

# Forest management and Hen Harrier *Circus cyaneus* conservation in Ireland

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Hen Harriers *Circus cyaneus* are birds of prey that are of conservation concern in Ireland where the population is small and in decline. Hen Harriers typically use upland habitats such as heather moorland and bog during the summer breeding season but will also use pre-thicket coniferous forest. Extensive afforestation of upland habitats has contributed to a decline in suitable nesting and foraging habitat for breeding Hen Harriers across their range. We used data from The 2015 National Survey of Breeding Hen Harrier in Ireland, forest data sources and CORINE land class maps to explore the abundance of five broad habitat categories in areas around Hen Harrier territories. The results demonstrate a concerning lack of heath and bog habitat at landscape-scale surrounding typical Hen Harrier breeding territories in Ireland. The high proportion of habitat of poor suitability in the landscape may reduce the reproductive potential of breeding Hen Harrier pairs, ultimately impacting at the population level. We discuss these habitat mosaics in the context of forest management options that are relevant to Hen Harrier conservation. Hen Harriers are vulnerable to commercial forestry and we outline key forest management options and land-use considerations to enhance habitat suitability for breeding Hen Harriers. We provide recommendations for future study, policy and management practice aimed at protecting Hen Harriers and their habitats.

## Introduction

Hen Harriers *Circus cyaneus* are medium-sized birds of prey that characteristically inhabit and use upland habitats in Europe during the summer breeding season, particularly heather moorland and grass-dominated moors (Fuller 2012). The species has experienced prolonged population declines across its range and, hence, is listed under Annex I of the EU



Birds Directive (European Council Directive 2009/147/EC) and is a Species of European Conservation Concern (Staneva & Burfield 2017). The Irish population is of national conservation concern (Colhoun & Cummins 2013), with a small and declining population of between 108 and 157 breeding pairs

**Plate 1.** Hen Harrier (Richard T. Mills).

recorded in The 2015 National Survey of Breeding Hen Harrier in Ireland (Ruddock *et al.* 2016). Conservation measures to protect Hen Harriers have been in place in Ireland since 2006 when the Hen Harrier Farm Plan Scheme was initiated. Six Hen Harrier Special Protection Areas (SPAs) were designated in the Republic of Ireland in 2007, with the objective of maintaining viable populations both nationally and within the Natura 2000 network. There is a requirement for member states in the EU to manage Natura 2000 sites to maintain sufficient suitable habitat for species of qualifying interest, such as Hen Harriers. In the wake of landscape degradation and land-use change across large areas of their preferred open heath and bog habitats (Watson 1977; Redpath *et al.* 1998; Amar *et al.* 2008; Wilson *et al.* 2009), Hen Harriers now also use pre-thicket coniferous forests i.e. forests  $\leq 12$  years post-planting, prior to significant foliage development (Petty 1996; Wilson *et al.* 2009; Geary *et al.* 2018), particularly during the breeding season. Coniferous forests provide favourable conditions for foraging harriers during the early growth stages and their use of forested habitats declines as the volume of foliage increases towards the end of the pre-thicket forest stage (Madders 2003, Wilson *et al.* 2009). The forests then remain un-useable by Hen Harriers for the remainder of the forest cycle (Arroyo *et al.* 2009, Madders 2000).

Anthropogenic land-use change in the uplands is a significant concern for Hen Harrier conservation as land-use change can have both direct (e.g. increased disturbance) and indirect (e.g. loss of habitat) effects (Amar & Redpath 2004). The disturbance of breeding birds of prey and reduction in the quality and quantity of foraging and nesting habitat can result in territory and/or nest desertion (McClure *et al.* 2018), changes to adult behaviour (González *et al.* 2006), reduced breeding success (Caravaggi *et al.* in press; Strasser & Heath, 2013), and impairment of chick growth (Remacha *et al.* 2016). Upland habitats in Ireland that are suitable for Hen Harriers have, and continue to be, subjected to many anthropogenic impacts that could have important implications for breeding Hen Harriers. These include livestock grazing (Douglas *et al.* 2008), illegal burning (Renou-Wilson *et al.* 2011), peat extraction (O'Riordan *et al.* 2015), recreation (Hynes & Buckley 2007), construction and transport (Jennings & Kane 2015), wind energy development (Fernández-Bellon *et al.* 2019), afforestation and forest management (Bonsu *et al.* 2015, National Parks & Wildlife Service 2015).

Forest expansion across traditional open heath and blanket bog Hen Harrier habitats in the uplands of Ireland and the UK has been associated with population declines in these areas (Watson 1977, Bibby & Etheridge 1993, Ruddock *et al.* 2016). In the Irish uplands, peatlands in particular, have been subject to extensive afforestation since the middle of the last century (Connolly 2018). Although there has been a downward trend in planting on peatland since 1990, forest

expansion continues across Ireland, and is now principally undertaken by private landowners (DAFM 2018a). Total forest cover is projected to increase from the current 11% to as much as 18% by 2046 (DAFM 2014), which will have significant further implications for Hen Harrier conservation.

