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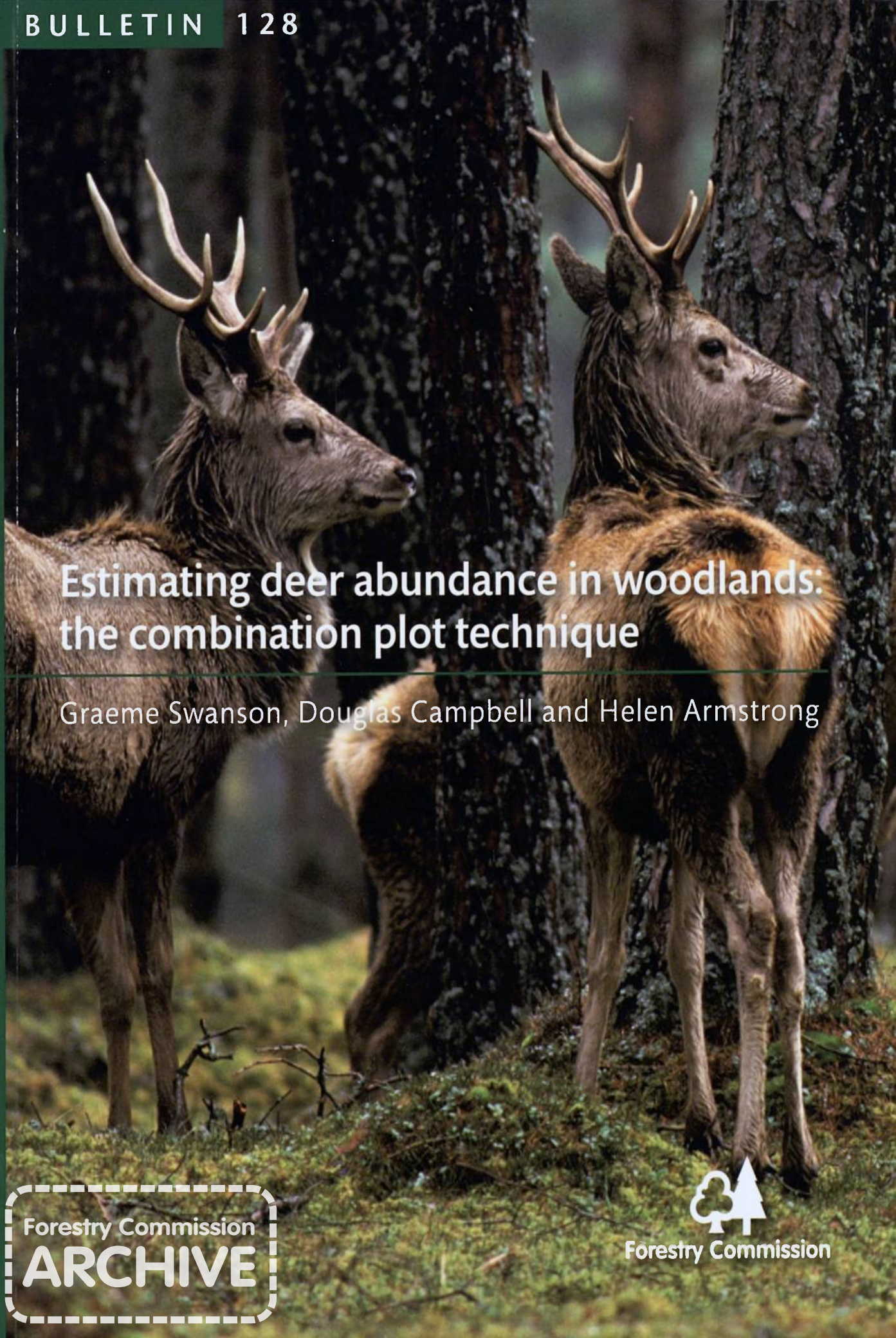

Estimating deer abundance in woodlands: the combination plot technique

Graeme Swanson, Douglas Campbell and Helen Armstrong

Forestry Commission

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Edinburgh: Forestry Commission

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First published in 2008 by Forestry Commission, 231 Corstorphine Road, Edinburgh EH12 7AT

ISBN 978-0-85538-750-1

Keywords: dung counting; deer density; forestry; sampling; monitoring.

Printed in the United Kingdom
FCBU128/FC(GB)/CLM/TP-750/MAR08

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Acknowledgements

The production of this Bulletin would not have been possible without the help of a number of people and organisations. Colin Legg, University of Edinburgh, contributed early ideas on the pros and cons of the various pellet group count methods. The past and present staff of Strath Caulaidh Ltd helped with data collection in very demanding circumstances. Forestry Commission Scotland staff supplied information on sites and helped with data collection on some sites. Jill Sales, Biomathematics and Statistics Scotland, Edinburgh, gave advice on Appendices 1, 3, 8, 12 and 13. Andy Peace, Forest Research, gave advice on Appendices 8, 9 and 13. Robin Gill and Brenda Mayle, Forest Research, commented on a final draft. Blackwell Publications gave permission to republish data first published in the Journal of Applied Ecology.

Contents

Preface

In 1998 the Forestry Commission contracted Strath Caulaidh Ltd to estimate deer abundance in a number of Scottish forests using a faecal pellet group count technique developed by Strath Caulaidh. Since then, the technique has been used on a large proportion of the land managed by Forestry Commission Scotland. This included upland and lowland conifer woodland, native woodland and open moorland.

As a result of its widespread application in Scotland, it was decided that key information on this faecal pellet group count technique should be made publicly available. To this end, Forestry Commission contracted Strath Caulaidh Ltd to write a bulletin describing the general background to faecal pellet group count methods, the essential details of the Strath Caulaidh Ltd technique and the technical justification behind it.

Although the general principles outlined in this Bulletin would apply to all types of site, the data used to justify various aspects of the method were mainly collected from conifer forests in Scotland. Therefore the conclusions made on the basis of these data may not always apply to other site types or locations.

Summary

Monitoring deer abundance, especially when combined with regular assessments of deer impacts, enables land managers to determine the effectiveness of control programmes. In woodlands, where tree cover normally makes visual counting impossible, faecal pellet group count methods can be used to estimate deer abundance. The 'combination plot' technique, employs aspects of both main faecal pellet group count methods normally used: the 'accumulation rate' and the 'standing crop'.

The area under study should ideally be stratified by habitat type before sampling, and sampling points located randomly within each stratum. The number of points allocated to each stratum is weighted according to the expected variance in pellet group number, where this can be estimated or measured beforehand. Use of one hundred sampling points is likely to result in a 95% confidence interval of ±20–35% around the final estimate of abundance.

Sampling at each point is undertaken by searching either side of the central line of a long, thin plot. Each pellet group found is marked and its distance to the line recorded. This information is used to determine whether the likelihood of a pellet group being detected is affected by its location in the plot. Two to four months later, the plots are revisited and the number of new pellet groups deposited is recorded. Losses of marked groups to decomposition between the first and second visits are also recorded. This indicates the likelihood of any pellet groups being deposited and then completely decomposed between visits. A key assumption of the accumulation rate method is that such 'intermediate decomposition' does not occur.

The total number of pellet groups deposited in the study area is calculated. Published values of defecation rate are then used to convert the data into an estimate of the average number of deer that used the study area during the time between visits to the plots. Assuming that deer movement in or out of the study area and deer mortality are insignificant during the study period, this value is also a measure of the abundance of deer living in the area. An adjustment can be made for deer culled during the study period.

The results of combination plot surveys are used as initial population estimates in models that predict changes in deer abundance over time. Repeat monitoring is used to provide statistically robust information on actual changes in abundance over time. Differences between predicted and measured abundance can indicate deer movement in or out of the study area.

The combination plot technique also supplies two sets of 'standing crop' data. If a study area is monitored several times, users may be able to derive a relationship between the accumulation rate and the standing crop of pellet groups. This may mean that only the standing crop method, which is less labour intensive, could be used in future surveys.

Resumen

Supervisar la abundancia de ciervos, especialmente cuando la tarea se combina con las valoraciones regulares del impacto de los ciervos, permite a los administradores de tierras determinar la eficacia de los programas de control. En los bosques, donde la cobertura forestal suele hacer imposible el recuento visual, pueden utilizarse métodos de recuento de densidad de grupos de heces para estimar la abundancia de ciervos. La técnica de 'unidad experimental combinada', emplea aspectos de los principales métodos de recuento de densidad de grupos de heces: la 'tasa de acumulación' y el 'censo'.

En condiciones ideales, el área objeto de estudio debería estar estratificada por tipo de hábitat antes del muestreo y los puntos de muestreo deberían estar situados aleatoriamente dentro de cada estrato. El número de puntos asignados a cada estrato se pondera de acuerdo con la varianza esperada en el número correspondiente a la densidad de heces, en aquellos casos en que esto se puede estimar o medir de antemano. El uso de uno de cada cien puntos de muestreo probablemente tenga como resultado un intervalo de confianza del 95% de ±20–35% en torno a la estimación final de la abundancia.

El muestreo en cada punto se lleva a cabo buscando a cada lado de la línea central de una unidad experimental larga y fina. Se marca cada grupo de heces encontrado y se registra su distancia hasta la línea. Esta información se utiliza para determinar si la probabilidad de detectar un grupo de heces se ve afectada por la localización de éste en la unidad experimental. Dos o cuatro meses después de visitan de nuevo las unidades experimentales y se registra el número de nuevos grupos de heces depositados. Se registran también las pérdidas de grupos marcados debido a la descomposición, entre la primera y la segunda visita. Esto indica la probabilidad de que cualquier grupo de heces depositado se descomponga después por completo entre dos visitas. Un supuesto clave del método de la tasa de acumulación es que dicha 'descomposición intermedia' no ocurre.

Se calcula el número total de grupos de heces depositados en el área de de estudio. Entonces se utilizan los valores publicados de tasa de defecación para convertir los datos en una estimación del número de ciervos que utilizaron el área objeto de estudio durante el tiempo transcurrido entre las visitas a las unidades experimentales. Suponiendo que el movimiento de ciervos que entran o salen del área objeto de estudio y la mortalidad de los ciervos son insignificantes durante el periodo de estudio, este valor es también una medida de la abundancia de ciervos que viven en el área. Es posible introducir un ajuste para los ciervos eliminados durante el periodo de estudio.

Los resultados de estudios de unidades experimentales combinadas se utilizan a modo de estimaciones iniciales de las poblaciones en modelos que predicen cambios en la abundancia de ciervos a lo largo del tiempo. Se utiliza la supervisión repetida para proporcionar información estadísticamente sólida sobre los cambios reales en cuanto a abundancia a lo largo del tiempo. Las diferencias entre la abundancia predicha y la abundancia medida pueden indicar un movimiento hacia fuera o hacia dentro del área objeto de estudio.

La técnica de unidad experimental combinada también proporciona dos conjuntos de datos de 'censo'. Si se supervisa en repetidas ocasiones un área de estudio, los usuarios tal vez puedan derivar una relación entre la tasa de acumulación y el censo de los grupos de heces. Esto puede significar que en futuros estudios sólo se utilice el método del censo, que requiere menos horas de trabajo.

Résumé

Le suivi de l'abondance des cervidés, notamment lorsque celui-ci est associé à des évaluations régulières de l'impact des cervidés, permet aux gestionnaires de territoire de déterminer l'efficacité des programmes de contrôle. Dans les zones boisées où le couvert forestier empêche en temps normal le comptage visuel, on peut utiliser des méthodes de comptage des groupes de fumées afin d'estimer l'abondance des cervidés. La technique des 'tracés combinés' utilise les aspects des principales méthodes de comptage des groupes de fumées normalement utilisées: le 'taux d'accumulation' et la 'population sur pied'.

La zone d'étude devrait être idéalement découpée en strates par type d'habitat avant l'échantillonnage et les points d'échantillonnage devraient être placés au hasard à l'intérieur de chaque strate. Le nombre de points attribués à chaque strate est pondéré selon la variance attendue dans le nombre de groupes de fumées où il peut être préalablement estimé ou mesuré. L'utilisation de 100 points d'échantillonnage est susceptible de donner un intervalle de confiance à 95% de ±20–35% autour de l'estimation finale de l'abondance.

On réalise l'échantillonnage à chaque point en faisant des recherches de chaque côté de la ligne médiane d'un tracé long et mince. On marque chaque groupe de fumées et on enregistre sa distance par rapport à la ligne. On utilise ces informations pour déterminer si la probabilité de détecter un groupe de fumées est affectée par son emplacement sur le tracé. Deux à quatre mois plus tard, on visite à nouveau les tracés et on enregistre le nombre de nouveaux groupes de fumées qui ont été déposés. On enregistre également les pertes des groupes marqués dues à la décomposition entre les première et seconde visites. Ceci indique la probabilité que tout groupe de fumées qui a été déposé s'est ensuite totalement décomposé entre les visites. Une hypothèse clé de la méthode du taux d'accumulation est que cette 'décomposition intermédiaire' ne se produit pas.

Le nombre total de groupes de fumées déposés dans la zone d'étude est calculé. Les valeurs publiées du taux de défécation sont ensuite utilisées pour convertir les données en une estimation du nombre moyen de cervidés qui ont fréquenté la zone d'étude entre les visites des tracés. En supposant que les mouvements des cervidés à l'intérieur ou en dehors de la zone d'étude et que la mortalité des cervidés ne sont pas significatifs durant la période d'étude, cette valeur représente également une mesure de l'abondance des cervidés vivant dans cette zone. On peut effectuer un ajustement pour les cervidés éliminés pendant la période d'étude.

Les résultats des études des tracés combinés sont utilisés comme estimations de la population initiale dans des modèles qui prédisent des changements de l'abondance des cervidés au fil du temps. On utilise une surveillance répétée pour fournir des informations statistiquement fiables sur les changements réels de l'abondance au fil du temps. Les différences entre l'abondance prédite et mesurée peuvent indiquer des mouvements des cervidés à l'intérieur ou en dehors de la zone d'étude.

La technique des tracés combinés fournit également deux ensembles de données de « population sur pied ». Si une zone d'étude est surveillée plusieurs fois, les utilisateurs peuvent être en mesure de déduire une relation entre le taux d'accumulation et la population sur pied des groupes de fumées. Ceci peut signifier que seule la méthode de la population sur pied, qui nécessite moins de travail, pourrait être utilisée lors d'études futures.

Zusammenfassung

Durch Wildbestandsmonitoring, insbesondere in Kombination mit einer regelmäßigen Bewertung der Wildschäden, können Landbewirtschafter die Wirksamkeit von Kontrollprogrammen bestimmen. In Wäldern, in denen der Baumbestand eine visuelle Zählung in der Regel verhindert, kann der Wildbestand durch die Zählung der Losungshaufen ermittelt werden. Eine Probeflächenmethode, die so genannte „Combination plot"-Methode, kombiniert Aspekte der beiden üblicherweise verwendeten Losungszählverfahren, bei denen entweder die Akkumulationsrate oder die Gesamtdichte der Losungen bestimmt wird.

Vor den Zählungen sollte das Untersuchungsgebiet idealerweise nach Habitattypen in Teilflächen unterteilt werden, auf denen die Stichprobenflächen zufällig verteilt sind. Die Anzahl der Stichprobenflächen auf jeder Teilfläche wird nach der erwarteten Varianz der Losungshaufenanzahl gewichtet, sofern diese im Voraus geschätzt oder gemessen werden kann. Bei 100 Stichprobenflächen ergibt sich bei der endgültigen Wildbestandsschätzung mit hoher Wahrscheinlichkeit ein 95%-Konfidenzintervall von ca. ±20–35%.

Die Zählung an den einzelnen Punkten erfolgt, indem beide Seiten entlang der Mittellinie einer langen, schmalen Probefläche abgesucht werden. Jeder gefundene Losungshaufen wird markiert, und sein Abstand zur Mittellinie wird festgehalten. Mit diesen Informationen soll festgestellt werden, ob die Wahrscheinlichkeit, dass ein Losungshaufen entdeckt wird, von seiner Lage auf der Probefläche abhängt. Zwei bis vier Monate später werden die Probeflächen erneut besucht. Dabei werden die Zahl der frischen Losungsgruppen sowie die Anzahl der markierten Gruppen notiert, die seit dem ersten Besuch vollständig zersetzt wurden. Dies gibt einen Hinweis auf die Wahrscheinlichkeit, dass Losungsgruppen zwischen zwei Besuchen ausgeschieden und vollkommen zersetzt werden. Eine Grundvoraussetzung für die Methode, die die Akkumulationsrate verwendet, ist, dass zwischen zwei Besuchen keine Zersetzung stattfindet.

Die Gesamtzahl der im Studiengebiet ausgeschiedenen Losungshaufen wird berechnet. Unter Verwendung veröffentlichter Defäkationsraten werden die Daten dann in eine Schätzung des durchschnittlichen Wildbestandes umgerechnet, der sich in der Zeit zwischen den beiden Besuchen im Untersuchungsgebiet aufgehalten hat. Unter der Annahme, dass Wildabwanderungen oder -zuwanderungen sowie Wildsterblichkeit während des Untersuchungszeitraums zu vernachlässigen sind, ist dieser Wert auch ein Maß für die Zahl der Wildtiere, die in dem Gebiet leben. Die Zahl kann korrigiert werden, wenn im Untersuchungszeitraum Tiere abgeschossen wurden.

Die Ergebnisse von Probeflächenuntersuchungen werden als anfängliche Populationsschätzung für Modelle verwendet, die Veränderungen des Wildbestands im zeitlichen Verkauf voraussagen. Die wiederholte Beobachtung dient dazu, statistisch sichere Informationen über aktuelle Veränderungen der Wildbestandszahlen im zeitlichen Verlauf zu erhalten. Unterschiede zwischen dem vorausgesagten und festgestellten Wildbestand können ein Hinweis darauf sein, dass Wildtiere in das Studiengebiet einwandern oder aus ihm abwandern.

Die „Combination plot"-Methode liefert auch zwei Datensätze über die Losungsdichte. Wenn ein Gebiet mehrmals untersucht wird, sind die Nutzer vielleicht in der Lage, einen Zusammenhang zwischen der Akkumulationsrate und der Losungsdichte abzuleiten. Dies könnte bedeuten, dass in späteren Beobachtungen nur die Losungsdichte bestimmt werden muss, was weniger arbeitsintensiv ist.

Crynodeb

Mae monitro niferoedd ceirw, yn enwedig pan wneir hyn ar y cyd ag asesiadau rheolaidd o effeithiau ceirw, yn galluogi rheolwyr tir i weld pa mor effeithiol yw'r rhaglenni rheoli. Mewn coetiroedd, lle mae'r gorchudd o goed yn ei gwneud yn amhosibl i gyfrif y ceirw, gellir defnyddio dulliau o gyfrif grwpiau o belenni ymgarthol i amcangyfrif niferoedd y ceirw. Mae'r dechneg 'llain gyfunol' yn gwneud defnydd o agweddau ar y prif ddulliau o gyfrif grwpiau o belenni ymgarthol a ddefnyddir fel rheol: 'y gyfradd gronni' a'r 'cnwd sefydlog'.

Dylai'r ardal a astudir gael ei haenu yn ôl y math o gynefin cyn mynd ati i gymryd samplau, a dylid dewis mannau samplu ar hap o fewn pob haen. Bydd nifer y mannau samplu a neilltuir i bob haen yn cael ei bwysoli yn unol â'r amrywiant disgwyliedig yn nifer y grwpiau pelenni, lle gellir amcangyfrif neu fesur hyn ymlaen llaw. Mae'n debyg y bydd defnyddio cant o fannau samplu yn rhoi cyfwng hyder o 95% o ±20-35% o gwmpas yr amcangyfrif terfynol o niferoedd.

Gwneir y gwaith samplu ym mhob man samplu drwy chwilio ar hyd pob ochr i linell ganolog llain hir, fain. Mae pob grŵp o belenni a ganfyddir yn cael ei farcio, a chofnodir y pellter o'r llinell. Defnyddir y wybodaeth hon i benderfynu a yw'r tebygolrwydd o ganfod grŵp o belenni yn dibynnu ar y lleoliad o fewn y llain. O fewn dau i bedwar mis yn ddiweddarach, ymwelir â'r lleiniau unwaith eto, a chofnodir y grwpiau newydd o belenni. Cofnodir hefyd a yw grwpiau a farciwyd wedi dadelfennu'n llwyr rhwng cyfnod yr ymweliad cyntaf a'r ail. Bydd hyn yn dangos y tebygolrwydd bod grwpiau o belenni wedi cael eu gollwng ac wedi dadelfennu rhwng yr ymweliadau. Un o brif dybiaethau'r dull 'cyfradd gronni' yw nad yw 'dadelfeniad rhyngol' yn digwydd rhwng ymweliadau.

