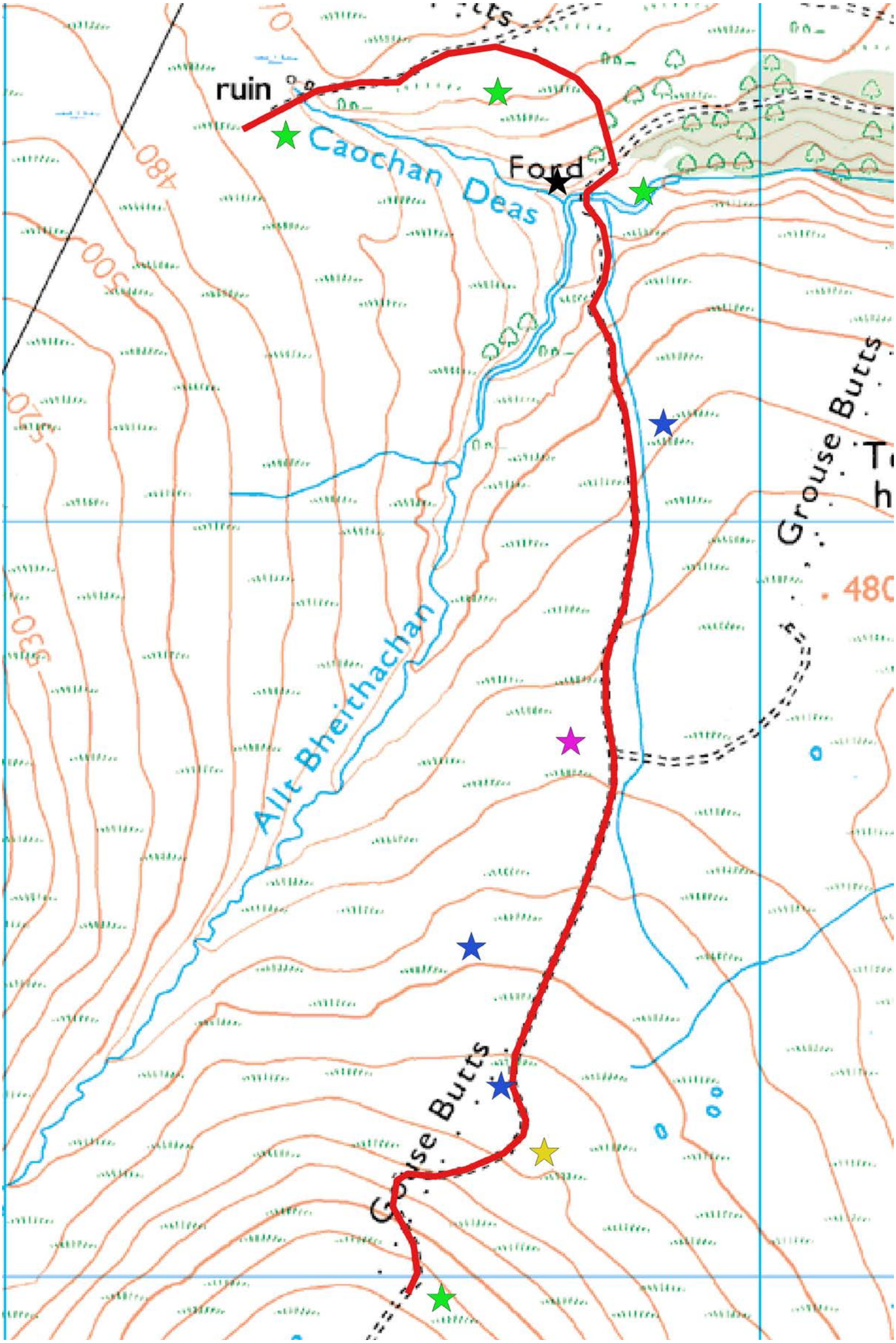


Figure 19: Glenavon – Glen Loin