Despite the persistence of Hen Harriers in forested landscapes across upland areas in Ireland and the UK, their populations in both areas continue to decline (Ruddock *et al.* 2016; Wotton *et al.* 2018). Recent research suggests that while breeding Hen Harriers are often associated with pre-thicket coniferous forests, upland habitat mosaics that include a substantial amount of forest may in fact be sub-optimal for the species and may negatively impact breeding success (Caravaggi *et al.* in press, Amar *et al.* 2003, Wilson *et al.* 2012). Moreover, forest management activities are among the human impacts most commonly associated with Hen Harrier territories (Ruddock *et al.* 2016). While the impacts of coniferous forest habitats may not directly or immediately affect breeding Hen Harrier pairs, sub-lethal effects (e.g. disturbance of foraging behaviour, reduction of foraging habitat and prey availability, accumulated stress, and increased predation risk associated with forest edge effects) may ultimately lead to population declines (e.g. Beckerman *et al.* 2007). Sensitive planning and management of commercial forests can be used to reduce/minimise negative impacts on species conservation (e.g., Kortland *et al.* 2011). Further, established plantations can support conservation objectives through small, targeted modifications in operations (Hartley 2002).

Key forest activities in Ireland are regulated by the Department of Agriculture, Food and the Marine, primarily via the Forestry Act 2014 and the Forestry Regulations 2017 (Statutory Instrument [S.I.] 191 of 2017). This includes forest management activities, such as afforestation, tree felling and forest road works undertaken by the private sector as well as by Coillte, the state-owned commercial forestry business. The Forestry Act 2014 also serves to integrate and link previous S.I.s more closely with the Habitats Directive, the Birds Directive and the Environmental Impact Assessment Directive. While the protection of Hen Harrier populations, and maintenance of sufficient habitat, is an important national conservation policy objective, extensive forest expansion in upland areas has been responsible for creating a challenging conflict between Hen Harrier conservation and forestry activities (Bonsu *et al.* 2015, 2019), as well as a negative human perception of such large scale forestry in some areas (Ní Dhubháin *et al.* 2009). Forest management should aim, therefore, to develop and promote sustainable forest management in line with EU directives, while attempting to maximise the economic, environmental and social value of forests. Research-based knowledge has an important role to play in the management of conservation conflicts (Hodgson *et al.* 2019), and scientific evidence is required to underpin the

development of strategies to reconcile the conflict between Hen Harrier conservation and forest expansion targets.

The aim of this study was to investigate the potential role of forest management in enhancing the habitat value of forests for Hen Harriers in Ireland. We examined forest management in Ireland in the context of Hen Harrier conservation, focusing on habitat mosaics that are associated with Hen Harrier territories and those management options that are likely to confer the greatest benefits to Hen Harrier conservation. We then review key forest management options and land-use considerations to provide recommendations for, policy, management practice and for future study.

## Methods

A total of 108 records of confirmed Hen Harrier territories collected during The 2015 National Survey of Breeding Hen Harrier in Ireland were provided by the National Parks and Wildlife Service (NPWS). Data collection was undertaken by staff, members and volunteers from the NPWS, BirdWatch Ireland (BWI), Irish Raptor Study Group (IRSG) and Golden Eagle Trust (GET), university researchers and ornithological surveyors across Ireland. Hen Harrier territories were classified as confirmed based on the behavioural and organisational categorisation of Ruddock *et al.* (2016).

Hen Harrier territories and nests were surveyed from a distance of 500–1000 m to minimise the risk of disturbance (Garcia & Arroyo 2002; Ruddock *et al.* 2016), therefore nest locations should be considered to be approximations. However, geo-referenced points were assumed to be actual

nest locations for the purposes of this study. Each nest location was buffered to 1 km, 2 km and 5 km, distances, selected to represent potential foraging distances from the nest and to facilitate comparisons with previous studies (Caravaggi *et al.* in press; Irwin *et al.* 2012; Arroyo *et al.* 2014; Wilson *et al.* 2009).