Bydd cyfanswm y grwpiau o belenni yn ardal yr astudiaeth yn cael ei gyfrifo. Yna defnyddir gwerthoedd cyhoeddedig o gyfraddau ymgarthu i drosi'r data yn amcangyfrif o nifer cyfartalog y ceirw a ddefnyddiodd ardal yr astudiaeth yn ystod y cyfnod rhwng yr ymweliadau â'r lleiniau. Os cymerir nad yw symudiad y ceirw i mewn ac allan o'r ardal a astudir a chyfradd marwolaethau y ceirw yn arwyddocaol yn ystod y cyfnod astudio, mae'r gwerth hwn hefyd yn fesur o niferoedd y ceirw sy'n byw yn yr ardal. Gellir gwneud cymhwysiad ar gyfer nifer y ceirw a gaiff eu difa yn ystod cyfnod yr astudiaeth.

Defnyddir canlyniadau arolygon o leiniau cyfunol fel amcangyfrifon poblogaeth cychwynnol mewn modelau sy'n rhagfynegi newidiadau yn niferoedd ceirw dros amser. Defnyddir monitro ailadroddus i ddarparu gwybodaeth ystadegol gadarn am newidiadau gwirioneddol mewn niferoedd dros amser. Gall gwahaniaethau rhwng niferoedd a ragfynegir a niferoedd a fesurir ddangos symudiad ceirw i mewn ac allan o'r ardal a astudir.

Mae techneg y llain gyfunol hefyd yn rhoi dwy set o ddata 'cnwd sefydlog'. Os bydd yr ardal a astudir yn cael ei monitro sawl gwaith, mae'n bosibl y bydd y defnyddwyr yn gallu gweld perthynas rhwng y gyfradd gronni a'r cnwd sefydlog o grwpiau o belenni. Gall hyn olygu y gellir defnyddio'r dull cnwd sefydlog, sy'n golygu llai o waith, ar gyfer arolygon yn y dyfodol.

1

Introduction

Reasons for measuring deer abundance in woodlands

Deer of various species are now present in the majority of woodlands in the UK (Figure 1). As a result, there is considerable concern that browsing by deer on young tree shoots (Figure 2) and stripping of bark from established trees could lead to significant growth defects and consequent economic losses for the forest industry. Deer may also have a detrimental impact on the biodiversity and nature conservation value of woodlands by over-grazing sensitive plant species (Figure 3) and preventing establishment of trees by natural regeneration. Therefore, many woodland owners implement deer control programmes.

One of two approaches is usually employed to collect information required to formulate a deer control programme and monitor its success in achieving stated management objectives: reactive or predictive.

Reactive management involves shooting deer in response to the level of their grazing and browsing impacts. Using this approach the

Figure 1

Wild Fallow deer in woodland.

Figure 2

Deer browsing impact on a young Norway spruce tree.

Figure 3

Lightly-browsed heather (*Calluna vulgaris*) (left) and heavily-browsed heather (right) either side of a fence-line in the uplands.

manager monitors deer impact levels and increases or decreases culling effort until a pre-determined impact level is achieved. Although this approach appears simple and easy to apply, in practice it is rarely possible to react quickly enough to prevent unacceptable impacts from occurring.

In addition, if choosing not to collect information on deer numbers, the manager cannot reliably predict cull requirements; therefore, resources must be allocated 'blindly' to the culling program. This approach poses problems in newly planted and naturally regenerating woodlands since the major effect of browsing tends to occur early in the establishment phase. Trees respond to browsing of the leading shoot by producing multiple leaders. Sitka spruce, the main crop species planted in Scotland, has a low propensity to self-single once multiple leaders have appeared (Perks, Smith and McEvoy, 2005) so the effects of browsing could last throughout the rotation. Browsing can also slow down the growth of trees and could increase the length of the establishment phase. High levels of browsing impact during establishment might therefore result in substantial economic losses. Since it will normally take several years to substantially reduce a deer population, the reactive approach to deer management would not be the most suitable for these situations. More generally, inappropriately resourced culling programs can lead to increased costs caused by, for example, delays in achieving management objectives.

The predictive approach to woodland deer management firstly requires that the dynamics of the deer population are quantified. A model, parameterised using estimates of local deer abundance, deer recruitment rate and deer mortality rate, is created (e.g. Ratcliffe, 1987b; Ratcliffe and Mayle, 1992). Surveys of local levels of deer impact are also carried out. Where impacts are deemed unacceptable on the basis of initial surveys, the cull is set at a level to exceed deer recruitment and reduce deer abundance on the assumption that the level of impact will also be reduced. Where impacts are deemed acceptable, the cull is set to maintain a stable population. On-going monitoring of deer abundance and impacts, together with regular population modelling, helps the man-

ager to objectively determine whether the culling programme is effective in achieving the management objectives for the area. In the situation where trees have not yet been planted, the manager must estimate deer abundance then try to predict the level of impact likely to occur. The level of cull is then set according to whether the deer population has to be reduced or maintained at current levels.

The Forestry Commission advocates the predictive approach because it enables managers to:

- assess how long a deer control program is likely to take to achieve the desired level of abundance;
- forecast how much the control programme is likely to cost;
- demonstrate to stakeholders that deer are being managed rationally;
- develop a greater insight into the local relationship between deer abundance and deer impact. This may enable the manager to carry out predictive management more effectively in the future.

To employ the predictive approach to deer management, estimates of deer abundance are needed. This bulletin describes a technique for producing such estimates.

Reasons for using faecal pellet group counts

A wide variety of deer count methods have been developed over the years (see Buckland, 1992 or Mayle *et al.*, 1999 for useful summaries). Many managers count deer directly on foot, from vehicles or from aircraft since animals are perceived as being easy to count accurately by these methods. However, direct counts can prove unreliable for a number of reasons. Firstly, deer may be frightened away by the sight, sound or smell of the surveyor or their vehicle before they have been counted. Deer subject to culling tend to be wary of human presence. Secondly, deer are difficult to see in the dense cover present in woodland or scrub and this often leads to significant under-estimates of the number of animals present. Thirdly, deer can move in and out of the surveyor's view during a census and so can be double counted. The errors caused by these three factors are known to be difficult to quantify. Also, direct counts are usually applied on a single, short visit and thus provide only a 'snapshot' of deer abundance. Since deer can move in and out of an area, a method which estimates average abundance over a longer time period would be more useful.

An alternative approach is to estimate abundance indirectly from the density of faecal pellet groups (Figure 4) on the ground (hereafter referred to as pellet groups). The main benefit of pellet group counts over direct counts is that bias due to counting errors can be assessed and reduced to an acceptable level. Although the method is based on sampling, rather than a complete count, the sampling errors are quantifiable.

Whilst the pellet group count approach offers a more accurate means of assessing deer abundance in woodlands than direct counts, it is not as easily employed by deer managers: technical knowledge is needed to choose the most suitable pellet group counting technique, to design a sampling framework, to audit data quality, to analyse data and to interpret the results. Deer managers do not always have the time to develop this knowledge. This can result in pellet group counts being badly designed and applied, and the potential benefits not realised.

In this bulletin the technical aspects of pellet group count methods are discussed, a technique developed by Strath Caulaidh Ltd is described, and the choice of each main element of the technique is justified.

2

Background to the combination plot technique

How pellet group counts work

Deer defecate frequently and regularly. In winter, when the vegetation they eat contains low levels of moisture and high levels of fibre, they produce discrete groupings of individual, similarly shaped faecal pellets (Figure 4). In summer, when moisture contents are higher and fibre levels lower, the individual pellets fuse to form a coagulated group (Figure 5). These pellet groups remain on the ground until they decompose. The density of pellet groups present on the woodland floor at any time is a function of the number of deer present each day, the mean daily rate of pellet group deposition per deer, the number of days for which the pellet groups have been accumulating and the rate at which pellet groups decompose. In theory, therefore, if all of these variables are quantified, the number of deer present can be calculated.

Figure 4

A deer faecal pellet group defecated in winter when vegetation growth is negligible and moisture content is low.

Figure 5

A coagulated or fused faecal pellet group defecated in summer when vegetation is actively growing and moisture content is high.

Information obtainable from pellet group count data

The density of pellet groups present in an area is related to the average number of deer present over a specified period. Where the deer population being studied is enclosed and suffers no mortality over the study period, pellet group counts can be used to estimate the total number of deer present. Where one, or both, of these conditions is absent, the relationship between pellet group counts and deer abundance becomes more complex since the number of deer using the area will change during the time that pellet groups are accumulating. Therefore the term effective deer utilisation (EDU) is used to describe the measure of abundance obtained from pellet group counts. EDU is the number of deer that would have produced the number of pellet groups observed, had all the deer been present throughout the entire survey period. Where deer movement in or out of the survey area has occurred during the survey period, fewer or more deer may have been present at any one time.

Methods of pellet group counting

Two approaches to pellet group counting are commonly employed. The faecal standing crop (FSC) approach (McClanahan, 1985) involves counting the total number of pellet groups present on a single visit to sample plots. The mean count of FSC pellet groups on each plot is then converted into EDU using estimates of:

- the average age of the pellet groups present in the sample area. This depends on the rate of decomposition of the pellet groups;
- the mean rate of pellet group deposition per animal during the time that the pellet groups accumulated;
- the area of each sample plot relative to the total area under study. This is used to convert the average number of pellet groups per plot into an estimate of the total number of pellet groups present within the study area.

The faecal accumulation rate (FAR) approach (see Bailey and Putman, 1981; Neff, 1968) involves two visits to a set of permanent sample plots. The pellet groups are cleared on the first visit, and on the second visit, the number of new pellet groups that has accumulated is assessed. If the method is applied at a time of year when little decomposition occurs, no estimate of mean pellet group age is required, the assumption being that all pellet groups deposited during the accumulation period are present at the end. EDU is then calculated by dividing the mean daily rate of pellet group accumulation in the study area by the mean daily rate of pellet group deposition over the accumulation period.

There has been much debate over the relative merits of each technique, mostly relating to precision, bias and cost-effectiveness (Buckland, 1992; Campbell *et al.*, 2004; Laing *et al.*, 2003; Marques *et al.*, 2001; Mitchell and McCowan, 1980; Plumptre, 2000; Ratcliffe, 1984; Smart *et al.*, 2004). However, little empirical evidence exists to support most of the claims made in the scientific literature.

Many researchers suggest that the FSC approach is more cost-effective because it only requires a single visit to the sample plots whereas FAR requires two. Also, FSC-based counts are thought to provide more precise estimates of pellet group density than FAR because the sample variance decreases as average pellet group density increases. Since the accumulation period is longer in FSC counts, more pellet groups are found on average on each FSC plot than on each FAR plot.

However, the major drawback of the FSC approach is that the average age of pellet groups on the woodland floor must be assessed in a local trial in the period leading up to an FSC count (Laing *et al.*, 2003). Fresh pellet groups need to be identified in the field at regular intervals and an assessment made of the proportion of each age of pellet group still in existence at the time of the pellet group count. As pellet groups can last for considerably more than a year in some conditions, such trials need to begin at least a year before the FSC assessment is made (Laing *et al.*, 2003; Welch *et al.*, 1990). At least twelve visits to at least fifteen permanent plots may be required to obtain an estimate of average pellet group age with low bias and acceptable precision since decomposition rates are affected by a wide range of environmental factors that vary in time and space (Laing *et al.*, 2003). Assessing average pellet group age is thus labour-intensive and expensive. In some situations, the resulting need for long term planning may also constrain the use of the FSC method.

As a result of the complexity of pellet group ageing trials, they are rarely carried out with the necessary rigour (Laing *et al.*, 2003) and average pellet group age is usually guessed. This results in an unknown level of bias being present in the resulting EDU estimate. Clearly, most managers would wish to minimise bias if they are using EDU estimates to help model populations accurately and hence calculate appropriate levels of cull.

If a large number of pellet group ageing trials were to be carried out and these showed that the average age of pellet groups varied little between years and/or between sites, or could be otherwise reliably predicted, a pellet group ageing trial may not be required every time an FSC survey was carried out. The FSC approach could then become more cost-effective than the FAR approach. However, carrying out such ageing trials would involve a large amount of effort, have a long lead time and would be expensive.

Campbell *et al.* (2004) found that the FAR approach is at least as cost effective as the FSC approach in most Scottish conditions (Appendix 1). It will also be less prone to the unknown additional amount of bias that may be caused by having to assess average pellet group age.

The standard application of FAR methods requires that pellet groups are cleared off sample plots on the first visit and the number of new pellet groups is assessed on the second. Typically, dense tree cover, deep vegetation and scattered pellets can make the process of removing or destroying pellet groups time-consuming on the first visit. The handling of faeces also has associated health risks. Therefore a hybrid technique is recommended that involves marking the original pellet groups present on the first visit to plots and re-assess-

ing the status of all pellet groups present on the second. This technique, termed the 'combination plot' technique, can be used to assess both the rate of accumulation of new pellet groups and to find out if any of the initial pellet groups have decomposed before the second visit. If most of the original pellet groups that were freshly defecated (Figure 6) are still in existence (Figures 7 and 8) by the time of the second visit, it can be reasonably assumed that no pellet groups have appeared and then completely disappeared between visits[1]. If many of the original pellet groups have decomposed, the survey will be biased because an unknown number of pellet groups are likely to have been deposited and then completely decomposed before the second visit. Where this is the case it may be appropriate to use a shorter accumulation period and/or carry out the survey at a different time of year in future.

The combination technique also yields FSC counts from both visits. If sufficient surveys are carried out, these data could be used to look for relationships between FSC and FAR pellet group counts on particular sites. Eventually it may be possible to use such relationships to predict the FAR pellet group count from the FSC pellet group count so that only one FSC pellet group count would be required in the field.

For a comparison of the cost effectiveness of the FSC and FAR approaches, see Appendix 1.

Figure 6

A freshly-defecated pellet group.

Figure 7

A pellet group in the early stages of decomposition.

Figure 8

A pellet group in the latter stages of decomposition.

[1] This assumption may not always apply. Most studies in Scotland are carried out from early winter into early spring. It is thus possible that fresh pellet groups defecated in warmer spring conditions could decompose faster than fresh pellet groups present from earlier in the winter. This could result in pellet groups deposited later having decomposed whilst some deposited earlier being in existence still. Studies which finish after the beginning of vegetation growth are more likely to experience this.

Time of year to use the combination plot technique

The combination plot technique is most successfully applied when pellet groups are easily visible and at the least risk of decomposing. This minimises the risk of not finding pellet groups, and of pellet groups being deposited and completely decomposing between visits.

In upland areas in northern Britain, where the majority of the data have been gathered, it appears that the best time to carry out initial surveys is after a sequence of hard frosts has caused tall vegetation such as grasses and bracken to collapse. This makes searching easier. The onset of colder winter conditions in these areas also coincides with a rapid reduction in biological activity that minimises decomposition caused by invertebrates and soil microbes. The date of the first occurrence of suitable conditions varies according to year, geographical location and altitude. Experience of local weather patterns is therefore required.

In general, studies in upland conifer plantations in northern Scotland could normally be set up from early November onwards, whereas those in upland areas further south may need to start at the end of December. In southern and lowland woodlands in England and Wales, vegetation growth and decomposition rates may slow down rather than cease and frosts may never occur. In these conditions both FAR and FSC techniques might be more difficult to apply; local research will need to be undertaken if the methods are to be applied in milder conditions.

In general, the second survey should be completed prior to the start of vegetation growth in spring as, after this time, pellet groups become more difficult to find among the new vegetation and start to decompose faster. In the north of Britain this can be May or early June whereas, further south, it may be as early as February. The combination plot techniques have been successfully applied in upland areas of Wicklow in Eire[2] where the second visit was carried out during April.

For further information on return times to plots, see page 23.

Other factors which may constrain the application of the combination plot technique

In general, the combination plot technique can be applied to any area of land where deer exist providing there is a time of year when pellet groups can be found easily and pellet group decomposition rates are low. However, a number of other site factors can affect the reliability of the results and their likely effects should be considered when a survey is being planned. The main factors are:

- the presence of more than one deer species;
- the presence of other herbivores;
- deer emigration and immigration;
- dangerous terrain;
- other management operations.

The presence of more than one deer species

Roe deer (*Capreolus capreolus*) are present in most woodland in the UK (Ward, 2005). Red deer (*Cervus elaphus*) are widely distributed in forests in the north of Scotland but are only locally common in England and rare in Wales. Significant numbers of Sika deer (*Cervus nippon*) are now present in increasing numbers of

[2] Wicklow lies on a similar latitude to Chester (53° north) and has a more oceanic climate.

woodlands throughout Scotland whilst they remain relatively uncommon in England, and are rare in Wales (Ward, 2005). In England and Wales, however, fallow deer (*Dama dama*) are widely distributed whilst being localised in Scotland (Ward, 2005). Muntjac deer (*Muntiacus reevesi*) are present in increasingly large areas of England and Wales but are almost completely absent in Scotland. Chinese water deer (*Hydropotes inermis inermis*) occur very locally in England (Ward, 2005).

Managers, if possible, would usually prefer to obtain separate estimates of EDU for each deer species present in their woodlands. Whether this is possible or not depends on the combination of deer species present. This is because a surveyor must be able to identify which deer species has produced each pellet group found. Systematic errors in classification would produce a biased pellet group count for each target species. The final EDU estimate could therefore also be biased because a pellet group deposition rate appropriate to the wrong deer species could be applied to a proportion of the pellet groups counted (see page 27).

However, quantitative techniques can be used to help determine the likelihood of a particular pellet group belonging to a particular species or group of species. Deer faecal pellets are generally torpedo or bullet shaped cylinders. In general, the diameter across the shorter axis of each pellet increases with deer body size (Mitchell and McCowan, 1982). Therefore, larger deer generally produce larger diameter faecal pellets. Where different deer species are present, the manager can therefore use pellets collected from culled deer to develop rules, based on mean pellet diameter, which can help surveyors with field identification. However, the efficacy of these rules is affected by the range of body weights present in populations of each deer species in the sampled area. In some cases, pellets of a particular diameter could have originated from two or more species of deer if they are of similar body weight.

The diameters of faecal pellets obtained from the rectums of deer culled across Scotland have been measured. Based on typical populations comprising 20% calves and 80% adults, it was found that roe and red deer can, on average, be distinguished relatively reliably using a 10 mm 'cut-off rule' which is easy to apply in field conditions (Figure 9). This is because approximately 96% of roe deer pellets measured had widths of less than 10 mm whilst approximately 77% of red deer pellets had widths of 10 mm or greater. The uneven overlap occurs because pellets produced by red deer calves often had a diameter of less than 10 mm whilst relatively few adult roe deer had pellet diameters of 10 mm or more. However, the actual proportion of pellet groups mis-classified in any one survey depends on the relative abundance of each species present (Table 1).

Figure 9

Typical red deer faecal pellets (top left) compared with roe deer faecal pellets (bottom right) with a 10 mm-wide marker stick in place as a reference to size.

Table 1

The likely extent of errors present in pellet group count surveys using the recommended diameter categories for roe deer (mean diameter of <10 mm) and red deer (mean diameter of ≥10 mm) according to the true relative abundance of roe and red deer present in a study area.

True proportion of population that is roe deer	Estimated proportion of pellets counted < 10 mm that are red deer	Estimated proportion of pellets counted ≥10 mm that are roe deer
0.10	0.72	0.00
0.20	0.53	0.01
0.30	0.40	0.02
0.40	0.30	0.03
0.50	0.22	0.04
0.60	0.16	0.05
0.70	0.11	0.08
0.80	0.07	0.13
0.90	0.03	0.26

Note. The calculations assume that both populations comprise 20% calves and deer body weights are representative of typical Scottish woodland populations. Calculations assume deer defecation rates as recommended on page 27.

It should also be noted that these errors will vary slightly according to the age-class distribution of deer in each population and the range of body weights present. In practice, although both red and roe deer are both present in many Scottish forests, often one species is much more abundant than the other.