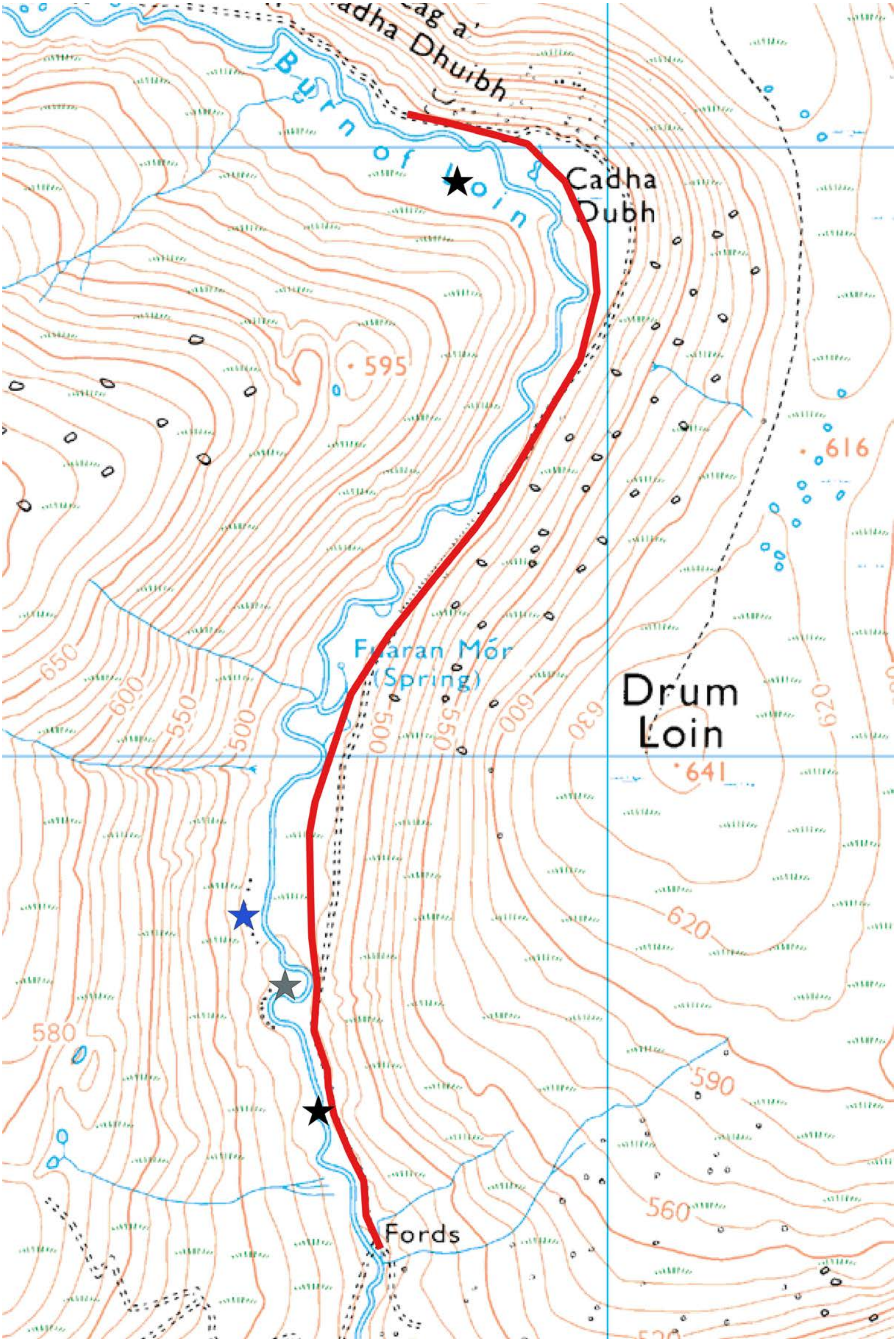


Figure 20: Glenavon – Inchrory