The total cover of five key Hen Harrier habitats, identified a-priori and according to their presence in the landscape, was calculated around each of the 108 nest locations and within each buffer. Previous research has demonstrated that Hen Harriers exhibit positive or negative associations with these habitats during the breeding season (see Caravaggi *et al.* in press): (i) agriculture and pasture (negative); (ii) broadleaved forest (negative); (iii) heather moorland, bog and shrub (positive); (iv) pre-thicket ( $\leq 12$  years, post-planting) coniferous forest (positive); and (v) post-thicket ( $> 12$  years post-planting) coniferous forest (2012; negative; see Table 1). Forest data were obtained from Coillte (public forests in Ireland), DAFM (private forests in Ireland), the Forest Service Northern Ireland (public and private forests) and the CORINE 2012 Land Cover dataset (European Environment Agency 2016; see Table 1). Coillte, DAFM and Forest Service forests were grouped as broadleaved or coniferous, where mixed forest with  $\leq 50\%$  coniferous cover were classified as broadleaved and mixed forest with  $> 50\%$  coniferous cover were classified as coniferous. We randomly selected four Hen Harrier territories, based on differences in the habitat mosaics present within 5 km of nest locations (i.e. where each contained a different amount of each land class), to serve as exemplars in our discussion of forest management and Hen Harrier conservation (Figure 1).

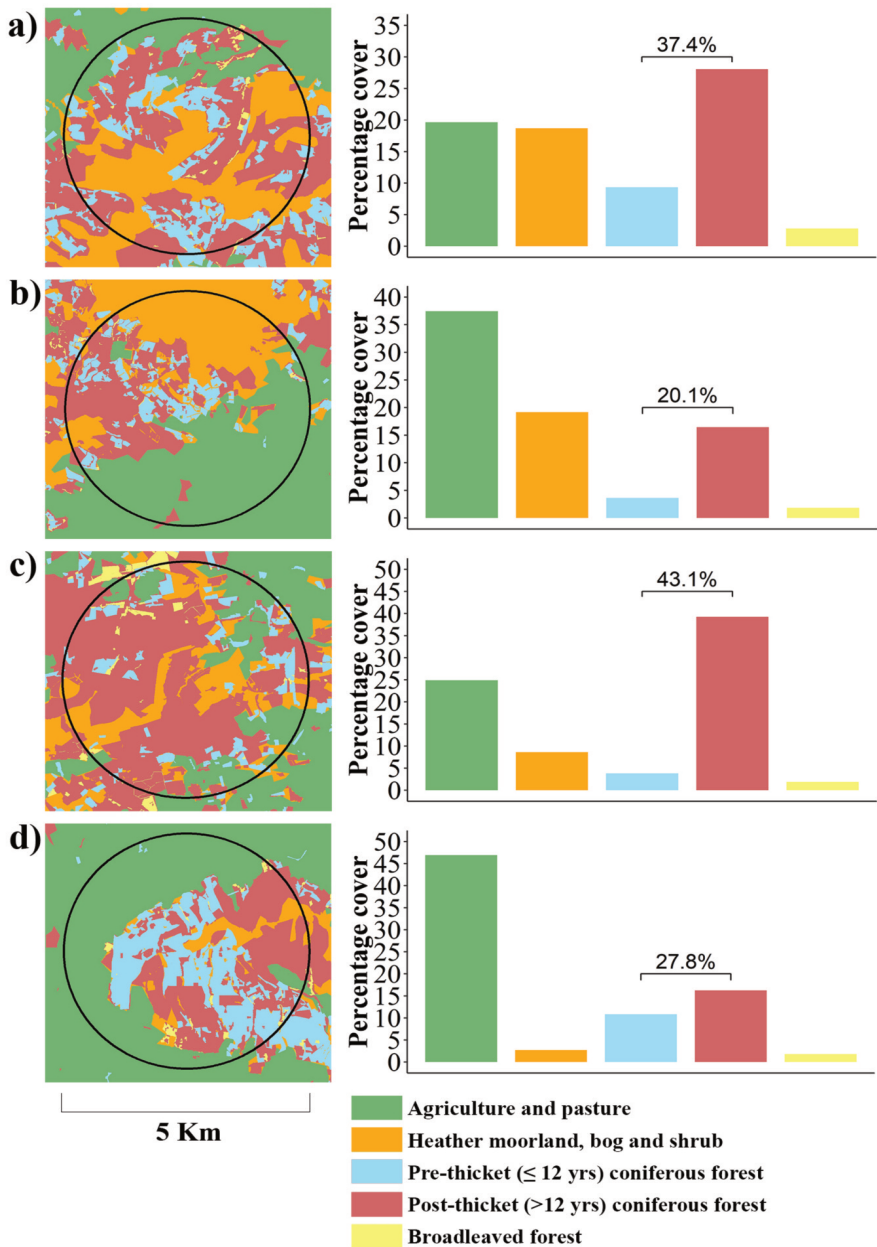
**Table 1.** Data used to calculate the proportional cover of each habitat in a 5 km buffer around confirmed Hen Harrier territories in 2015 (see Figure 1). CORINE class details are given in parentheses where appropriate. Coniferous forest data were subset based on time-from-planting in Coillte, NPWS and Forest Service Northern Ireland shapefiles.