Whilst the true relative abundance of species is usually unknown, a useful estimate can sometimes be obtained from cull data. It is recommended that data are analysed in two ways to assess the degree of error that might be present. Firstly, data are analysed with no adjustment for error. Then, secondly, using an estimate of the relative abundance obtained from cull records, appropriate adjustments should be made to pellet group count data to produce an alternative estimate of EDU. Managers can use the findings to ascertain the extent to which errors in allocating pellet groups to deer species might affect the resultant EDU estimates.

However, managers should be aware that the effort applied in a cull can be heavily skewed towards one or other species depending on the management objectives. Managers are best placed to know how representative cull records are.

It is more difficult to distinguish between the pellet groups of Sika deer and those of roe or red deer as data suggest that there is a large overlap between the diameters of Sika and roe deer faecal pellets. There is also a smaller overlap with red deer faecal pellets because larger Sika deer can have pellet diameters of 10 mm or more. Whilst the data available on fallow deer is limited, it has been found that their faecal pellets tend to fall in a similar size range to those of roe and Sika deer. As a result, we recommend at present that where roe, Sika and /or fallow deer occur with red deer, faecal pellets of less than 10 mm in diameter are assumed to belong to one of the first three species and those of 10 mm or greater are assumed to belong to red deer. The limited data currently available for these species prevents any further guidance being given as to the extent of error that may be present under varying scenarios of relative abundance and age-class distribution.

For more information on estimating deer numbers in mixed species populations, see Appendix 2.

The presence of other herbivores

Varying combinations of deer, sheep, wild goat, rabbit and hare are found in many woodland areas. Therefore, successful application of combination plot techniques requires that surveyors can distinguish the pellet groups of deer from those of other herbivore species.

Rabbit and hare pellets can be reliably identified by their flattened or teardrop shape and more fibrous consistency compared to deer faecal pellets (Figure 10). If field surveyors receive the correct training, distinguishing deer faecal pellets from those of rabbit or hare therefore does not present a problem.

Figure 10

Roe deer (left), brown hare (middle) and rabbit (right) faecal pellets with a 10 mm-wide marker stick in place as a reference to size.

It is difficult to accurately differentiate between the pellet groups of the mid-sized deer species (roe, fallow, Sika) and those of sheep or goats. It is recommended to avoid sampling in areas with sheep or goats present if at all possible, because of the unknown level of bias that will result from mis-classification.

If it is necessary to carry out a survey, local staff may be able to indicate parts of the survey area that are used by the sheep or goats since these species are often 'hefted' to specific areas. This may help highlight areas where surveyors should be especially cautious about assuming that pellet groups have been produced by deer. Also, it is often possible to see where sheep have been in woodland and scrub due to a trail of wool on branches. Moreover, sheep tend to group together and surveyors may therefore see them during the course of the surveys. They can then note which plots are affected. Pellet groups found on plots in areas thought to be used by sheep or goats can be highlighted in the data as 'queries' and analyses carried out both with and without the suspect data. This involves using the same number of plots in each analysis, but, for the latter analysis, assuming that no deer pellet groups were found in plots located in areas where sheep or goats were thought to be present. This type of adjustment may underestimate the number of deer present.

Deer emigration and immigration

Variation in deer abundance due to deer movement in or out of the survey area during the dung accumulation period will cause the estimate of EDU to differ from the actual number of deer present in the area at any one time. However, it is not usually possible to adjust for deer movement since this cannot easily be measured. Pellet group count studies can therefore only produce a genuine abundance estimate in areas where deer movement is completely restricted. This is very rarely the case as very few deer fences are truly intact.

The degree to which the level of the EDU estimate and the number of live deer on the ground in transient populations agree is likely to improve as the size of the sampled area increases since the bigger the area, the more likely it is to encompass the whole range of the local deer population. Also, the FAR technique measures EDU over a shorter period of time than does the FSC technique and this may also help ensure that population size is stable during the survey. Physical obstacles, such as lochs, lochans and mountain ridges, can also form effective boundaries that act as complete barriers to movement during the sampling period. Areas

considered to encompass actual populations, as opposed to administrative deer management areas, are termed 'biological units'.

In practice, as the surveyed area increases in size the data obtained from a 'biological unit' will cease to be of direct use to the manager whose area of responsibility may only comprise a small part of the land sampled. Ideally, surveys in these conditions should therefore be set up to measure EDU at both the 'biological unit' scale (i.e. based on the population home range) and the deer management unit scale (i.e. based on ownership boundaries). This will provide an overall population estimate, as well as a measure of the relative use made by the deer of each management unit. The total cull can then be determined at the overall scale before being divided up between the management units on the basis of their contribution to overall EDU.

In situations where it is not possible to carry out a survey of a whole biological unit, managers can use EDU as an estimate of the average number of deer present over the time between survey visits. When setting cull levels, managers should be aware that it is possible that there may have been a larger, or smaller, number of deer present at any one time during the survey period.

Alternatively, managers can use EDU as a measure of deer occupancy in their area. In the context of protection, where deer may only spend part of their time on vulnerable sites, this measure of occupancy is very valuable as it is more likely to be related to the level of deer impact than is the actual number of deer present on any one day. In this situation, setting culling targets solely on the basis of EDU is unreliable. However, repeat measures of EDU can tell the manager how culling has affected deer pressure on the area over a period of time.

To read more about how deer movement can affect EDU estimates, see Appendix 3.

Dangerous terrain

The nature of the terrain in the study area can prevent work from being undertaken if there are dangerously rocky slopes, deep bogs or extensive areas of windblown trees. Clearly, bias will occur should the deer make use of areas that surveyors cannot access. This possibility should be considered prior to undertaking a survey. Where surveyors cannot access dangerous areas, one could assume that deer do not access the areas either. In the analysis of data, these plots would therefore be included as 'zero' counts. Clearly, the degree of bias this causes will depend on the proportion of sample plots that are inaccessible as well as the likelihood that deer can access sample plots whilst surveyors cannot.

Other management operations

Combination plot surveys can be affected by other management operations that occur in the study area. Difficulties occur when sample plots set up on the first visit are damaged by subsequent forestry operations and cannot be relocated on the second visit. Thinning operations may not completely destroy plots but may cover the ground in fresh branch material and make searching for pellet groups very time-consuming and difficult. Consideration should therefore be given to the likely extent of such practical problems prior to beginning a survey.

3

Survey design and interpretation of results

Introduction

Following the information given in Section 2 *Background to the combined plot technique*, a manager would be able to establish that:

- a pellet group count survey using the combination plot technique can provide the quality and type of information they require;
- their study area meets with the basic criteria for successful application of the technique.

The next stage is to define the objectives of the survey. Almost all managers use pellet group count techniques in order to:

- obtain a baseline measure of abundance in the study area by measuring pellet group accumulation rate then transforming the data into EDU;
- parameterise a deer population model with

Figure 11

Typical sampling conditions in a compartment of Sitka spruce in the Scottish uplands.

the estimate of initial population size (the baseline EDU);
- monitor EDU over time by re-measuring EDU every few years;
- test, and interpret, predictions of deer population size made by a deer population model by comparing them with measured EDU values.

The design of the baseline survey is central to the success of this process as the precision of the baseline survey affects the size of change in EDU that can be detected. It also determines, in part, the accuracy of the population model built to test and interpret predictions of abundance made with additional EDU estimates obtained at later dates.

Measuring pellet group accumulation rate

A number of questions need to be answered before the field survey can begin:

- How do we define a pellet group?
- What size and shape of plot do we use to sample the pellet groups?
- How do we distribute the plots in a study area?
- How many plots do we use?
- How long do we leave the plots between visits?
- What information do we gather in the field?
- How do we check that data are of suitable quality for analysis?
- How likely it is that pellet groups will appear and then completely decompose between survey visits?

Once these questions have been answered, a manager can estimate the precision of the pellet group accumulation rate and have confidence that the survey will be set up in such a way as to facilitate future monitoring. They can also estimate how long the survey will take and how much it is likely to cost.

Definition of a pellet group

Pellet groups can only be counted effectively if two conditions are satisfied:

- The pellets counted as a single group all originated from a single deposition event.
- The centre point of the counted group of pellets falls within the boundary of the sampled plot.

Although deer generally produce discrete pellet groups, there is variation in the number of pellets present in a group even before any decomposition has occurred. To be able to count them accurately, we therefore need to decide what constitutes a discrete pellet group at various stages of decomposition.

One study of red deer in the British uplands (Mitchell and McCowan, 1984) found that red deer produced between 30 and 200 pellets per deposition event in winter. Data collected in winter by Strath Caulaidh Ltd suggest that freshly defecated pellet groups[3] always contain more than 18 pellets per group for all species, with roe deer averaging 40 pellets in a group and red deer averaging 60. The maximum number of pellets in a group recorded by Strath

[3] To count the number of pellets in a pellet group, a 'group' first had to be defined. As deer were not observed defecating, a method of defining groups as individual depositions had to be developed. A single defecation event was therefore defined as a grouping of pellets found in the field whose pellets were all of similar size, shape and colour and still had mucous on the surface. This combination of characters was assumed to maximise the likelihood of the measured pellet group originating from a single, recent defecation event.

Caulaidh Ltd is around 200 for roe deer and around 300 for red deer, but groups of this size are very rare.

Where the individual pellets within a group are found to be intact, i.e. with no signs of an individual pellet losing its shape due to the onset of decomposition, it is recommended that surveyors only record a pellet group if it contains at least 18 pellets. If fewer pellets than this are found in a group then it is assumed that they do not represent a full defecation event. Ideally, this should be verified by a further search outwith the plot boundaries to find the remainder of the group.

Following the onset of decomposition the number of pellets in a group gradually reduces so it is necessary to choose a practical cut-off based on a number of pellets that can be assumed to have originated from a discrete deposition event. If pellets show signs of decomposition on the first visit to a plot, it is recommended that a group is defined as consisting of at least six visible pellet shapes. If fewer than six pellet shapes are visible, it is assumed that it has 'decomposed' beyond recognition and it is destroyed[4]. This avoids having to make a decision about whether to count it or not on the second visit. The consequence of this set of rules is that the time between visits should be set so that it is no longer than the time it takes for new groups to decay to less than six pellets in a group.

On the second visit to a site, new pellet groups (i.e. pellet groups that were not present at the time of the first visit) are sometimes found that show signs of advanced decomposition and that consist of fewer than six pellets. If they have one identifiable pellet present within the pile of decomposed remains, they are counted as 'possible' new groups. It is assumed that they were produced at some point between the two visits and have almost completely decomposed during that time. The analysis is then carried out separately using two sets of data; one including the 'possible' groups and one not including them. A manager might justifiably assume that the analysis including 'possible' groups is the more accurate. If the time between visits is such that some of the groups found on the first visit have decomposed completely by the time of the second, then an unknown amount of decomposition has taken place, the assumption of no decomposition becomes invalid, and an unknown level of bias is introduced.

It should also be noted that the individual pellets of a pellet group produced in late spring or summer can be fused together or coagulated (see page 5). As such, their morphology does not lend itself to the definitions given. Such coagulated pellet groups tend to appear as one mass so each should be counted as an individual group. Some may be found on the initial winter visit (as carry-overs from the previous summer) but the majority will be found as new pellet groups during second visits to plots sampled after the vegetation has started growing again.

For more information on the number of pellets in a pellet group, see Appendix 4.

Deer pellet groups vary not only in the number of pellets but also in the way they are distributed spatially. Within a group, the pellets can be clumped together in a small area (a 'pile'), scattered across the ground (a 'spread'), strung out in a line (a 'string') or fused together ('coagulated'). The majority of pellets within pile and spread groups, which are the most common types, are normally present

[4] Care should be taken in determining this. Often, heavy rainfall breaks down the surface of the pellet group and makes it appear as if there are no individual pellets remaining. However, inspection under the capped, surface layer often reveals that most of the pellets are, in fact, still entire underneath. These pellet groups should be counted.

within a small central pile with a minority being further away. Most pellets within a group usually appear well within a circle of 50 cm diameter. This helps surveyors to define discrete pellet groups.

For more information on the spread of pellets in a pellet group, see Appendix 5.

Having decided that the pellet group originated from a discrete event, the surveyor must then decide if the pellet group falls within the boundaries of the sampled area for the purposes of the count. With 'pile', 'spread' and 'coagulated' groups, the surveyor can quickly and objectively locate the centre of the pellet group. Then a decision can be made as to whether it falls within or outwith the boundary.

Whilst it is harder to determine the centre of a 'string', it is generally possible to follow the string of pellets and find the ends of the group. Then, its centre can be determined from the mid-point of the two furthest apart pellets and a weighting 'by eye' made for any bias caused by a disproportionately large amount of the pellets being present on one side of the mid-point.

A range of additional factors also help the surveyor to define and count discrete pellet groups in field conditions. Generally, only a small number of new pellet groups are found within sample plots of the size recommended (on average, the range is 1–10) and they rarely fall on top of, or in immediate proximity to, one another. The pellet groups present on a plot also have usually been deposited over a range of times and therefore look physically different to each other in terms of their state of decomposition. Moreover, the pellet groups on a plot usually originate from more than one species and/or size of deer making them look different from each other in most stages of decomposition.

However, surveyors must take care in defining the centre of pellet groups, as poor assessment may cause bias on the narrow plots recommended if pellet groups are systematically included or excluded erroneously (see page 19).

Size and shape of plots

Regardless of the habitat types and size of area sampled, it has been consistently found that individual pellet groups are never distributed evenly across the ground and tend to be aggregated, i.e. clumped. The result is wide variation in the number of pellet groups found per plot. This appears to be the case for the various sample plot sizes and shapes that have been trialled by Strath Caulaidh Ltd. These had lengths ranging from 50–150 m and widths ranging from 50–400 cm (see Appendices 6 and 7). The use of even larger plots may reduce the between plot variance but it is considered to be too difficult to sample larger plots accurately enough in all field conditions to establish whether this is true or not (see page 19). The high level of variation in pellet group count between plots generally results in precision being low, unless sampling is intensive. There is, however, a slight decrease in between-plot variance as the mean count of pellet groups per plot in a habitat increases.

In statistical terms, where a component of the aggregation occurs on a much larger scale than the size of potential sampling plots, a more precise estimate of variance is generally obtained by using many small plots rather than a smaller number of larger plots of equivalent total sampled area. However, there is a point at which the area of a sampled plot would become too small and most of the survey time would be spent marking, locating and travelling between plots rather than sampling them. Therefore, due consideration must be given to the best shape and size of sample plot to use.

It is recommended to use long, narrow plots because it has been found that it is easier and often takes considerably less time to lay out a

long, narrow plot than a square plot of equal size in a dense tree crop or in dense vegetation cover. This is because, for counting to be accurate, internal divisions need to be marked out within square plots. This is to allow surveyors to walk along the internal divisions searching a limited area between the lines. This is the most efficient way of searching an area for pellet groups. Without internal divisions, it is possible that the number of pellet groups will be mis-counted. Alternatively, several surveyors will be required to ensure that groups are not missed or double-counted. Laying out the plot and its internal divisions is a time-consuming task, particularly for a lone surveyor in habitats such as thicket-stage tree crops where branching is heavy.

Also, use of long, narrow plots may result in a lower variation in pellet group count between plots compared to square plots of equivalent area. This is because long plots are more likely to incorporate areas of both high and low pellet group density than square plots of the same area. The disadvantage of using long, narrow plots is that they have more edge than a square plot of the same area. They are therefore more prone to inducing bias due to edge error (the erroneous inclusion or exclusion of groups located at the edge of the plot). When sampling is carried out carefully, and strict rules for inclusion and exclusion applied, edge error can be minimised.

When choosing the length and width of plots to use, there are a number of other practical and statistical issues to consider. Most important, there is an upper limit to the dimensions that surveyors can search accurately and with confidence, because various combinations of close planted trees, dense branching, deep ground vegetation (Figure 12), poor weather and lower ambient light levels make sampling inherently difficult.

Figure 12

A surveyor searching for pellet groups in deep ground vegetation within a Scots pine forest.

It has been found to be impractical to use permanent plots of any more than around 150 m in length due to the time taken to set up and survey them. Plots of this size can sometimes have very large numbers of pellet groups present and so take a long time (2–3 hours) to search. This can result in surveyors becoming cold or mentally fatigued before completing the plot, losing concentration, and not finding all the pellet groups. It is suggested that no more than one hour should be spent searching a plot in cold or wet conditions. Ideally, considerably less time should be spent and it may therefore be necessary to work in pairs to reduce the time an individual spends on some plots.

Data gathered in early studies by Strath Caulaidh Ltd also showed that increasing the length of a sample plot from 50 m to 100 m or 150 m did not result in a consistent or large enough reduction in variation in pellet group count between plots to justify the effort involved. It is therefore recommended that plots are 75 m long in unplanted and scrub habitats

as well as in restock, thicket, pole-stage and mature broadleaf and conifer woodland (Table 2). In pre-thicket conifer woodland, 50 m long plots should be used due to the difficulty of laying out a line amongst the low-lying branches. In habitat types other than conifer pre-thicket it may be wise to choose a plot length of 50 m if the vegetation is consistently dominated by heather or grasses of roughly 40 cm or more in height (Figure 12). Searching for pellet groups in such conditions is mentally demanding so keeping the plots relatively short will help maintain high concentration levels during searches.

In the conditions studied, one skilled surveyor can set up and sample a plot of 50–75 m in an average of 30–45 minutes. Travelling time between plots varies greatly depending on the forest area and can add from no time (at roadside) up to one hour per plot per visit in typical Scottish conditions.

For supporting data from studies on plot length, see Appendix 6.

The likelihood of missing pellet groups on transects also increases as the width of the strip being searched increases. Therefore, the width of plot chosen for the FAR technique is important because it requires that no pellet groups are missed on the first visit. Otherwise, they could then be recorded as new groups on the second, leading to an over-estimate of EDU.

Using line transect techniques, where the distance to each pellet group was measured from a centre line on the sample plots, it was established that surveyors generally missed a significant proportion of pellet groups if strips either side of the line, when searched separately, were greater than 50–75 cm wide depending on habitat type. The proportion of missed groups also seemed to be greater for a given width of plot when the vegetation was taller.

Table 2

Recommended plots dimensions for different forest habitat types.

Habitat type	Description	Plot length (m)	Search width (each side of central line) (cm)	Overall plot width (cm)
Unplanted land	No trees planted.	75*	50	100
Felled	Mature trees felled. Not yet re-planted.	75	50	100
Re-stock	Area felled and re-planted with new trees. Tree height too low to provide cover for deer.	75	50	100
Pre-thicket	Tree height sufficient to provide cover for deer. Branches not yet interlocked.	50	50	100
Thicket	Branches interlocked with vegetation dying underneath canopy. Branches on trees right down to the ground.	75	75	150
Pole-stage	Branches dead on tree stem above 1 m in height; can walk through crop rather than crawl.	75	75	150
Mature	Trees now tall with most side branches dead to a height of well over 2 m; often thinned.	75*	75**	150
Native or retained woodlands including broadleaf	Deciduous or Scots pine woodlands with low disturbance.	75*	50	100

* Could be reduced to 50 m when searching in uniformly tall vegetation such as mature heather.

** Could be reduced to 50 cm when searching in uniformly tall vegetation.

It is therefore recommended that search strip widths of 75 cm are used in habitats with short or minimal vegetation (thicket, pole-stage, mature) and 50 cm in others where taller or denser vegetation predominates (re-stock, pre-thicket, unplanted, broadleaf). By delineating the plot using a single, central line, a strip of the appropriate width can be assessed on either side to create plots of 1 m or 1.5 m width that can be searched effectively. Recommended plot dimensions for different forest habitat types are given in Table 2 and these relate to the typical ground conditions found in managed conifer-dominated forests.

For supporting data from studies on plot width, see Appendix 7.

Distribution of plots over the study area

The way in which plots are distributed within the study area can have a significant effect on the precision of the estimate of pellet group accumulation rate. Whilst other complex methods can be used to devise the most suitable sampling approach, for simplicity, a conservative and practical sampling framework that gives unbiased estimates of pellet group count in most circumstances is recommended here.

Firstly, using knowledge of deer habitat preferences, or data from previous surveys, it is recommended that the forest is stratified into habitat types which deer are likely to use to different degrees (Figure 13). Each habitat type should be classified as of likely high or low deer usage (additional levels can be introduced if the information is available). Each of these strata of likely deer usage is then sampled separately. The number of sample plots needed in each stratum can then be determined. Random sampling of the whole area would result on average in the proportion of sample plots falling in each stratum being equal to the proportion of the total area made up of that stratum. Stratified sampling results in the variation in pellet group counts between plots in each stratum being less than it would be if there had been no stratification prior to sampling (see below). The separate estimates of the variation in pellet group counts for each stratum of likely deer usage are then combined. This approach produces a more precise overall estimate of the number of pellet groups accumulated over the whole survey area than if there had been no stratification.