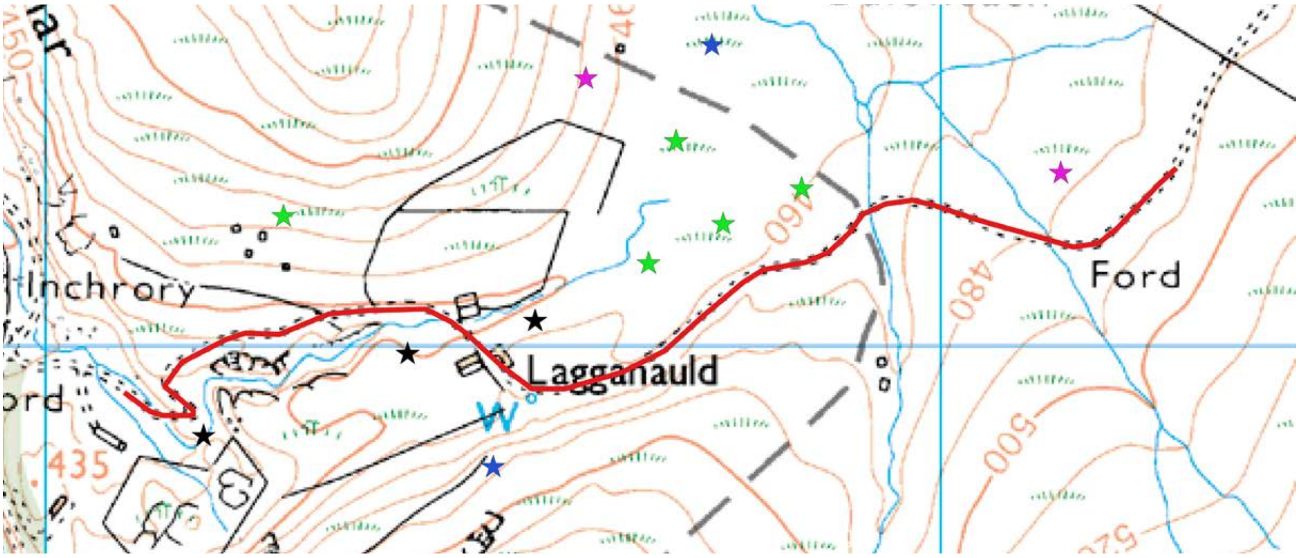


Figure 21: Mar – Glen Ey North