Figure 13

A re-structured upland forest showing a typical range and distribution of habitat types.

Where no previous survey data are available, it is recommended that conifer forests are stratified into closed canopy areas (where most of the original ground vegetation has died) and open canopy areas (where ground vegetation is present i.e. on unplanted ground or under open canopy trees). As the faecal accumulation rate tends to be 1.5–5 times higher in open canopy habitats compared to closed canopy in conifer plantation woodland, this is usually an effective sub-division. The limited data available on broadleaf woodland does not allow any recommendations or guidance to be given. Of

course, further stratification may become possible after the first survey has been completed if the results indicate other habitat types, or areas, have high, or low, usage. This could be used to improve the stratification of subsequent re-surveys.

A further improvement in precision can be obtained by weighting sampling effort so that those strata likely to show the highest variation in pellet group number between plots are sampled more intensively than those likely to have a lower variation. Areas with higher deer usage also tend to have higher levels of absolute variation in pellet group count between plots so the higher the likely deer use of a stratum, the more intensively it should be sampled.

The recommended technique for weighting the sampling effort between strata is the 'Neyman allocation'. In this technique, the total number of plots available is divided amongst the strata in proportion to the expected variance[5] in mean plot pellet group count in each stratum and the area of each stratum. The result is that strata expected to have more variable pellet group counts have a higher sampling intensity per unit area than others. This approach can reduce the overall level of sampling error when compared to simple random sampling for a given amount of sampling effort.

Once the allocation of plots to habitat types has been decided, the locations of the plots should be marked on a map of 1:10 000 scale. The plots should be randomly-located and orientated in a pre-determined random direction to avoid biases caused by surveyors selecting their own plot start points or searching subconsciously for easier paths through the trees. As stratification necessitates that plots are restricted to their allotted stratum, when a plot falls across a stratum boundary it is re-directed away from the edge by returning to the plot start and running out the remaining length on the reverse bearing. In very tight spaces where the area to be sampled is small and this approach fails to enable the whole length to be run out, the remaining length can be run out at right angles to the start point. This approach could create bias if the spatial distribution of pellet groups differs between the edges and 'interior' of blocks of a particular stratum and if the length of the sample plot is very large relative to the dimensions of the block being sampled. However, in practice, blocks of a particular stratum are generally large (commonly 20–50 ha) and their dimensions (commonly 500–700 m across) are much larger than those of the 50–75 m long plots recommended here. On average, it has been found that less than 10% of plots will need to be re-directed in this way during a survey.

For supporting data on stratification of the survey area and weighting of sampling effort, see Appendix 8.

Number of plots

The number of plots used in a survey also has a direct effect on the precision of the result and, together with the size of the survey area and accessibility of the plots, largely determines the cost of the survey.

From the pellet group count data obtained from the survey, the mean pellet group density and the variance associated with that mean can be calculated. This allows the confidence interval associated with the mean to be calculated. The confidence interval shows the range of values between which the true value of pellet group density is likely to lie, for a given level of probability. Usually a 95% confidence

[5] The sample variance is a measure of the spread of the pellet group densities around the calculated mean. The larger the variance, the lower the precision of the result for a given sample size.

interval is calculated which gives, with 95% certainty, the lower and upper values between which the true mean lies. The smaller the variance and the confidence interval, the more precise is the estimate of pellet group density.

In general, sampling more plots results in improved precision. However, increasing sample size has a large initial benefit but, as more plots are added to the sample, the additional benefit becomes less. There thus becomes a point at which sampling additional plots results in an insignificant increase in precision. Since additional plots increase the expense of the survey, a compromise has to be found between increasing sample size to increase precision and reducing sample size to limit cost.

Areas with lower deer densities tend to produce results with larger confidence intervals, as a proportion of the mean pellet group density, than those with higher deer densities for the same number of plots. However, the confidence interval is likely to be smaller in absolute terms at lower deer densities.

If a baseline survey has poor precision i.e. a large 95% confidence interval, it will be more difficult to determine, from a subsequent survey, whether the EDU has gone up or down. In general, a higher precision is required to detect smaller changes. It is worthwhile ensuring that the initial survey is precise if the level of change that needs to be detected by subsequent surveys is not known. Subsequent surveys can be less precise if it is decided that it will be sufficient to be able to detect only a large change.

What this means in practice is that, typically, the 95% confidence intervals of EDU estimates obtained using 70 plots are ±25–50%. With 100 plots, confidence intervals of ±20–35% could be expected. However, it should be noted that very different levels of precision can be obtained for each of two deer species co-existing within the same forest where one is much less abundant than the other. For example, in a forest with 15 roe deer km^{-2} and 1 red deer km^{-2}, the confidence intervals for a 100 plot survey would typically be ±20% for roe deer and ±80% for red deer. However, it should be noted that this is a proportionate difference. The precision of the red deer estimate may be quite adequate since 80% of 1.0 is 0.8. This may suffice for planning purposes, especially if the objective is to get the deer below a target density.

Whilst this level of precision may appear poor, it is not atypical of most biological monitoring schemes. Most managers can accept confidence limits of this size because the EDU survey result is not the only measure used to determine the likelihood that deer abundance has changed. As well as EDU surveys, impact surveys, population modelling and changes in culling success with respect to effort are normally all used to inform decision-making.

If in doubt, seek professional advice on this issue. Errors at this stage that result in poor data will increase the likelihood of inappropriate management decisions being made.

For supporting data on the number of plots to sample, see Appendix 9.

Time between visits to plots

The number of days that combination plots are left out between visits is important for two main reasons:

- The longer that plots are left, the more pellet groups will accumulate on them. This tends to improve the relative precision of combination plot techniques compared to FSC techniques.
- If plots are left for too long, pellet groups start to decompose before they are counted on the return visit resulting in a biased estimate of accumulation rate.

Combination plot studies by Strath Caulaidh Ltd generally last for 60–100 days. However, deer densities vary greatly between forests. Also, local factors such as rate of vegetation growth, weather, altitude and soil type can all influence decomposition rate, and therefore, can affect the level of bias that occurs. The amount of time plots are left out therefore has to be a decision made locally and should, ideally, be evidence-based.

Areas with lower deer densities benefit from having a return time in the upper range to maximise pellet group accumulation. Areas prone to pellet group decomposition must be revisited before there is significant vegetation growth. Therefore, an area with low deer density in the south-west of Scotland could have plots laid out in early January and returned to in late March. A study in a forest with high deer density in north Scotland in Caithness could have plots laid out in mid-March and returned to in mid-May. In Caithness, the plots could be laid out earlier in the winter and, if this were done, would accumulate more pellet groups. But if deer density is high, plots left out even for a shorter time will accumulate enough pellet groups to obtain a precise estimate of EDU. There is less flexibility in potential surveying times in warmer regions where the return time may be determined solely by the time between the weather becoming suitable for surveying and the vegetation starting to grow.

For supporting data on the length of time to leave sample plots between visits, see Appendix 10.

Field data collection

Once the survey design is complete, fieldwork can start. The main tasks are as follows.

a) Mark the plot start locations on a 1:10000 scale map to aid accurate location in the field.
b) Create a list of the plots with their associated random bearings to ensure surveyors are objective when laying out plots.
c) Visit the first plot and lay out the appropriate length of line. This is most easily achieved using a thread distance measurer.
d) Mark the line with marker sticks (such as short bamboo canes) at regular intervals and small flags of marking tape (ideally placed at head height on trees).
e) Walk round the plot one side at a time close to the central line[6], recording any pellet groups with more than the minimum number of pellets and whose centres are within the plot.
f) Place a small wooden stick at the approximate centre of each marked pellet group.
g) Record the distance (in cm) from the central line to the marked centre of the group (for auditing purposes; see page 25).
h) Classify the pellet group according to deer species.
i) Assess, by eye, its state of decomposition:
   - fresh, mucous present;
   - surface of all pellets in the group is intact and smooth;
   - surface of one or more pellets in the group is rough and beginning to weather, i.e. decompose;
   - shape of up to 25% of pellets in the group is lost due to decomposition.
   - Shape of more than 25% of pellets in the group is lost due to decomposition;

[6] The method used to check data quality on plots (see paragraphs that follow; also Appendices 7 and 11) relies on all pellet groups immediately beside the line being found. Errors relating to an undercount of those further away from the line can be accounted for using various mathematical techniques. Whilst the plot widths recommended here should not suffer from this incomplete detection of groups within the sampled width, it is still advised that surveyors walk close to the central line and that data are checked for potential errors at the analysis stage.

k) Destroy, by removing or stamping on them, any pellet groups that have:
   - fewer than the minimum number of pellets;
   - are partly within the plot but whose centre is outside the plot;
   - are completely outside the plot.

l) Remove the line and leave the plot to accumulate new pellet groups.

m) Repeat steps d) to l) for each plot.

On the second visit to each plot:

n) Re-lay the thread line.

o) Count the number of new pellet groups.

p) Assess the decay status of all the original pellet groups.

q) Remove the thread but leave all other markers in place for future monitoring.

The proposed approach to plot layout can be modified where experience has shown that markers are likely to disappear between visits due to disturbance. Plots can be sub-divided into shorter segments (i.e. sub-sections) for the purposes of 'mapping' the locations of pellet groups marked on the first visit. To do this, the position of each pellet group on the first visit is mapped (e.g. in the third segment, 25 cm from the line). This mapped location can be used together with information on its species (e.g. roe), decay state (e.g. 1) and group type (e.g. pile) to help distinguish between old pellet groups, which have lost their markers between the first and second visit, and new pellet groups that have no marker. Unless sampling in areas with exceptionally high deer densities, the likelihood of an old group with a lost marker being confused with an unmarked new one is low. Generally considerably less than 1% of pellet groups found on the first visit lose their marker between visits.

Checking data quality

If a combination plot study is executed poorly the results might be compromised. To ensure that plots have been adequately prepared for the measurement of faecal accumulation rate on the second visit, it is recommended that an audit is carried out after the first visit. The critical factor is to assess whether any pellet groups present on the first visit were missed and left unmarked by surveyors. Another audit after the second visit can also be informative as, ultimately, the determining factor in calculating EDU is the accumulation rate of new pellet groups. Whilst auditing adds time to the sampling scheme, it is a useful way of maintaining motivation if surveyors are informed before the work starts that an audit may be carried out at any time.

Another level of quality checking can be introduced by analysing the distances of marked pellet groups recorded from the central line. This analysis can be carried out on data from both the first and second visits. If a frequency distribution of the distances of marked pellet groups from the central line is approximately flat then it can be assumed that the distance of a pellet group from the central line does not affect the likelihood that it will be found. Any 'tail-off' in frequency towards the edges may indicate that poorer search effort has been applied at the peripheries. If a consistent bias in pellet group count is thought to be present, it is possible to use statistical techniques to adjust the data. These vary in complexity from removing the portion of the data thought to be unreliable (termed 'cutting'), and analysing the data with a revised plot width, to distance sampling approaches (Buckland *et al*, 1993; Burnham *et al.*, 1985). However, these techniques should not need to be used normally because use of the strip widths recommended should ensure that

few, if any, pellet groups are missed by diligent surveyors.

Likelihood of pellet groups appearing and completely decomposing between survey visits

If any new pellet groups are deposited on sample plots after the first visit but decompose before the second visit, then 'intermediate decomposition' is considered to have occurred. If intermediate decomposition occurs, EDU will be underestimated since fewer pellet groups will be counted than were deposited during the time between visits. An estimation of the number of such pellet groups is therefore required. Ideally, sets of pellet groups would be marked in sequential weeks across the entire study area and monitored constantly in different habitats in case the rate of decomposition of fresh pellet groups changed during the time between visits. In fact, this type of trial is not normally carried out as most data gathered to date for northern and upland areas points to decomposition rates being negligible in the winter and early spring for freshly-deposited pellet groups. Also, most studies are completed before widespread vegetation growth begins and this usually coincides with decomposition rates increasing. However, it is recommended that data relating to the changes in decay state of original marked pellet groups is collected so that the assumption of no decomposition can be tested for the pellet groups present at the time of the first visit.

The analysis should focus on those pellet groups that were assessed as having absolutely no sign of decomposition on the first visit (decay state 1 and 2; see page 24) For each habitat type, the proportion of those pellet groups that have decomposed completely (i.e. no sign left) is calculated as a proportion of the total number that are initially counted. The percentage decomposed is a measure of the 'maximum' rate of intermediate decomposition for that cohort of pellet groups. If some decomposition has occurred EDU could be adjusted upwards by a factor that compensates for the scale of the losses measured. However, this type of adjustment cannot be guaranteed to be unbiased.

Assuming that the rate of decomposition does not increase towards the end of the survey period, the rate of intermediate decomposition is likely to be considerably lower than the rate of decomposition of pellets that were fresh on the first visit since each successive cohort of newly deposited pellet groups will have had less and less time to decompose as the survey nears the time of the second visit.

The decomposition information can also inform managers of the most appropriate time of year to carry out subsequent surveys. Where studies are started in early spring, and would thus finish in late spring or early summer, it is advised that the time between visits be kept short enough that intermediate decomposition is unlikely to occur since it is better to accept slightly worse precision than to have biased EDU estimates.

For supporting data on the occurrence of intermediate decomposition, see Appendix 11.

Calculating the pellet group accumulation rate

Before EDU can be estimated, the total number of pellet groups that have accumulated in the study area during the survey period has to be estimated. Firstly, for each stratum, the mean number of new pellet groups per plot that has accumulated is calculated. If cutting, or distance sampling analysis, has been carried out, an adjustment to the plot area will need to be

made as the plot widths will effectively have been reduced. Then, the mean count per plot is 'scaled up' to the stratum level using knowledge of the proportion of the total area of the stratum that was sampled. Stratum estimates are then summed to provide an estimate of the total number of pellet groups that has accumulated in the entire survey area. Precision can then be calculated using standard statistical equations.

For the equations needed to analyse data and other supporting information on data analysis, see Appendix 12.

Transforming pellet group count data into effective deer utilisation (EDU)

The next stage is to transform pellet group count data into a measure of Effective Deer Utilisation (EDU). To do this the following has to be established:

- Which rate of pellet group deposition to use.
- How to carry out the EDU calculation.
- How much the EDU estimate might have been affected by deer being culled during the survey period.

The pellet group deposition rate to be used

Measuring the pellet group deposition rate of wild deer is notoriously difficult. To date, the most commonly used method in the UK involves the application of pellet group count methods to small, enclosed deer populations of known size. However, the pellet group technique is itself prone to the many practical difficulties already described. There are also very few suitable study sites where populations of wild deer of known size exist in undisturbed, natural conditions. Therefore, only a few studies involving small numbers of deer at a small number of sites, have been carried out in the UK (Mitchell and McCowan, 1984; Mitchell *et al.*, 1985). Managers should therefore be aware of the significant potential for bias in the EDU estimates that can be introduced by the use of these published measures of pellet group deposition rates.

There is a general consensus that several factors can affect the mean deposition rate of a population of deer. These include time of year, gender ratio, age structure and forage type (Mitchell and McCowan, 1984; Mitchell *et al.*, 1985). These factors should be taken into account when deciding on the deposition rate to use. However, until more research is undertaken in this area it is recommended that the currently published rates are used (Mitchell and McCowan, 1984; Mitchell *et al.*, 1985). These studies estimated the mean over-winter deposition rate (± the standard error) for roe deer and red deer in upland conditions in Scotland to be 16.5 (±2.9) and 20.0 (±4.0)[7] pellet groups per day respectively. Currently, it is recommended that the roe deer rate is also used for Sika and fallow deer in these areas. It should be noted that the sampling error associated with these estimates of deposition rate should be incorporated into the calculation of the precision of the EDU estimate, (Appendix 1).

[7] The original research for red deer quantified their deposition rate on three sites. Whilst the mean over-winter deposition rate (20) quoted in the research was calculated from the combined results from the three sites, the associated standard error of the combined estimate was not presented. However, the coefficient of variation of the individual estimates ranged from 10–15%. To be conservative, the standard error of the combined defecation rate for red deer was estimated to be 4.0.

How EDU is calculated

Once an estimate of the total number of pellet groups in the overall study area is obtained, this value is divided by the average number of days between visits to each plot (i.e. the 'return time'). This provides a measure of daily accumulation rate (pellet groups per day deposited over the whole study area). Then the measured rate is divided by the estimate of deer deposition rate (see page 27) to work out how many deer, on average, must have been in the area to produce that number of pellet groups each day.

The effect of culling on the EDU estimate

Where deer are being culled during the faecal accumulation period, the number of deer using the survey area will decline during this time assuming that no movement occurs. Thus, the number of deer remaining by the time of the second survey visit will be less than the average number that is estimated by the EDU figure. To avoid this happening, the number of pellet groups attributed to culled deer (termed 'ghost groups') must be estimated and the final EDU adjusted accordingly. However this can only be done if accurate cull records are kept of when each deer was shot in the survey area. In addition it has to be assumed that all the deer culled in the survey area have been resident there from the time of the first survey visit until the day they were culled. Estimates of numbers of deer killed by other means than culling could be added to the cull numbers if deemed appropriate.

Culling generally causes an over-estimate of EDU at the end of the accumulation period of between 1–14% depending on the intensity of culling in the block. The timing of the survey affects this since deer culling in most woodlands tends to peak between November and February and decline during April and May. Where deer movement and culling have both occurred during the time between survey visits, the relationship between EDU and actual deer numbers is complex and site-specific. In these circumstances, cull adjustments should be applied with caution.

For the data and equations supporting the cull adjustments, see Appendix 13.

Monitoring changes in EDU

Most managers intend to repeat EDU surveys to assess the size and direction of any change that might have occurred between two points in time. A number of additional issues then have to be considered. Firstly, great care must be taken to ensure that all stages of the baseline survey are carried out appropriately. Where major bias has occurred due to surveyor error, it will prove very difficult to assess whether any subsequent changes are real or not. Secondly, the EDU survey should, ideally, be repeated at the same time of year as the baseline survey. This helps to ensure that any change in EDU between years is not masked by seasonal variations.

The most useful approach to monitoring is to return to the same plots as were marked out on the first survey. This enables changes in pellet group count to be detected with a smaller sample size. In essence, it becomes possible to look at the average change in pellet group count at the plot level rather than looking at the change in the average pellet group count across all plots. This is termed 'a paired plot' approach (see Sokal and Rolf, 1995, for discussion of this topic). Alternatively, two EDU estimates can be calculated separately without carrying out a comparison at the individual plot level. In this case, a larger sample size is likely to be needed to detect a given change than

would be the case if the same plots were used for both surveys.

If using permanent plots, initial plot location must be described accurately to enable subsequent relocation to be successful. However, changes may have occurred in the forest since the initial survey was undertaken. Firstly, the trees in some of the plots that were initially in closed canopy habitat types may have been felled, turning the area into an open canopy habitat type. Secondly, some open canopy habitat types, and particularly pre-thicket, may have developed a closed canopy. Since the relative area of closed and open canopy habitat types generally affects sampling strategy, problems can occur at the analysis stage if this has happened.

Re-survey of these plots and analysis of the data using their original stratum classification is recommended. This is because the levels of change seen in forests as a whole are normally small over the likely time between surveys (3–5 years). Not re-classifying these plots simply leads to a possible increase in sample variation and a reduction in precision. If changes are extremely marked across large areas (e.g. a whole forest closes canopy), the same plots can be used but the plots should be re-assigned to another stratum. Prior to the first re-survey, an 'add-on' design should also be created to facilitate a new baseline survey being undertaken at the same time as the re-survey. This simply involves re-calculating the allocation of plots for the new habitat sub-divisions. Old plots are retained if they fit in with the new design. Any new plots required for the baseline are simply added on to the old design. When the new baseline survey is re-monitored (i.e. when the site is being re-surveyed for the second time), plots from the first baseline survey that have been discarded are left unvisited.

This approach means that there are then two different results for the second survey – one with the original plots and one with the new plots. These two second visit estimates of EDU should not be statistically significantly different from each other if the sampling has been carried out correctly.

Occasionally, it may not be possible to re-find a plot. In these circumstances, locating a replacement plot as close as possible to the location of the old plot is recommended. With the use of a global positioning system (GPS) to record the exact location of plots, or nearest point if in a closed canopy tree crop, this should not present any problems. At the analysis stage, it can then be decided whether to treat these plots in the same manner as successfully relocated fixed plots. This is advised only if the GPS point has been exactly re-located and no sign of the original plot was found. If some plots are not re-located, a paired plot analysis of data from only those plots that were successfully re-located could still be undertaken.

Modelling population trends using EDU data

A further step in the process of predictive management is to build a population model that can be used to help predict the effect of different cull scenarios on the deer population. For a basic model[8] it is necessary to estimate:

- initial population size;
- recruitment rates: the number of new young that survive from birth to the end of their first year (incorporating natural mortality);
- natural adult mortality rates i.e. not due to culling;

[8] The use of a simple spreadsheet model is advised. Advice on building and using models and examples can be obtained from the authors – see page (ii) for contact details.

- population gender ratios: the ratio of males to females in the population;
- population age structure: the proportions of juvenile and adult deer of each gender.

The first stage is to prepare the EDU data for modelling. Once the data are adjusted for culls and any intermediate decomposition, the EDU figure then relates to the end point of the survey. For most surveys, this date will be in February, March or April. However, cull records are normally grouped by the culling season, which runs from 1 April of one year to 31 March of the next year. Population models are usually designed to predict the deer population at the start of the culling season in each year. To synchronise EDU data with the model, an adjustment should be made so that the EDU estimate applies to the 1 April. For surveys completed later than 31 March, the number of deer culled between that date and the date of the second survey visit should be added to the EDU estimate; for surveys completed prior to 31 March, the number of deer culled between the date of the second survey visit and 31 March should be subtracted from the EDU estimate.

The population model will then require estimates of recruitment and mortality rate to predict how the population will change over time. See Ratcliffe (1987b) and Ratcliffe and Mayle (1992) for a discussion of recruitment and natural mortality rates in UK red and roe deer respectively.

Once the model is ready, the initial deer population is set to the adjusted EDU estimate and the model is used to compare the effect of different culling rates on future deer populations. The model may be run with a range of input EDU values to investigate the effect of errors in these values. Ideally, these runs should be displayed on a single figure to clearly show the impact of errors on the trends in the predictions made. The upper and lower limits of the 95% confidence interval of EDU are useful values to use for this.

Where reliable historical cull data are available, it is also possible to reconstruct the population at a previous time. The manager may wish to do this to assess historical changes in the population. However, this process, as with the forward modelling, relies heavily on assuming that the population has been effectively closed over this time. It also relies on an assumption of no natural mortality. This is a reasonable assumption to make for heavily culled woodland populations in northern and upland areas of Britain where the rate of natural mortality is considered to be extremely low (Ratcliffe, 1987b; Ratcliffe and Mayle, 1992).

Interpreting changes in EDU: modelled versus measured

One of the most informative uses of EDU data is to compare changes in EDU with changes in deer numbers predicted by a population model. A population model is used to forecast the expected level of EDU on a particular date in the future using the initial measured EDU and information on the culls taken in the period between the baseline, and subsequent EDU measurement. The second measure of EDU is then compared with the predicted value.

In most cases, it has been found that measured and modelled deer population sizes agree fairly closely. However, some forests show steeply declining populations based on modelled outcomes but no detectable change in EDU between the first and second surveys. This implies that a net movement of deer into the study area is occurring. The converse has also been detected. The discrepancies between ex-

pected and modelled outcomes need to be fairly large, however, for the manager to be sure that differences between measured and predicted deer numbers are due to deer movement and not merely to sampling error associated with the estimate of the initial population size. However, the measure of EDU will have a confidence interval associated with it so the manager should have confidence that any difference is real if the predicted population size lies outside this interval. However, there is also an error on the predicted population size since the inputs to the model are not error free. One way of investigating the effect of this is to run the model with a range of different possible inputs.

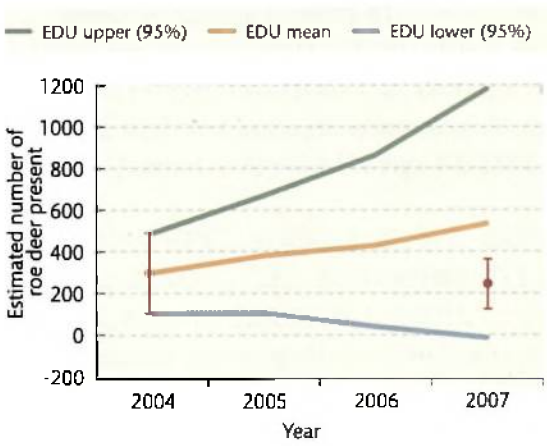
In most cases it will take at least 2–3 years, even at maximum rates of increase without culling or decline under heavy culling, before any change in EDU will be large enough for the manager to be reasonably sure that any discrepancy with the predicted population size is 'real'. The same applies to the certainty with which any change in EDU can be detected. Because the confidence interval associated with an EDU estimate is usually fairly large (see page 23), a large change in EDU is needed for the difference between EDU measures to be statistically significant and for the manager to be sure that it is a 'real' change (Figure 14).

Figure 14

Examples of comparisons of measured and predicted deer numbers for roe deer (a) and red deer (b).

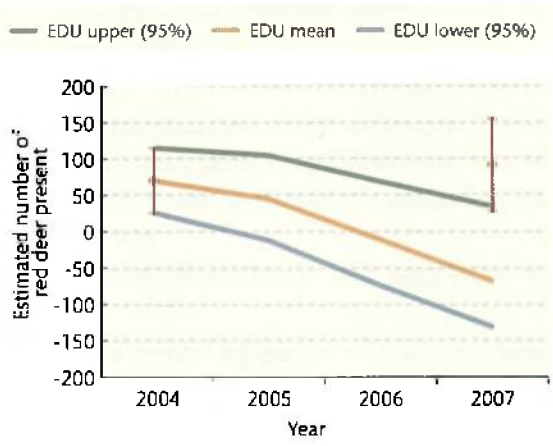
a. The final measured number is lower than the final predicted number but well within the number predicted using the upper and lower 95% confidence limits of the initial number of deer. It could be assumed that immigration had not occurred.

b. The final measured number is considerably higher than the number predicted using the upper 95% confidence limit of the initial number of deer. It could be assumed that the difference was due to immigration.



Roe deer population model run over four years using three input values of EDU obtained in 2004–5: the mean, the lower 95% CL of EDU and the upper 95% of EDU.

Red lines: the mean value of EDU obtained during surveys in 2004–5 and 2006–7 along with the 95% CLs.



Red deer population model run over four years using three input values of EDU obtained in 2004–5: the mean, the lower 95% CL of EDU and the upper 95% of EDU.

Red lines: the mean value of EDU obtained during surveys in 2004–5 and 2006–7 along with the 95% CLs.

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Appendices

Introduction to appendices

These appendices are designed to provide the interested reader with a technical justification based on empirical evidence presented for each of the main recommendations made in the body of the text. Each appendix describes the purpose of the analysis presented, the source of the data, the calculations carried out and the results obtained.

The majority of analyses described in the appendices are based on the data set described in Campbell, *et al.* (2004). However, some notes use unpublished data gathered by Strath Caulaidh Ltd. Additional background to this is provided where necessary.

It should be recognised that the data presented in the appendices were gathered during routine monitoring operations for the Forestry Commission. As a result, some sections have more extensive data sets than others. Their general applicability to geographical areas outwith those studied is unknown. However, it is planned to continue monitoring Forestry Commission sites using these methods and updates to this set of appendices will be produced as further data are obtained. It is also hoped that the methods will be applied more widely elsewhere in the future and this will also help to test the wider applicability of the conclusions to date.

Appendix 1: Choosing between the FAR and FSC approach

In choosing between the FSC and FAR approach to measuring pellet group density, differences in their cost-effectiveness, bias and precision should be considered.

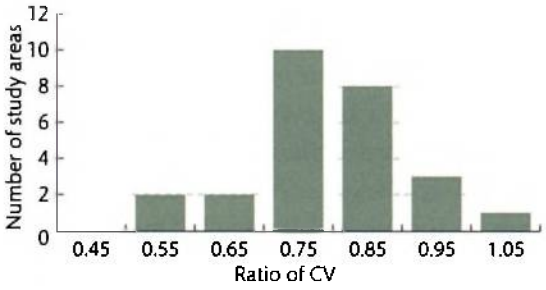
Campbell *et al.* (2004) describe 26 pellet group count surveys carried out between 1999 and 2003 in a wide range of forests in upland

Scotland. In each area, combination plot techniques were used to gather FSC and FAR count data in equivalent conditions. The data were used to compare the relative precision and estimate the relative cost-effectiveness of the count techniques in terms of the overall precision of their EDU estimates. The relative potential for bias was not investigated. FSC count data from the second visit were used in the analysis in preference to those from the first as most FSC studies are carried out in late spring when the majority of the 26 studies ended.

The ratio of the coefficients of variation (CV) of FSC counts to those of FAR counts was used to quantify relative count precision (see Appendix 12 for equations used to calculate the sampling error associated with FSC and FAR count data). The CVs of the FAR pellet group count data ranged from 11% to 29%. The CV count ratios (CV_{FSC}/CV_{FAR}) ranged from 0.57 to 1.04 with 70% falling in the range 0.7–0.9 (Figure A1).

Figure A1

Frequency distribution showing the ratio of coefficients of variation (CV) of pellet group count estimates (CV_{FSC}/CV_{FAR} obtained using FSC and FAR count techniques applied in equivalent conditions on each of 26 study areas). The values on the x axis indicate the mid-points of each range.



The overall error of the estimate of EDU obtained using either the FAR or FSC approach, as measured by the coefficient of variation (CV_{EDU}), is made up of three components. These are: the error due to estimating pellet group deposition rate ($CV_{deposition}$); error due to sampling pellet groups (CV_{count}); and error due to estimating the amount of pellet group decomposition during the dung accumulation period ($CV_{decomposition}$; Equation 1). The CV of the deposition rate ($CV_{deposition}$) is common to both techniques and is not considered further.

Equation 1

$$CV_{EDU} = \sqrt{CV^2_{deposition} + CV^2_{count} + CV^2_{decomposition}}$$

We assume that $CV_{decomposition}$ is zero for the estimate of EDU made using the FAR approach. However, an estimate of $CV_{decomposition}$ is needed for the FSC approach. For the precision of FSC-based and FAR-based estimates of EDU to have been comparable, the estimate of decomposition rate used in the FSC calculations would have required a CV of between 5 and 20% (Figure A2). A number of studies report this to be possible (Laing *et al.*, 2003; Marques *et al.*, 2001).

On average, FSC count data took 80 minutes per plot to obtain and analyse whereas FAR data took 1.6–1.9 times longer (Campbell *et al.*, 2004). This includes all time for processing data and returning to plots for FAR data. As a minimum of 15 plots are recommended for a decomposition trial (Laing *et al.*, 2003) the time needed to obtain the necessary level of precision is generally greater than the time saved by using FSC rather than FAR pellet group counting techniques (Figures A3 and A4).

In conclusion, FSC techniques appear to be generally less cost-effective than FAR techniques for a given level of precision in the upland conifer forests studied. As FAR techniques are also thought to have less potential for bias (Buckland, 1992; Ratcliffe, 1987a; Webbon *et al.*, 2004), it is currently recommended that FAR techniques are used in preference to FSC techniques.

Figure A2

The minimum level of precision (maximum CV) that would be needed from a decomposition rate trial for FSC count data to result in EDU estimates with a comparable level of overall precision to those obtained from FAR data. This assumes that both techniques are carried out under comparable conditions and that equal numbers of plots are used in both FAR and FSC studies. Results are shown for three values of CV ratio that lie at the top, bottom and mid-point of a range of values in which 70% of the 26 CV ratio estimates fell.

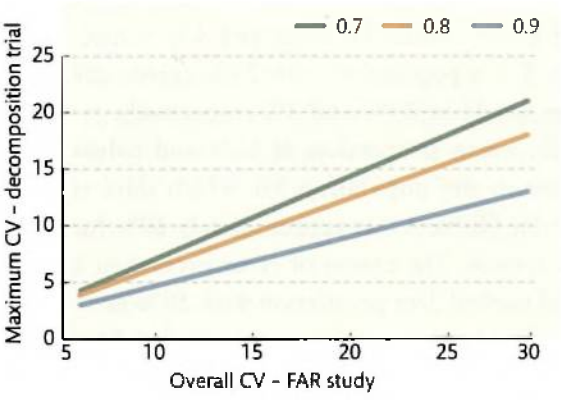


Figure A3

The maximum numbers of days that are available to carry out decomposition trials in a study area assuming equal numbers of plots are used for both FSC and FAR surveys. The results shown are for three different values of the ratio of the time needed to collect FAR pellet group data to the time needed to collect FSC pellet group data. To estimate the total time needed for the application of FSC and FAR techniques in a study area, data were used from Campbell *et al.* (2004).

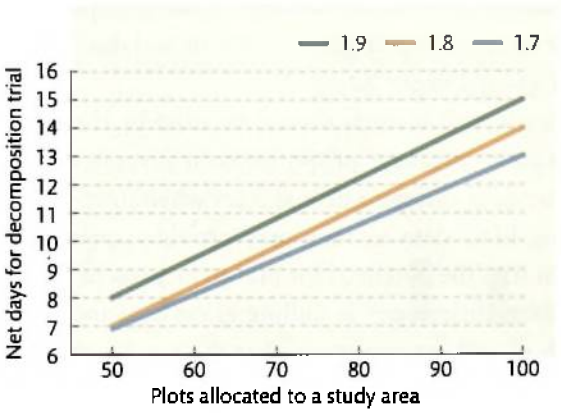
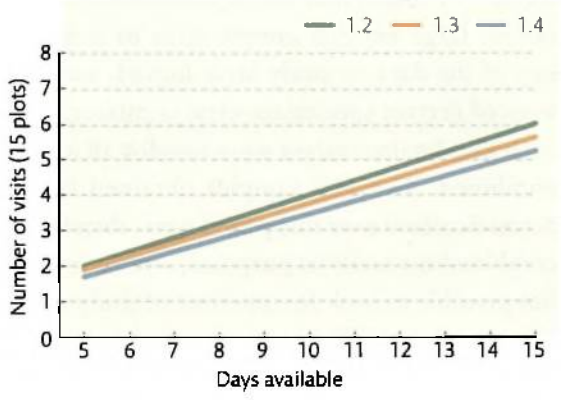


Figure A4

The maximum numbers of visits, for a given number of available days, which can be made to a set of 15 plots to carry out a decomposition rate trial. The number of plots has been taken from Laing *et al.* (2003). The results shown relate to the range of typical average amounts of time (1.2, 1.3 or 1.4 hours) needed per plot to gather and analyse the FSC count data described in Campbell, *et al.* (2004). It is assumed that this time is equivalent to the time needed to sample a plot in a decomposition trial since Laing *et al.* (2003) do not provide data on timings.



Appendix 2: Identifying the pellet groups of different deer species

Managers try to set deer culls within a given area for each deer species separately due to both local and species-specific differences in population dynamics. Effective rules should therefore be developed to enable surveyors to classify pellet groups in the field according to the species of deer from which they originated.

During 1999–2004, FC wildlife rangers working in 17 conifer plantations across Scotland were asked to provide six rectal samples from culled deer of each species present in each area studied (roe, red and/or Sika) and from three age and gender categories (calf <12 months, adult female >12 months, adult male >12 months). The deer had all been culled in winter prior to the start of pellet group surveys.

A random sample of six pellets was then obtained from each rectum provided and the diameter (to the nearest millimetre) was measured using 'Vernier' callipers. A mean pellet diameter value for each group was calculated from each set of six pellets.

Due to local variations in the timing of culls, the relative abundance of each species in each area and the effort involved in gathering the rectums in field conditions, it proved difficult to obtain large enough sample sizes to analyse any of the data by study area. Indeed, sample sizes of certain species/age-class combinations such as Sika deer calves were low for all areas combined. The 290 samples obtained from across Scotland over this period were, therefore, combined for analysis purposes, and so it was not possible to look for an effect of study area on pellet diameter.

Frequency distributions of the mean pellet diameter (calculated from six pellets from each sampled rectum) were constructed for deer of each species (roe, Sika and red) according to age-class and gender (juvenile female, juvenile male, adult female, adult male) (Figures A5a, b and c).

The extent of mis-classification error present in a particular study when the 10 mm rule is applied will vary according to the proportion of calves present in the sampled population, the relative abundance of each species present and local variations in deer body size.

The proportions of calves estimated as present from cull records in ten woodland populations from across Scotland over a 5-year period are presented for roe and red deer (Table A1). Estimates of the variation in mis-classification error according to the proportion of calves present were made based on this range of typical values. No calculations were made for Sika deer due to the lack of reliable pellet diameter data.

With all else being equal, the extent of under-estimation of red deer pellet groups would be greatest where the proportion of calves is highest. For a population with equal proportions of roe and red deer with body weights typical of the areas sampled and 15% calves present, 20% of pellet groups classified as 'roe deer' would likely be red deer and 4% of pellet groups classified as 'red deer' might be roe deer. For a population with 20% calves, the same errors would be 23% and 4% respectively. For a population with 25% calves, the errors would be 25% and 3% respectively.

The mean proportion of kids and calves present in the population for which data is available (Table A1) is approximately 20% for both species. The extent of error present in a mixed roe/red deer population with 20% juveniles of each species present was calculated for varying levels of relative abundance of each species. Where 90% of deer in a study area are roe, up to 26% of pellet groups counted as 'red deer' using the rule might actually be roe deer whilst only 3% of 'roe deer' pellet groups might be red deer.

If roe and red deer exist at equal densities, approximately 22% of 'roe deer' pellet groups might be red deer on average and 4% of 'red deer' pellet groups might be roe deer.

Where red deer account for 90% of deer present, up to 72% of 'roe deer' pellet groups might be red deer and less than 1% of 'red deer' pellet groups might be roe deer.

Ideally, cull records should be used by the manager to estimate proportions of juveniles and ratios of different deer species when interpreting EDU data as they may provide some insight into the potential for bias to be present. However, differences in culling effort and the length of cull seasons mean that the results of such calculations are, themselves, subject to error.

Site	Total roe kids shot	Total roe does shot	Estimated proportion of kids present	Total red calves shot	Total red hinds shot	Estimated proportion of calves present
1	311	569	0.21	19	30	0.24
2	414	572	0.27	44	62	0.26
3	51	112	0.19	19	46	0.17
4	50	71	0.26	56	126	0.18
5	96	175	0.22	101	187	0.21
6	10	43	0.10	150	330	0.19
7	10	55	0.08	13	36	0.15
8	59	120	0.20	155	310	0.20
9	187	399	0.19	266	496	0.21
10	131	222	0.23	22	40	0.22

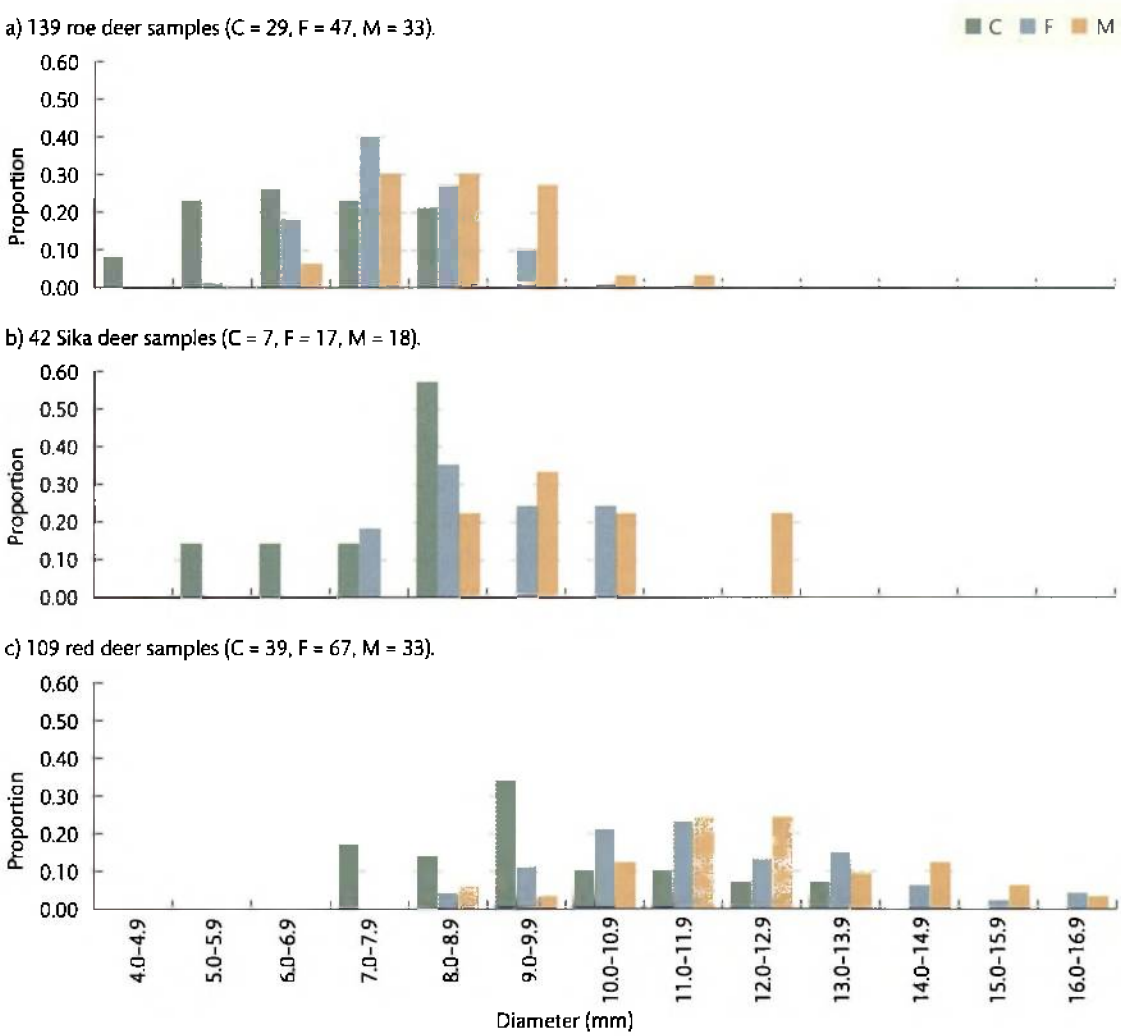
Note: Calculations assume that there are the same number of acult males as adult females in each population.