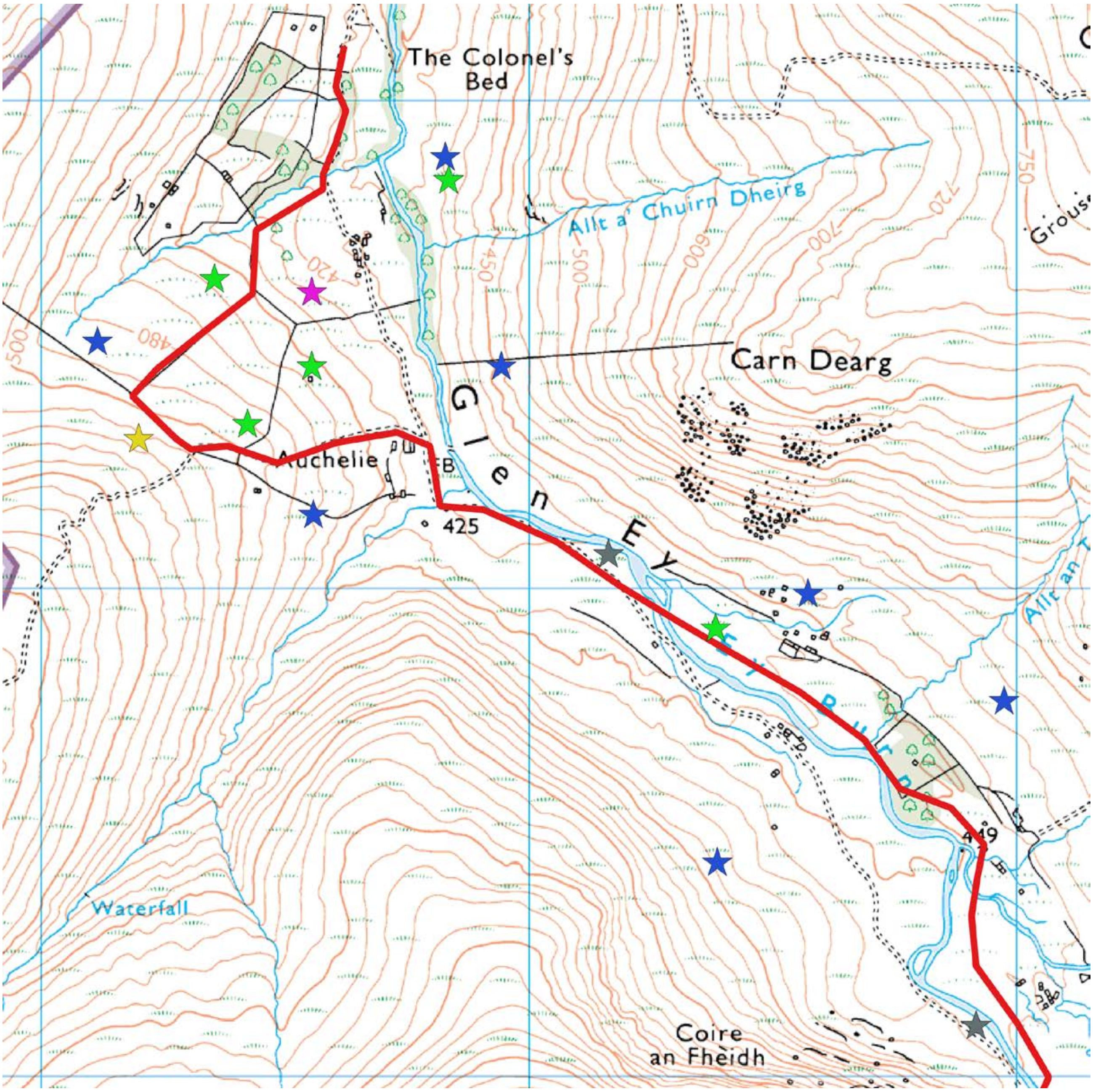
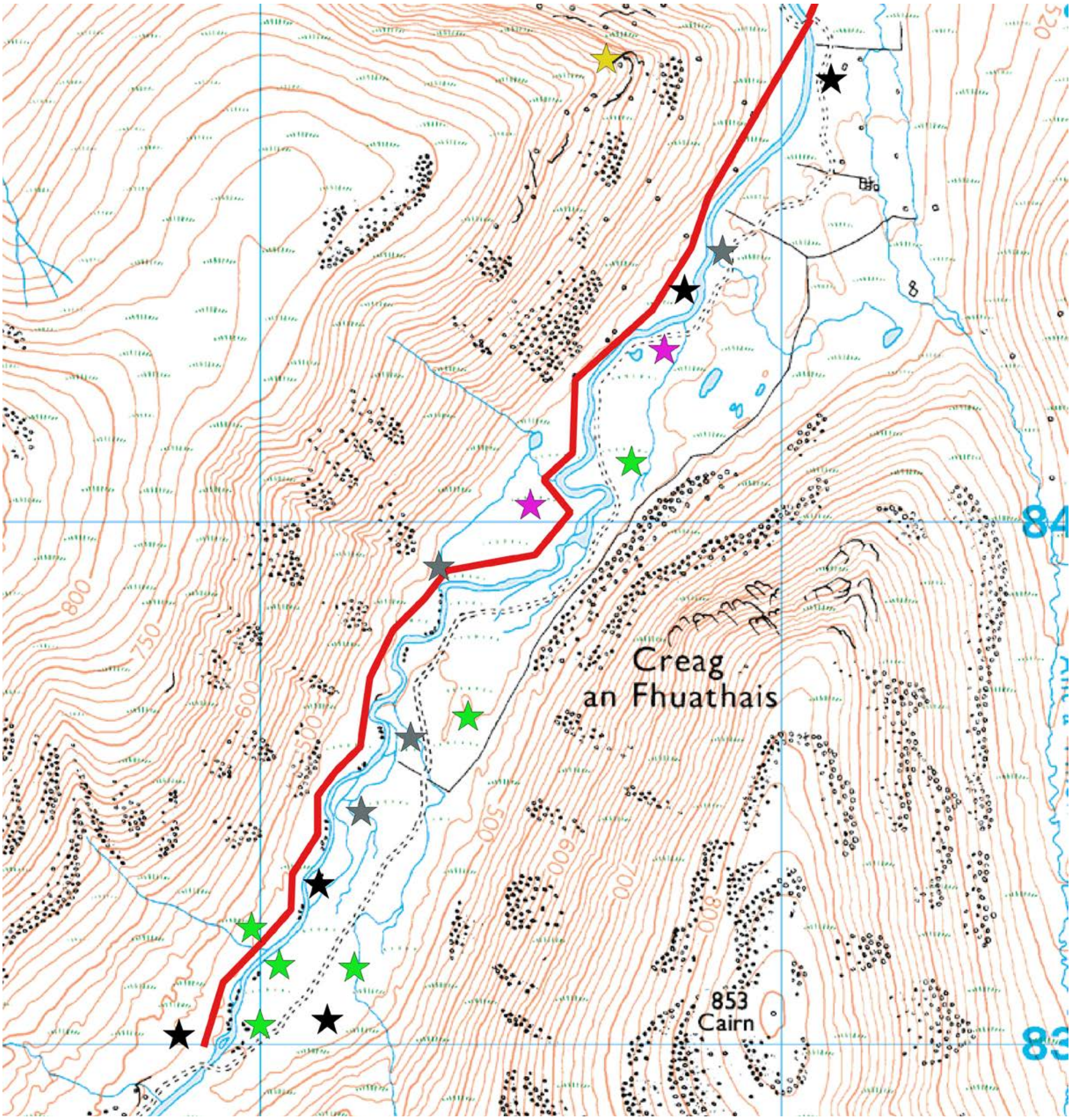