Table A1

The estimated proportion of calves present in ten culled populations across Scotland, calculated from the total number of animals culled over five seasons.

Figure A5

The proportions of mean faecal pellet diameters falling into different diameter categories for three deer species in Scottish forests. Sampled faecal pellets were sourced from deer shot in 17 study areas over the period 1999–2004. C = calf; F = adult female; M = adult male.

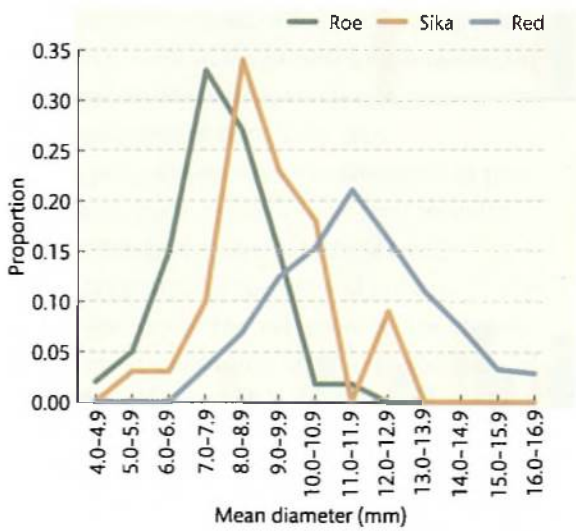


A more accurate approach involves measuring the mean pellet diameter of every pellet group sampled. If the number of pellet groups that are conclusively roe i.e. have a mean pellet diameter of less than 7 mm, and red i.e. have a mean pellet diameter of 12 mm or greater, are known, the frequency distributions of mean pellet diameter for each deer species (Figure A6) can be used to estimate the likely number of pellet groups in the overlapping area i.e. the number that might be either roe and red. However, this process involves large increases in fieldwork time in areas with moderate or high deer densities due to the large number of pellet groups encountered. Therefore, the benefits may not outweigh the costs.

When the information held on Sika deer were incorporated and it was assumed that equal densities of each species were present with 20% calves, the distribution of Sika deer pellet diameters largely overlaped that of roe deer, although sample sizes were small (Figure A6). Sample sizes of pellet groups from adult male Sika, which tended to be 10 mm or larger, were very small and this accounts for the unusual frequency distribution obtained (Figure A5b). The data suggest that about 73% of all Sika deer pellets are likely to have diameters of less than 10 mm although further data are required to establish this conclusively.

Figure A6

The proportions of mean faecal pellet diameters falling into different diameter categories for three deer species in Scottish forests. Data were taken from Figure A10. Calculations assume equal numbers of all three species with 20% juveniles present for each species.



Appendix 3: The effects of deer movement on EDU estimates: a case study

Pellet group count techniques can be successfully used to estimate total deer abundance where the study population is discrete. However, when deer movement occurs during the faecal accumulation period the resultant EDU estimates become more difficult to interpret. An example is given in the following case study.

A pellet group count study was carried out in an area of the British uplands where two neighbouring properties (referred to below as A1 and A2 individually, and together as the 'combined area'), both with timber production objectives, required estimates of deer abundance for management purposes. Area 1 was 2700 ha and Area 2 was 4200 ha.

The neighbouring land on the northern, southern and eastern boundaries of the combined area was used for sheep production. The combined area had a stock fence around all boundaries, other than on the high mountain ridge to the west where no fence was present. The boundary between A1 and A2 was also stock fenced. The stock fences ensured that no sheep entered the area. Had there been sheep present this would have created difficulties in distinguishing between deer and sheep pellet groups.

The western boundary of the area comprised a high mountain range rising to over 800 m above sea level, which separated the combined area from another large conifer plantation to the west. As such, the combined area was considered to harbour a discrete population of roe deer. Red deer were also present in the combined area but, for the sake of clarity, have not been considered in this analysis. Whilst A1 and A2 comprised similar types of habitat, two distinctly different roe deer culling regimes operated within the two areas with the cull being considerably greater in A1 than A2.

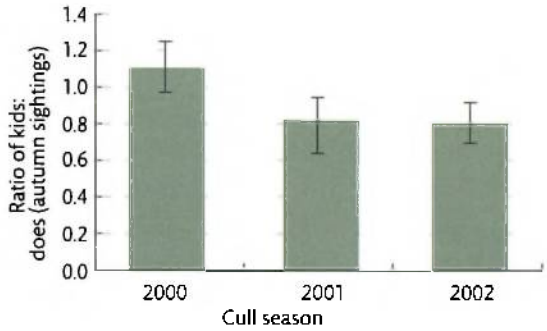
EDU for roe deer was estimated independently in A1 and A2 using 30 and 80 combination plots respectively in 2000 and again in 2003. A population dynamics model was built to predict the change in the roe deer population size expected by the end of the 2002–03 culling season in each area. The initial population size was set in the model using the EDU results from 2000. Recruitment and culling rates in the model were set using data collected between 2000 and 2003. Recruitment was estimated from autumn sightings of roe deer made by wildlife rangers (Figure A7).

Values of EDU predicted for 2003 within A1 and A2 were then compared with the EDU data actually measured in 2003. The EDU estimates for A1 and A2 were also combined and a separate model built using the combined figures for recruitment and culling rates.

The initial EDU estimate for the combined area, on 31March 2000, was 210 ±98 (95% CL) roe deer following a cull adjustment of 1.8% (Figure A8a). The predicted EDU in the combined area for 31 March 2003 (54 roe deer) lay within the confidence limits associated with the actual EDU estimate for 2003 (109 ±60 roe deer; 95% CL) with a cull adjustment of 8.4% having been incorporated (Figure A8b).

Figure A7

Numbers of roe deer kids (< 1year old) seen in relation to adult roe does (> 1year old) in the autumn of 2000, 2001 and 2002 (with 95% confidence limits). These data were used to form the estimates of recruitment rate in the population models.



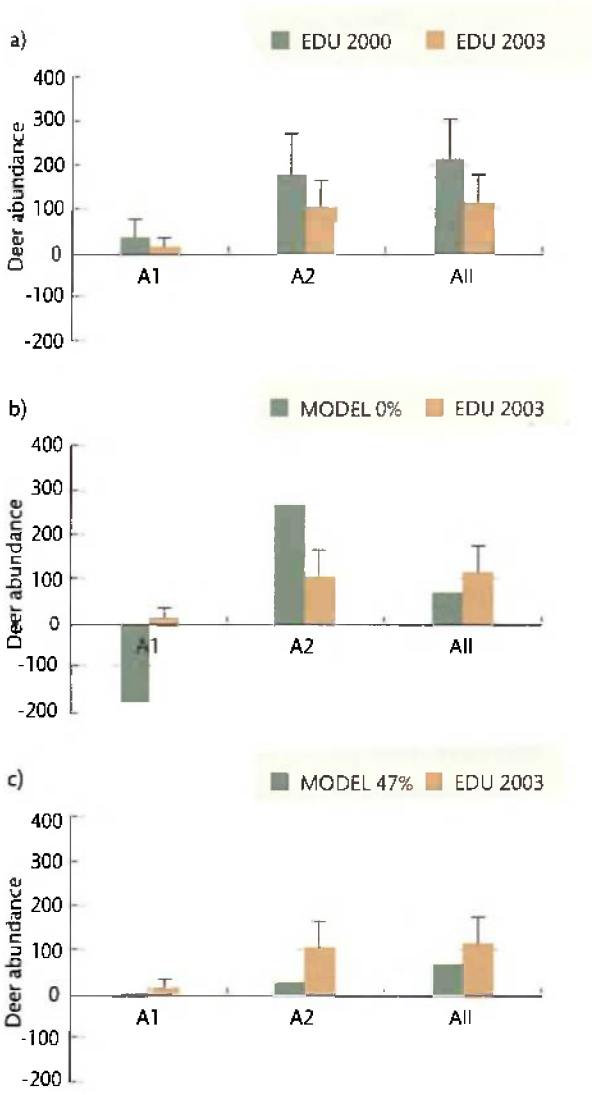
The initial EDU for A1 on 31 March 2000 was 34 ±36 (95% CL) roe deer after a cull adjustment of 0.2% (Figure A8a). The model predicted extinction of the population in 2001 (Figure A8b). A further 168 roe deer were culled after the predicted population reached zero (Figure A8b). Deer were also detected in the area in 2003 during the re-assessment of FAR when the EDU was re-assessed as 10 ±22 (95% CL) following a cull adjustment of 43% (Figure A8a).

The initial EDU for A2 on 31 March 2000 was 175 ±92 (95% CL) roe deer after a cull adjustment of 2.1% (Figure A8a). The model predicted a rise in population to 263 by 31 March 2003 on the basis of the limited culls that were subsequently taken (Figure A8b). The EDU measured in 2003 during the re-assessment was 99 ±55 (95% CL) following a cull adjustment of 2.9% (Figure A8a).

The precision of EDU estimates was generally low due to the low densities of deer calculated to be present in 2000 (A1 – 1.3 deer km^{-2}; A2 – 4.2 deer km^{-2}; combined – 3.0 deer km^{-2}) and 2003 (A1 – 0.4 deer km^{-2}; A2 – 2.4 deer km^{-2}; combined – 1.6 deer km^{-2}). Also, the

Figure A8

Trends in roe deer abundance as:
a) measured by EDU surveys in spring 2000 (EDU 2000) and 2003 (EDU 2003).
b) predicted by population models (MODEL 2003) for spring (with no immigration) based on EDU data from spring 2000 and compared with EDU data for spring 2003.
c) predicted by population models (MOD 47%) where 47% of the population was migrated annually from the A2 model into A1 model compared with EDU data for spring 2003. Models used the recruitment rate estimates from Figure A7 and assumed equal numbers of adult male and female deer in the starting population.



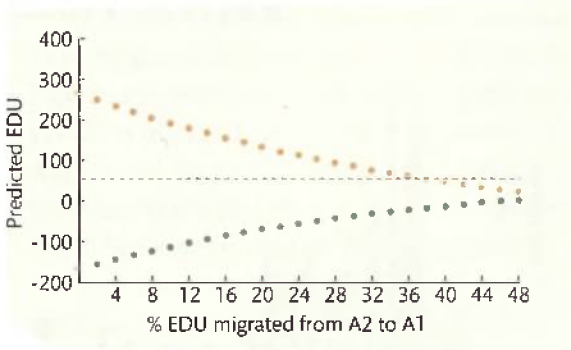
sample size in A1 was low (n = 30 plots) due to budget limitations.

If it is assumed that the A1 and A2 populations were discrete, the model predicted a significantly higher EDU than was observed in A1 and a significantly lower EDU than was observed in A2 in 2003 (Figures A8c and A9). The model was then run for both A1 and A2 assuming that various proportions of the deer population in A2 moved into A1 in each year. The movement rate in the model run was kept constant for each year of the survey period. The proportion of the population in A2 that was assumed to move to A1 was gradually increased until the final population predicted by the model for each area in 2003 most closely matched the actual EDU measurements made in that year. An annual movement of 47% of the population in A2 to A1 was required for the model runs to predict that deer would still be present in 2003 in A1 and A2 though the prediction for A2 was outwith the 95% confidence limits of the EDU re-survey. Although confidence intervals are relatively large due to the low deer densities present, and the true rates and directions of deer movements were likely to be more complex than those modelled, it can still be concluded that a considerable net movement of deer must have occurred from A2 into A1 over the period of the study to explain the discrepancies between the predicted and measured outcomes.

The findings of the case study demonstrate the difficulties a manager faces when pellet group count techniques are applied in an area where some of the deer population are transient. Such data are particularly difficult to interpret where neighbouring land is not included in the survey. In these circumstances surveys that cross administrative boundaries to incorporate all the land associated with a particular deer herd are therefore of great benefit.

Figure A9

Predicted population size in 2003 for the A1 and A2 areas from population models set up to 'migrate' proportions of EDU annually. Outputs for area A1 (green) and area A2 (orange) are shown for increasing amounts of movement from A2 to A1. Predicted EDU on 31 March 2003 from the combined model (A1 and A2) is also shown (dotted line).



Appendix 4: The number of pellets in a pellet group

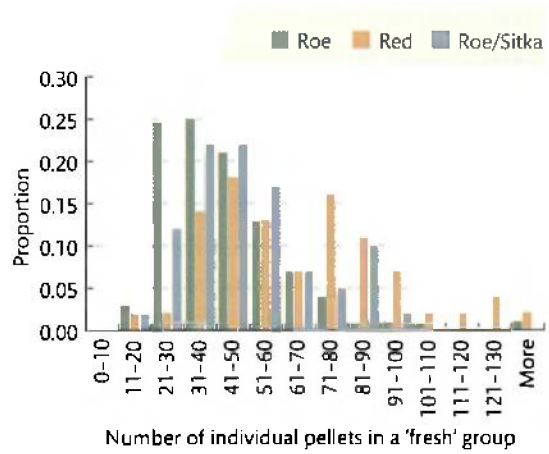
An important aspect of pellet group count techniques relates to the definition of a 'countable' pellet group. Ideally, the extent of variation in the number of individual pellets that can be found in the depositions of free-ranging wild deer should therefore be quantified to ensure that robust rules for sampling are created and applied.

Over the period 2002–04, Strath Caulaidh Ltd set up combination plots in 29 study areas for operational monitoring purposes. During the first visit to sample plots within each study area, discrete pellet groups found in a 'fresh' decay state (i.e. with no signs of surface decomposition) were located and marked. The number of individual pellets in each group was counted. The frequency of different numbers of pellets in sampled groups was calculated for each deer species present. Each pellet group was assigned to a deer species on the basis of its mean pellet diameter (Appendix 2). The deer species categories used in the analysis varied according to the deer species present in each study area. In some areas, only roe and/or red deer were present. This enabled surveyors to allocate pellet groups to each of the two species. These data are presented as 'roe' and 'red'. In some study areas, roe and Sika deer were present together and their pellets could not be differentiated (Appendix 2). The data are presented as 'roe/Sika'.

Pellet groups identified as belonging to roe deer averaged approximately 40 pellets in a group. Those classified as red deer averaged approximately 60 pellets in a group. Those belonging to roe/Sika were, on average, between these two values. Less than 5% of all sampled pellet groups had more than 130 pellets present (Figure A10). The maximum number of pellet groups recorded for roe was 215 and for red deer was approximately 360.

Figure A10

The proportion of 'fresh' pellet groups found with different numbers of individual faecal pellets, recorded from 29 study areas over the period 2002–04 for various species categories. Sample sizes were: roe pellet groups: n = 150, roe/Sika pellet groups: n = 41, red pellet groups: (= 55. Two outlying observations ('More') had values of 215 pellets (roe deer) and 360 pellets (red deer).



None of the 246 groups sampled consisted of fewer than 18 pellets. 95% of groups sampled had more than 30 pellets present. The rule advocated for fresh pellet group inclusion (a minimum of 18 pellets) would therefore appear to be robust for all species in the conditions studied.

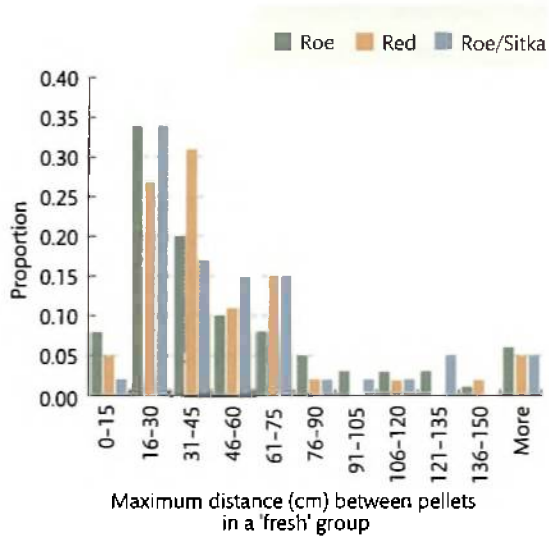
Appendix 5: The spread of pellets in a pellet group

Surveyors must be confident of their ability to determine 'discrete' pellet groups on the ground for pellet group count techniques to be successfully applied. Therefore, the variation in the scatter of individual pellets from the same group should be quantified. Frequent, extensive scatter could result in individual pellet groups being difficult to differentiate.

During the surveys outlined in Appendix 4, the distance between the two furthest apart pellets in each marked, fresh pellet group was measured. The resultant frequency distribution of the spread of all pellet groups assessed was presented using the same species categories as described in Appendix 4. Findings indicate that 83% of pellet groups recorded had a spread of between 0 and 75 cm (Figure A11). However, informal observation during the study indicated that the majority of pellets in each marked group tended to occur in a far more defined central zone than the 'maximum spread' data suggest. Observations suggest that the majority of pellet groups appear as discrete 'piles' of pellets within a circle of 50 cm, as opposed to a 'string' of pellets spread over 75 cm or more.

Figure A11

The proportion of 'fresh' pellet groups in different categories of maximum spread recorded from 29 study areas over the period 2002–04 for roe deer (n = 150), roe/Sika deer (n = 41) and red deer (n = 55). 6% of outlying observations ('More') ranged in maximum spread from 160 cm up to 380 cm.



Appendix 6: The length of sample plots

Plot length can affect the between plot variance in pellet group density and the proportion of time spent travelling between plots rather than sampling them. It can thus affect both the precision of the survey and its cost.

In three pilot surveys[9] carried out by Strath Caulaidh Ltd during spring 1998, sampling was carried out on a number of randomly placed plots. Each plot was surveyed in sections to assess the impact of different plot lengths on precision and survey time. Each plot was 150 m long, 1.5 m wide and covered 225 m^2. Each was marked on the ground with a central line. The plot area was split into 30 segments of 5 m

[9] Drumjohn (Galloway Forest District) and Einig Wood and Loch a' Choire (both Dornoch Forest District).

length. Each segment was assessed by walking clockwise around the central line. On each segment within each plot, the number of pellet groups was counted. For each study area, mean pellet group density and variance was calculated for plots of each of three different lengths (50 m, 100 m or 150 m), but the same width.

Plot length had little effect on the estimates of pellet group density (Figure A12). Increased plot length was associated with an increased precision in Area 1, little change in precision in Area 2 and, in Area 3, an increased precision between 50 m and 100 m and a decreased precision between 100 m and 150 m (Figure A13).

Since there appears to be no consistent advantage, in terms of precision, in using longer plots, it is recommended that plots shorter than 150 m are used. This will maximise the number of plots that can be sampled for a given amount of effort as well as keeping the amount of time that is spent searching plots with deep vegetation and/or large numbers of pellet groups to within the limits of a surveyor's concentration span.

Figure A12

Mean density of pellet groups (m^{-2}) obtained from three study areas where data from contiguous plots made up a total of 150 m in length. Area 1 (n = 12 plots); Area 2 (n = 23 plots); Area 3 (n = 9 plots).

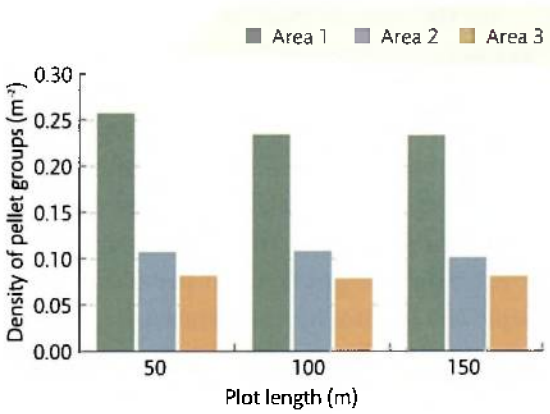
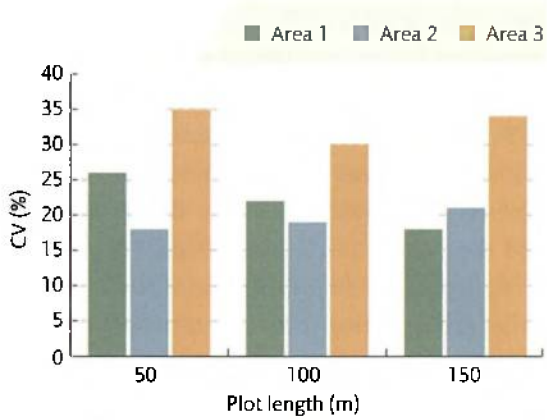


Figure A13

The coefficient of variation (CV) of pellet group density obtained from plots of three lengths at three study areas. Area 1 n = 12 ; Area 2 n = 23 ; Area 3 n = 9.



As a compromise between maintaining the surveyor's concentration level by having short plots and minimising the time spent travelling between plots by having long plots it is suggested that 75 m plots are used in all habitat types other than pre-thicket. In pre-thicket, 50 m plots should be used due to the difficulty of laying out a central line through low-lying branches. Shorter plots can be used in deeper vegetation (Table 2, page 20) if the manager considers that difficult search conditions may reduce the surveyor's abilities to search plots effectively.

Appendix 7: The width of sample plots

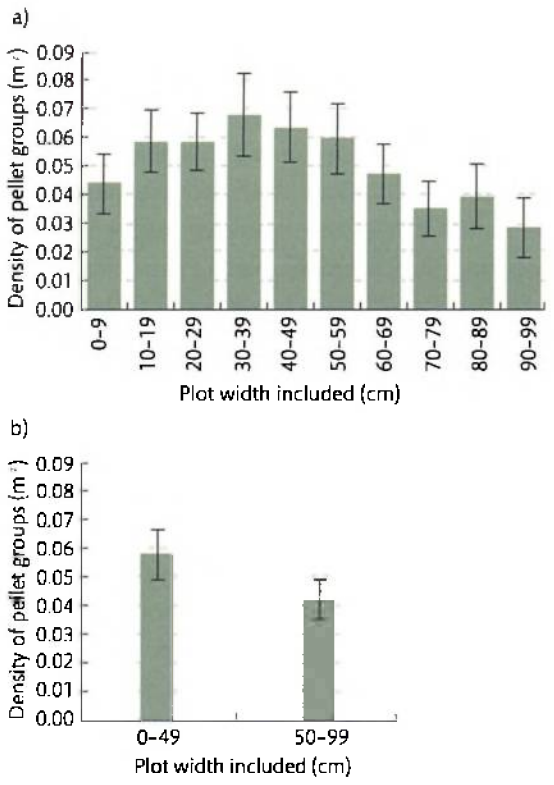
In a large study carried out by Strath Caulaidh Ltd during winter 1998–99, the majority of plots used were 2 m wide i.e. 1 m wide either side of the central line. Surveyors sampled pellet groups by walking clockwise around the plot at the central line sampling one side at a time. The distance of each pellet group from the central line was recorded.

FSC data from the pre-thicket habitat, dominated by grasses but with some heather, were used to examine the effect of plot width on the density of pellet groups recorded. A total of 90 plots were sampled. The results indicated that surveyors missed significant numbers of pellet groups on the inner and outer peripheries (0–9 cm and 60–99 cm from the central line; Figure A14a). There was also a significant difference between the inside half of the strip (0–49 cm) and the outside (50–99 cm) (Figure A14b).

It is possible that this trend was due not to pellet groups being missed, but to biases in the recording of the distance of pellet groups from the central line. Surveyors tend to walk 20–30 cm out from the line rather than on the line itself so their search effort is likely to be focussed on this area. Given that most pellet groups are in fact an aggregation of individual pellets with some scatter (Appendix 5), it is possible that surveyors may spend too short a time locating the true centre of all the pellet groups they see before recording the distance, and simply place small marker-sticks in the centre of the proportion of the pellet group seen. This could particularly be the case in deeper vegetation. A bias towards recording pellet groups in the middle distances may therefore occur, though this is unlikely to be the only reason for the trend.

Figure A14

Density of pellet groups (with 95% confidence limits) in plots within pre-thicket habitat (n = 90) obtained from (a) ten neighbouring 10 cm strips within a plot of width 100 cm from the central line and (b) from two neighbouring 50 cm strips.

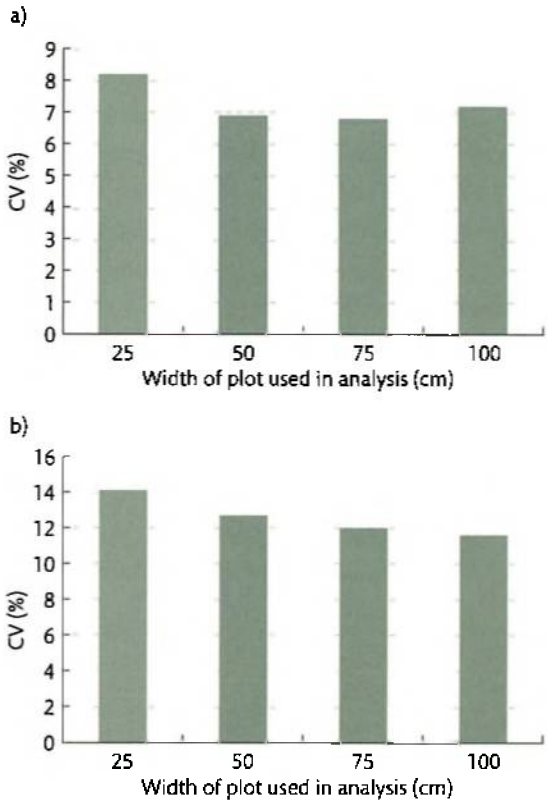


Data from pre-thicket and closed canopy habitats gathered in Cowal Forest District in west Scotland were then used to examine how the precision of pellet group density estimates from these habitats would have been affected had strip width been set at 25 cm, 50 cm or 75 cm instead of 100 cm (Figures A15a and b). It is clear that in both the pre-thicket and closed canopy habitat types there is relatively little difference in the level of precision attained by using strips of 50 cm width compared to 75 or 100 cm (Figures A15a and b). However, there appears to be some benefit to using strips of 50 cm compared to 25 cm. The under-recording of pellet groups on the peripheries of the plot may confound these results.

On the basis of these findings, the decision was made to recommend a strip width of 50 cm in dense vegetation, e.g. in pre-thicket, to reduce the risk of bias. Where limited, or no, vegetation exists, and searching is therefore relatively easy, e.g. in closed canopy forest, a 75 cm strip width is recommended to maximise the pellet group count per plot. This is important in these habitats since they generally have a lower level of deer use hence a high variance in pellet group density (Appendix 8).

Figure A15

The coefficient of variation (CV%) of pellet group density estimates in plots within (a) pre-thicket (n = 90) and (b) closed canopy habitats (thicket, pole-stage and pre-fell; n = 89), as calculated by incorporating increasingly large portions of the original data gathered on plots of 100 cm original width.



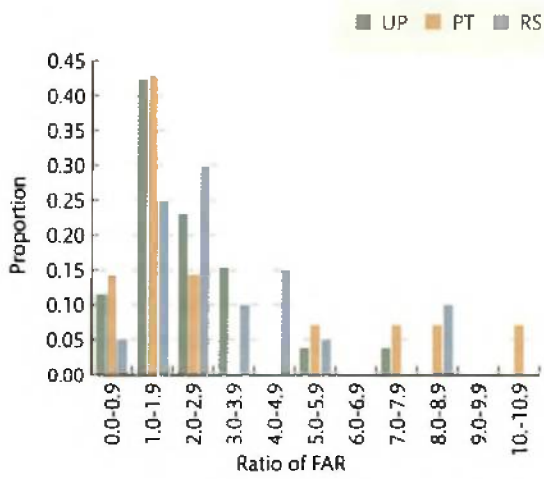
Appendix 8: The sampling framework

The way in which sampling locations are selected within a study area can have an effect on the precision of the pellet group count obtained. Two common techniques used to reduce sampling error for a given amount of effort are stratification and weighting. Use of these techniques relies on prior knowledge of patterns of deer use in forests and for an initial survey, this is not always available.

The FAR data set described by Campbell *et al.* (2004) was used to assess how FAR counts varied with habitat type in 26 study areas. A ratio reflecting the relative rate of faecal accumulation (FAR) between open habitats (unplanted, re-stock and pre-thicket) and closed canopy habitats (thicket, pole-stage and pre-fell combined) was used. The data indicated that, on average, deer used open canopy habitats more often than closed canopy habitats in 90% of the areas studied with the utilisation rate being more than twice as high in 50% of areas (Figure A16).

Figure A16

A frequency distribution of the relative rates of faecal accumulation in unplanted (UP), pre-thicket (PT) and re-stock (RS) habitats compared to closed canopy (thicket, pole-stage and mature) measured in 26 study areas. Ratios < 1 indicate that the level of use is higher in closed canopy than in open.

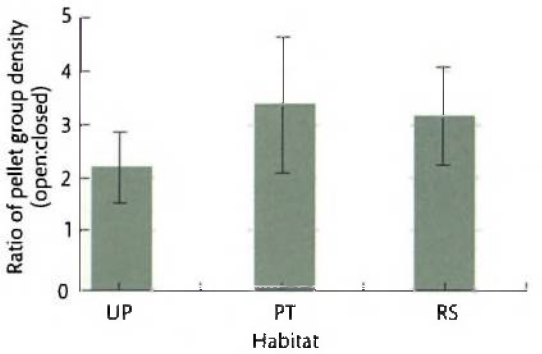


The mean relative rate of accumulation in open canopy habitats compared to closed canopy habitats across all study areas varied between habitats and forests but was generally between 1.5 and 3 times higher in open canopy habitats (Figure A17). These results suggest that on average deer use open habitat types

more than closed canopy habitat types. It is recommended that sampling of all areas is stratified on this basis unless there are pre-existing data on pellet group distribution to indicate that a different stratification system would be better.

Figure A17

The relative pellet group accumulation rates in open habitats (unplanted (UP), pre-thicket (PT) and re-stock (RS)) compared to closed canopy habitats (thicket, pole-stage and pre-fell combined) measured in 26 study areas (with 95% confidence limits).



These data can also be used to consider whether to weight sampling effort according to the habitat types present within the study area. Figure A18 shows the standard deviation of mean FAR pellet group count in relation to mean pellet group count recorded in four habitat types.

In general, the standard deviation increases as the mean increases. It should be noted that only pellet group count estimates based on more than five plots were used in this analysis as the estimate of variance in habitats with fewer plots than this is likely to be poor.

The mean relative standard deviation of pellet group counts in open canopy habitats compared to closed canopy habitats across all study areas varied between habitats and forests but on average was 1.5 times higher in open canopy habitats (Figure A19). Sampling of study areas can be weighted according to a 'Neyman allocation' (see equations on page 49). Using this technique, researchers can find the sample allocation plan that provides the highest level of precision given a fixed sample size. Researchers could use the data presented here if there are no pre-existing data to indicate that a different weighting system would be better. The use of previous survey data is preferable. Simple random sampling can be used if it is thought that deer are using all habitat types to the same extent.

Figure A18

The standard deviation (SD) of mean FAR pellet group count plotted against mean pellet group count recorded in four habitat types from 26 FAR surveys.

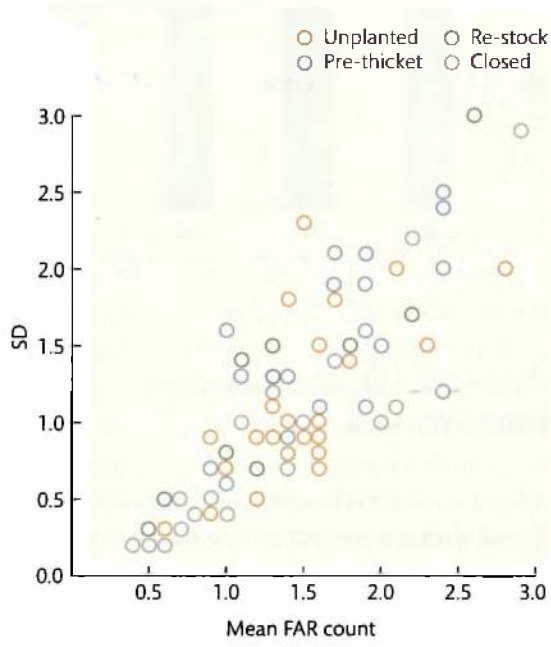
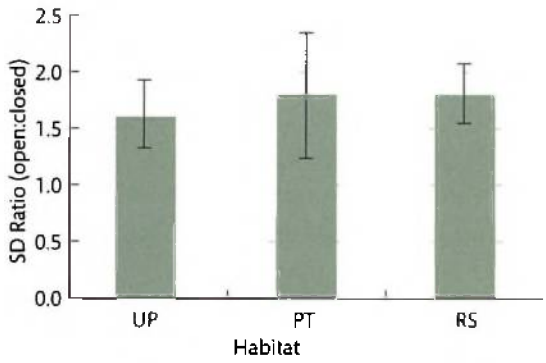


Figure A19
The relative standard deviations (SD) of pellet group counts in open habitats (unplanted (UP), pre-thicket (PT) and re-stock (RS)) compared to closed canopy habitats (thicket, pole-stage and pre-fell combined), termed the SD ratio (open: closed), as measured in 26 study areas (with 95% confidence limits).



For any method of allocating plots to strata, the variance of the estimate of the total number of pellet groups present in the survey area, Var(T) , can be calculated using Equation 2.

Equation 2

$$Var(T) = \sum N_i^2 \frac{\sigma_i^2}{n_i}\left(1 - \frac{n_i}{N_i}\right)$$

- N_i is the maximum number of plots, of a standard size, that it would be possible to fit into stratum i,
- n_i is the actual number of plots used in stratum i and
- σ_i is the standard deviation of the total number of pellet groups in stratum i.

The element in brackets in Equation 2, the finite sampling correction, can be ignored when the proportion of the total survey area that is sampled is low. This is usually the case. This gives Equation 3.

Equation 3

$$Var(T) = \sum N_i^2 \frac{\sigma_i^2}{n_i}$$

If σ_i is known, or can be estimated, for each stratum prior to the start of the survey, Var(T) is minimised for a fixed total sample size, n, if the Neyman allocation (Equation 4) is used to calculate the number of plots to allocate to each stratum, n_i.

Equation 4

$$n_i = \frac{N_i\sigma_i}{\sum N_i\sigma_i} n$$

Substituting n_i from Equation 4 into Equation 3 gives:

Equation 5

$$Var(T) = \frac{\left(\sum N_i\sigma_i\right)^2}{n}$$

The minimum percentage coefficient of variation (defined as the standard error of the total divided by the mean of the total) is therefore:

Equation 6

$$\%CV = \frac{100}{\sqrt{n}} \frac{\sum N_i\sigma_i}{\sum N_i\mu_i}$$

In practice, S_i, the standard deviation of the sample rather than of the whole population, is used in Equations 3–6 as an estimate of σ_i.

Appendix 9: Sampling intensity

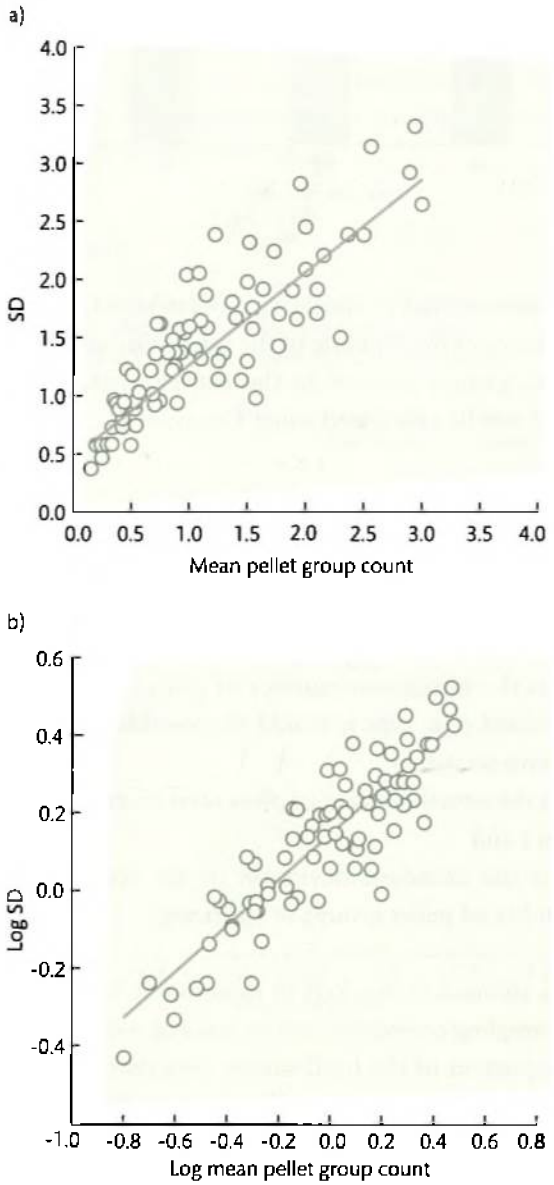
One of the principal determinants of precision in the overall estimate of EDU is the number of sample plots used to measure the faecal accumulation rate. Decisions relating to sample size are normally informed by a pilot study in which the local relationship between mean pellet group count and variance is established using a minimum number of plots (6) in each stratum of the study area. With these data it is possible to forecast the level of precision that could be attained using different numbers of plots. For surveys using Neyman allocation Equation 6 (Appendix 8) can be used.

The data from 26 study sites used in Campbell *et al.* (2004) represent a cross section of forest types in Scotland, with respect to proportions of habitat types present, levels of deer density and relative deer species abundances. These data (Table 2; page 20) were used to examine the relationship between sample size and FAR count precision for the standard sizes of plots recommended.

The ratios of the standard deviation (SD) to the mean FAR pellet group count ranged from 0.80–2.89 with 84% of observations having a ratio of 1 or more (Figure A20a). This means that the variance in pellet group counts is generally high relative to the mean and therefore that there must be spatial aggregation of pellet groups in most, or all, habitat types at the scale of the sample plots used. However, a transformation of the mean pellet group counts and standard deviations to log10 (Figure A20b; log SD = 0.601 * log mean + 0.137; r^2_{adj} = 78.4%; df = 80; $p < 0.0001$) normalises the data and improves the fit of the line compared with the untransformed data (Figure A20a; SD = 0.778 * mean + 0.561; r^2_{adj} = 73.0%; df = 80; $p < 0.0001$). The gradient of the best fit line in the log-log model (Figure A20b; 0.601) indicates

Figure A20

(a) Un-transformed standard deviations (SD) plotted against mean pellet group counts per plot and; (b) Log 10-transformed standard deviations (Log SD) plotted against log10-transformed mean pellet group counts per plot derived using FAR methods. FAR data were obtained from up to four strata sampled from each of the 26 study areas as in Figure A18. Each point relates to a stratum-specific estimate of mean pellet group count per plot based on n > 5 plots per stratum. The solid lines represent the linear model that best fitted the data.