Figure 22: Mar – Glen Ey South





Images: Liz Cutting / Hugh Insley / Edmund Fellowes. Cover image: Liz Cutting

Investigating wader breeding productivity in the East Cairngorms Moorland Partnership Area using collaborative methods

Breeding wader populations in Britain have declined markedly in recent decades. During this time, areas of moorland managed for grouse shooting and adjacent areas of rough pasture have been identified as persisting strongholds. Targets for forest expansion across Scotland can deliver conservation gains for woodland biodiversity and other environmental benefits but in some areas could also potentially further constrain breeding waders. Land management planning in the Cairngorms National Park requires a balance between these and other competing objectives. Improved knowledge on the distribution, trends and breeding success of waders and the constraints they experience will help achieve a balance to the benefit of competing objectives.

This report describes two years (2018–19) of a project carried out collaboratively with the East Cairngorms Moorland Partnership (ECMP), which comprises six estates (Mar Lodge, Mar, Invercauld, Balmoral, Glenavon and Glenlivet) and the Cairngorms National Park Authority. The over-arching purpose of the partnership is to demonstrate a clear contribution to the aims of the Cairngorms National Park, including priority species conservation through sustainable moorland management. These estates contain a mix of farmland, woodland, moorland and montane habitat, with objectives including management for driven grouse shooting, deer stalking and woodland expansion. Predator control associated with management for grouse shooting is carried out across much of the partnership area.

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