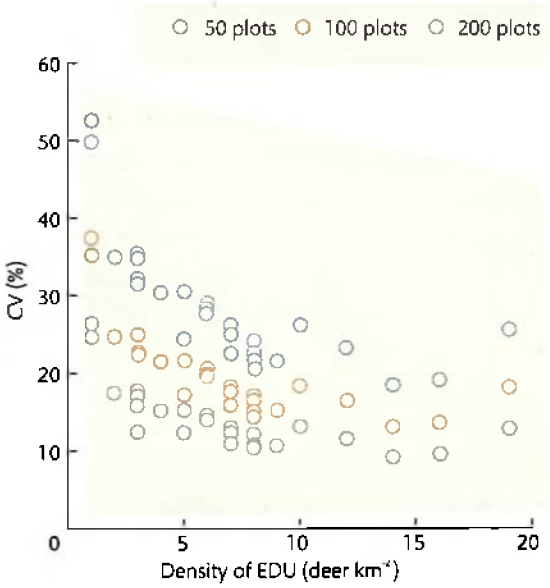
that precision relative to the mean increases with pellet group density.

The roe deer pellet group count data relating to the FAR techniques (Campbell *et al.*, 2004) were used to show how the precision of the 26 FAR surveys would have varied had they been sampled using differing numbers of plots. Firstly, the FAR data were transformed into EDU using the recommended roe deer deposition rate (page 27). EDU densities for each study area were calculated using data on the area of each study site. Coefficients of variation (CVs) were projected for 50, 100 and 200 plots (Figure A21) in each area using Equation 6 (Appendix 8). It should be noted that these levels of precision are unlikely to be attained in baseline surveys if no prior variance information is available with which to allocate numbers of plots to strata.

The data indicate that precision is inherently higher at high EDU densities (e.g. 20 deer km^{-2}) than at low densities (e.g. 5 deer km^{-2}). In general, precision is doubled for a quadrupling of sampling effort. It should be noted that some of the variation in CV is also attributable to differences between the areas in the proportions of each habitat present.

Figure A21

Predicted coefficient of variation (CV) of roe deer pellet group count estimates against EDU density, obtained using FAR techniques in 26 study areas using 50, 100 or 200 sample plots.



Appendix 10: The effect of the return time on precision

The overall precision of an EDU estimate obtained using combination plot techniques is partly determined by the density of pellet groups that has accumulated in the study area (Appendix 9). The density of pellet groups is, in turn, determined by both the EDU and the length of time that the plots are left between visits (termed the return time). It is known that the CV of pellet group density declines with increasing density (Figure A21). It therefore follows that the return time also has an effect on the precision of the pellet group density estimate.

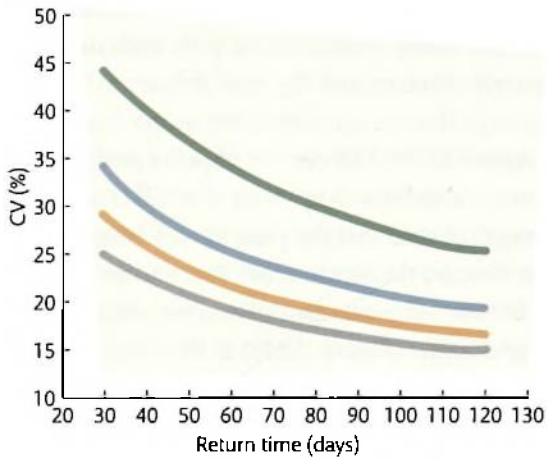
Data from the 26 study sites described in Campbell *et al.* (2004) were used to model the effect of return time on the precision of pellet group density estimates. A spreadsheet model was built to simulate pellet group surveys carried out in four study areas where red deer, defecating at 20 groups day^{-1}, were present at densities of 5, 10, 15 and 20 deer km^{-2} respectively. The simulations were based on sets of 70 sample plots of 100 m^2 that were left for 30–120 days between visits.

The expected pellet group count per 100 m^2 plot was calculated for increasing lengths of return time at each of the four deer densities. The expected standard deviation of each expected pellet group count per plot was predicted from the linear model presented in Appendix 9, Figure A20b. The CV of the pellet group count per plot for each return time and density scenario

was then calculated. These CV values were then plotted against the return time (in days) for increasing numbers of days under the four deer density scenarios (Figure A22).

Figure A22

The CV of pellet group count per plot obtained from FAR studies where sets of sample plots of 100 m^2 were left for increasing numbers of days between visits in simulated study areas with 20 (grey), 15 (orange), 10 (blue) and 5 (green) deer km^{-2} present.



The strength of the association between the variables indicates that the predictive power of the model illustrated in Figure A20b should be high. However, it should be noted that the model is based on data from 26 study areas. The analysis assumes that this same relationship exists within each study site but data are not currently available to test this.

The simulations indicate that return time is likely to have a stronger effect on the CV of the pellet group count per plot at very low deer densities than at very high deer densities although at low densities absolute precision is normally of more interest. Also, the benefit of leaving plots out for longer periods appears considerably less at high deer densities than at low densities.

The decline in CV with every extra day of return time decreases as return time increases. At 5 deer km^{-2}, the CVs associated with return times of 30, 60, 90 and 120 days were approximately 44%, 34%, 29% and 25% respectively. At 20 deer km^{-2}, the equivalent CVs were 25%, 19%, 16% and 15%. The return times of FAR studies carried out in Scottish conditions by Strath Caulaidh Ltd usually range from 60–100 days although the majority are in the range 80–90.

With all else being equal, return time should be lengthened to minimise the CV of the pellet group count per plot. However, as return time is lengthened the risk of bias due to intermediate decomposition will increase and this should be avoided (Appendix 11). Therefore, the choice of return time is a balance between accumulating the maximum number of pellet groups and minimising the risk of intermediate decomposition occurring.

Appendix 11: Determining the likelihood of intermediate decomposition

The combination plot technique assumes that no pellet groups accumulating after the first visit to plots will decompose before the second. A failure of this assumption could create significant levels of bias. Should any intermediate decomposition occur, the overall level of bias would be determined by the mean proportion of each daily cohort of newly-deposited pellet groups that decomposed completely prior to the second visit taking place.

The bias relating to the cohort of pellet groups deposited immediately after plots are laid out can be estimated on combination plots by measuring the proportion of groups present in a fresh state on the first visit that have de-

composed completely by the second visit. It is then assumed that new pellet groups deposited after this time are increasingly less likely to decompose due to the shorter time remaining before re-survey.

The level of bias associated with decomposition of fresh pellet groups marked on the first visit to 23 study sites in Scotland was measured by Strath Caulaidh Ltd during 2003–04. During each first visit survey, all pellet groups were marked and assigned a decay status from 'fresh' through to 'almost-decomposed'. On the second visit, their decay status was re-assessed. The rate of decomposition was measured as the proportion of fresh pellet groups from the first visit (when they had no signs of surface decomposition) that had completely disappeared by the second.

The recorded rates were inherently low and ranged from 0–3% of the total marked on the first visit (Table A2, Figure A23). These data included surveys completed as late as the second week of June. There was no association of return time or completion date with the rate of decomposition, although the majority of decomposition that did occur was noted to be on

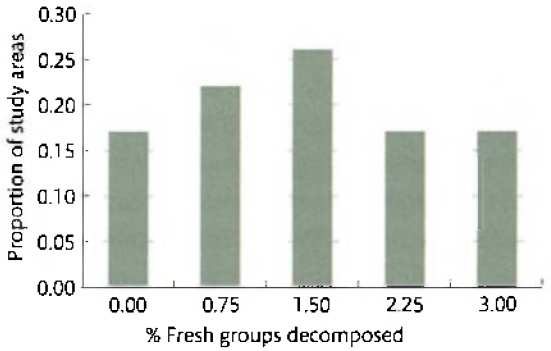
Table A2

The percentage of pellet groups marked on the first visit that had disappeared on the second visit in 23 study sites across a range of general geographical locations and altitudes in Scotland. Study sites are ordered from the earliest to latest second visit sampling date. 'Location': South (south of Glasgow), North (north of Inverness), West (west of Killin and between the north and south locations) and East (east of Killin and between the north and south locations); 'Type': Lowland (area generally below 400 m above sea level), Upland (area generally above 400 m above seas level) and Mixed (area spans the altitudinal range of Lowland and Upland).

Location	Type	Visit 1 Month	Visit 2 Month	Visit 1 Date	Visit 2 Date	Return time (days)	% original groups disappeared on visit 2
South	Lowland	November	March	25/11/03	2/3/04	98	1.2
South	Upland	December	March	9/12/03	9/3/04	91	0.9
South	Upland	January	March	6/1/04	15/3/04	69	0.0
West	Lowland	December	March	15/12/03	17/3/04	93	0.0
West	Mixed	December	March	2/12/03	30/3/04	119	0.5
West	Lowland	January	April	19/1/04	19/4/04	91	2.0
West	Lowland	January	April	20/1/04	23/4/04	94	0.0
West	Mixed	January	April	20/1/04	27/4/04	98	1.4
West	Mixed	January	April	20/1/04	28/4/04	99	0.9
West	Lowland	January	April	14/1/04	29/4/04	106	0.2
West	Lowland	February	May	3/2/04	10/5/04	97	0.6
West	Mixed	January	May	26/1/04	10/5/04	105	0.4
North	Upland	February	May	19/2/04	17/5/04	88	1.3
North	Lowland	February	May	5/2/04	18/5/04	103	2.0
North	Upland	February	May	11/2/04	20/5/04	99	1.8
East	Upland	March	May	23/3/04	20/5/04	58	1.8
North	Upland	March	May	4/3/04	24/5/04	81	2.5
East	Upland	March	May	22/3/04	25/5/04	64	2.4
East	Lowland	March	May	26/3/04	25/5/04	60	1.1
East	Upland	February	May	25/2/04	26/5/04	91	2.5
East	Upland	March	May	23/3/04	27/5/04	65	0.0
North	Upland	February	May	13/2/04	30/5/04	107	0.1
East	Upland	March	May	22/3/04	31/5/04	70	3.0

Figure A23

The proportion of pellet groups on each of 23 study sites, assessed as fresh on the first visit, that had completely decomposed by the second (from Table A2).



plots in fertile or low-lying grasslands and broadleaf woodland. In the conditions studied, these areas comprised no more than 5% of total sampled area.

If it is assumed that environmental conditions were constant over the period between visits, this rate is a measure of the maximum possible rate of decomposition of pellet groups defecated after the first visit that would have been undetected on the second visit. In reality, the overall rate would be much lower as the majority of pellet groups deposited later would not decompose. However, this assumption may be invalid if the re-visit is carried out during late spring or early summer. At this time 'mummified' pellet groups present from earlier in the winter may be more resistant to decomposition than newly defecated, coagulated pellet groups (see page 8 and Figures 6–8), which tend to be softer and affected more quickly by invertebrates. Currently no data are available with which to test this.

Where higher rates of decomposition are found to have occurred, e.g. where 20% or more of the original pellet groups have disappeared, two options are open. Firstly, an upward adjustment of up to 25% could be made to the measured pellet group accumulation rate for the purposes of estimating EDU and hence abundance. This may, or may not, overestimate EDU as described above. Alternatively, the overall count data obtained on the second visit (first visit count plus the number of pellet groups that have accumulated minus the number that have disappeared) is a measure of the standing crop of pellet groups and could be used as an index to monitor future change over the same period. Clearly, though, one would ideally establish the potential for intermediate decomposition to occur prior to establishing a combination plot survey if the study environment is unlike any of those for which results are presented in Table A2 and Figure A23.

Appendix 12: Calculating the precision of the pellet group count

Once the mean pellet group density has been calculated from the samples, the precision of the result should be determined as follows.

For each of the i strata calculate the mean ($\bar{x}_i$) and standard deviation (s_i) of the number of pellet groups per plot, for the n_i randomly chosen sample plots. Then calculate:

The estimated total number of pellet groups present in all strata:

Equation 7

$$= \sum N_i \bar{x}_i$$

where N_i is the notional number of sample plots that it would take to completely sample stratum i.

The estimated variance (total)

$$= \sum N_i^2 var(\bar{x}_i)$$

Equation 8

$$= \sum N_i^2 \left(1 - \frac{n_i}{N_i}\right) \frac{s_i^2}{n_i}$$

The estimated standard error

Equation 9

$$= \sqrt{\sum N_i^2 \left(1 - \frac{n_i}{N_i}\right) \frac{s_i^2}{n_i}}$$

Equation 8 gives the variance, irrespective of whether the same number of plots was allocated to each stratum, the plots were allocated randomly to each stratum or the number of plots was allocated to each stratum using the Neyman approach. The standard error of the total pellet group count is the square root of the variance as calculated using Equation 9. The standard error can then be used to calculate confidence limits associated with the estimate of the total number of pellet groups present in the study area. The equation for calculating the estimated variance for the overall estimate of EDU is given in Appendix 1 (Equation 1, page 36).

Appendix 13: Adjusting pellet group count data for culled deer

If it is necessary and appropriate to adjust pellet group count data for the number of deer culled during the survey period, the adjustment process is as follows.

Assume that the total number of pellet groups counted during a study (X) has accumulated over T days (T = the faecal accumulation period) with a pellet group deposition rate of r_d (the number of pellet groups produced, on average, by a deer in a day).

If c_j deer are culled on day j (j = 1 to T) then the total number of pellet groups contributed by each animal culled on that day

Equation 10

$$= jr_d$$

The total number of 'ghost' pellet groups produced by deer culled on day j

Equation 11

$$= c_j j r_d$$

The total number of groups defecated by deer still alive at the start of day T+1

Equation 12

$$= X - \sum_{j=1}^{T} c_j j r_d$$

Therefore the estimate of the number of deer still alive at the start of day T+1

Equation 13

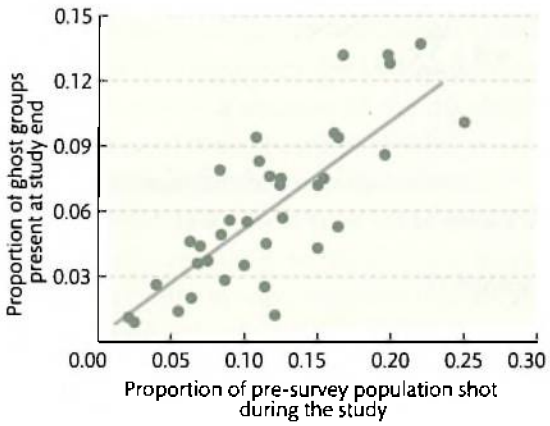
$$= \frac{X - \sum_{j=1}^{T} c_j j r_d}{r_d T} \equiv \frac{X}{r_d T} - \sum_{j=1}^{T} \frac{c_j j}{T}$$

Strath Caulaidh Ltd gathered data from 36 study sites during 1999–2005 from sites that were likely to have experienced minimal deer movement during the period of faecal accumulation. These data were used to investigate the extent of bias present in EDU estimates due to the presence of ghost groups. The proportion of ghost groups present was calculated using cull records from each study area.

These were compiled and compared with the proportion of the estimated number of deer present immediately before the survey that were culled during it. This was estimated by dividing the size of the cull taken during each pellet group survey by the sum of the EDU estimate (adjusted for ghost pellet groups) for the end of the survey plus the cull taken during the survey. Figure A24 illustrates the extent of bias present due to ghost groups in the 36 EDU estimates.

Figure A24

The proportion of ghost groups present in 36 study areas plotted against the proportion of the population present at the start of the study that were recorded as being culled during the period of pellet group accumulation. The line of best fit was derived by linear regression.

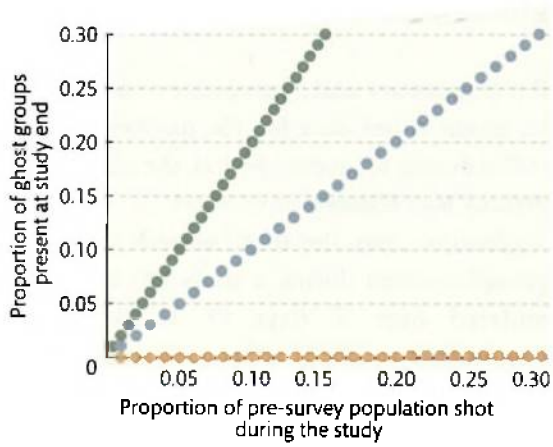


Downwards adjustments to EDU estimates for ghost groups in the 36 areas ranged from 1–14%. 78% of adjustments lay in the range 2–12%. As might be expected, the relationship between the proportion of ghost groups present in a count and the proportion of the deer population culled in a study area during a survey is strong (proportion of ghost groups = 0.529 * proportion of pre-survey population shot during survey – 0.0005; r^2_{adj} = 62.3%; df = 35; $p < 0.0001$). The residual variation in the proportion of ghost groups present is explained by variations in the timing of the cull during the studies. Some areas had similar numbers of deer culled on a week-to-week basis throughout the study whilst some had disproportionately large numbers culled over very short periods at the beginning or the end of the survey period.

The effect is illustrated in a simulated study area where a combination plot assessment is undertaken over ten weeks (70 days) in an enclosed population of 1000 roe deer defecating at 16.5 groups per day on average. Three runs of the model show the same population culled at a range of intensities mirroring those measured in real studies (1–30% of the pre-study population) but with the entire cull taken at midday on the first day, the entire cull spread uniformly across all 70 days and the entire cull taken at midday on the last day (Figure A25).

Figure A25

A simulation of an enclosed population of 1000 roe deer (defecating at 16.5 groups per day) where the same proportion of cull is taken over a 70 day period of faecal accumulation, but the cull is taken at varying times. In the first run (orange), the entire cull is taken at midday on the first day of the study. In the second run (blue), the cull is spread uniformly across all 70 days. In the third run (green), the entire cull is taken at midday on the last day.



Glossary

Accumulation period	Time over which faecal pellet groups have accumulated on the ground between two visits to sample plots.
CV	Coefficient of variation. The ratio of the standard deviation to the mean multiplied by 100 (to convert it to a percentage).
EDU	Effective Deer Utilisation. The number of deer that would have produced the number of faecal pellet groups observed, had all the deer been present in the survey area throughout the entire survey period.
FAR	Faecal Accumulation Rate. A method of estimating animal abundance using the density of faecal pellet groups that have been deposited between two points in time.
FSC	Faecal Standing Crop. A method of estimating animal abundance using the density of faecal pellet groups present at one point in time.
Variance	A statistical term describing the spread of sample points around the mean value.
Return time	See 'Accumulation period'.

Notes

Dr Graeme Swanson spent ten years studying wild deer in the Scottish uplands. He now teaches biology in New Zealand but was previously a Director of Strath Caulaidh Ltd, a consultancy specialising in ecological research. His main interests are in estimating deer abundance in a range of habitat types, modelling deer population dynamics and quantifying the impacts of deer in woodlands.

Douglas Campbell has spent over ten years developing methods to quantify the dynamics of a wide range of ecological systems in the UK uplands. He is the Managing Director of Strath Caulaidh Ltd. His main interests are in quantifying and modelling herbivore abundance and impacts in woodlands and open range, restoring damaged semi-natural vegetation and investigating the hydrology and ecology of blanket mires during windfarm development.

Dr Helen Armstrong has spent over twenty years studying the impact of large herbivores on ecosystems. She is currently the co-ordinator of the herbivore impacts programme at the Northern Research Station, one of the main research stations of Forest Research. Her main interests are in modelling deer population dynamics and predicting the impacts of large herbivores on woodlands.

There are six species of deer living in Britain today and one or more species can be found in most woodlands. At low densities deer browsing rarely impairs tree growth and can enhance the biodiversity value of woodlands. At higher densities, however, deer may affect the success of woodland establishment and damage biodiversity. It is often necessary to control deer populations through culling to limit these effects. Land managers need a means of measuring the numbers of deer on their land to help them set appropriate culling targets and discover how effective control measures have been.

This Bulletin describes a technique for measuring deer abundance in woodlands. The technique is a variation of the faecal accumulation rate method and was developed and refined using data from more than ten years of monitoring and research by Strath Caulaidh Ltd. In justifying their choice of each element of the technique, the authors also provide one of the most comprehensive overviews of dung counting methods available. This Bulletin will be of use to both deer managers and deer researchers as well as being of interest to those considering using a dung counting method to monitor the density of other herbivore species.

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