Habitat	Source	References
Agriculture and pasture	CORINE (2.1.1. Non-irrigated arable land; 2.3.1. Pastures; 2.4.2. Complex cultivation patterns; 2.4.3. Land principally occupied by agriculture)	Wilson <i>et al.</i> 2012; Feys <i>et al.</i> 2013; Sachslehner <i>et al.</i> 2016; Geary, Haworth & Fielding 2018
Broadleaved forest	Coillte; NPWS; Forest Service Northern Ireland; CORINE (3.1.1. Broad-leaved forest)	Moran & Wilson-Parr 2015
Coniferous forest (Pre-thicket: $\leq 12$ years; Post thicket: $> 12$ years)	Coillte; NPWS; Forest Service Northern Ireland; CORINE (3.1.2. Coniferous forest)	Madders 2000; Wilson <i>et al.</i> 2009; Wilson <i>et al.</i> 2012; Sachslehner <i>et al.</i> 2016
Heather moorland, bog and shrub	CORINE (3.2.2 Moors and heathland; 3.2.4. Transitional woodland shrub; 3.3.3. Sparsely vegetated areas; 4.1.2. Peat bogs)	Madders 2000; Arroyo <i>et al.</i> 2009; Amar & Redpath 2004; Cormier <i>et al.</i> 2008; Arroyo <i>et al.</i> 2009; Irwin <i>et al.</i> 2011; Wilson <i>et al.</i> 2012

Forest management options were extracted from the Plan for Forests & Freshwater Pearl Mussel in Ireland: Consultation Document 2018 (DAFM 2018b; Table 2) that was identified as the best source of relevant, contemporary information (K. Collins, Forest Service and P. Neville, Coillte, pers. comm.).

Management options relevant to Hen Harrier conservation were identified a-priori based on their likely application in upland habitats that are used by breeding Hen Harriers.

Data processing and management were carried out using the statistical program R (R Core Team 2019).



**Figure 1.** Aerial land class maps and proportional land cover across five habitat categories (see Table 1) at four representative Hen Harrier territories. Black circles represent 5 km buffers centred on Hen Harrier territories. The total amount of coniferous forest across both age classes is also given.

**Table 2.** Forest management options in Ireland (under the Forestry Act 2014). Adapted from DAFM (2018).

Afforestation	Tree felling		Forest access	Ancillary works <sup>†</sup>
	Thinning & clearfell	Post-clearfell		
No afforestation			No access	Brash mats
Agro-forestry	Standard thinning	Broadleaved reforestation	Co-operative roading	Brash removal
Native woodland	None – retain	Conifer reforestation	New forest road	Drain management
Standard afforestation	None – clearfell	Mixed forest reforestation	Road abandonment	Fell-to-waste
	Aerial extraction	Conifer regeneration	Temporary access	Fire
	Cable extraction	Natural, native regeneration	Track network for CCF	Grass seeding
	Clearfell at maturity	Permanent forest removal		Grazing
	Pre-mature clearfell	Permanent native woodland via Biodiversity and Water (BIO) objective		Invasive species
	Over-mature clearfell	Permanent native woodland via CCF objective		Mechanical horses
	Continuous Cover Forestry (CCF)			Motor manual felling
	Halo-thinning			Pollard native broadleaves
	Over-thin			Reduce product range
				Ring barking
				Settlement areas
				Timing of operations

<sup>†</sup> Sediment and nutrient control, grazing, invasive species, fire, hazardous material

## Results

Heather moorland, bog and shrub and post-thicket forest were the most abundant land classes at the 1 km and 2 km distances from Hen Harrier nests. Total coniferous forest cover accounted for up to 97% (3.1 km<sup>2</sup>;  $\bar{x}$  = 1.6 km<sup>2</sup> ± 0.8 km<sup>2</sup>) of total land cover at 1 km, 92% (11.6 km<sup>2</sup>;  $\bar{x}$  = 5.7 km<sup>2</sup> ± 2.5 km<sup>2</sup>) at 2 km and 83% (65.2 km<sup>2</sup>;  $\bar{x}$  = 22.2 km<sup>2</sup> ± 12.6 km<sup>2</sup>) at 5 km. Agriculture and pasture accounted for up to 97% of total land cover at 5 km, though average coverage (21%) was lower than heather moorland, bog and shrub (24%). The proportional abundance of post-thicket forest in the landscape was comparable across all buffers (27% at both 1 km and 2 km, 24% at 5 km). In contrast, the abundance of pre-thicket forest in the landscape declined from the 1 km scale ( $\bar{x}$  = 22%) to 5 km ( $\bar{x}$  = 12%). Similarly, the amount of bog and heath/shrub surrounding territories declined with increasing buffer distance, from an average of 45% at 1 km to 24% at 5 km (Figure 2).

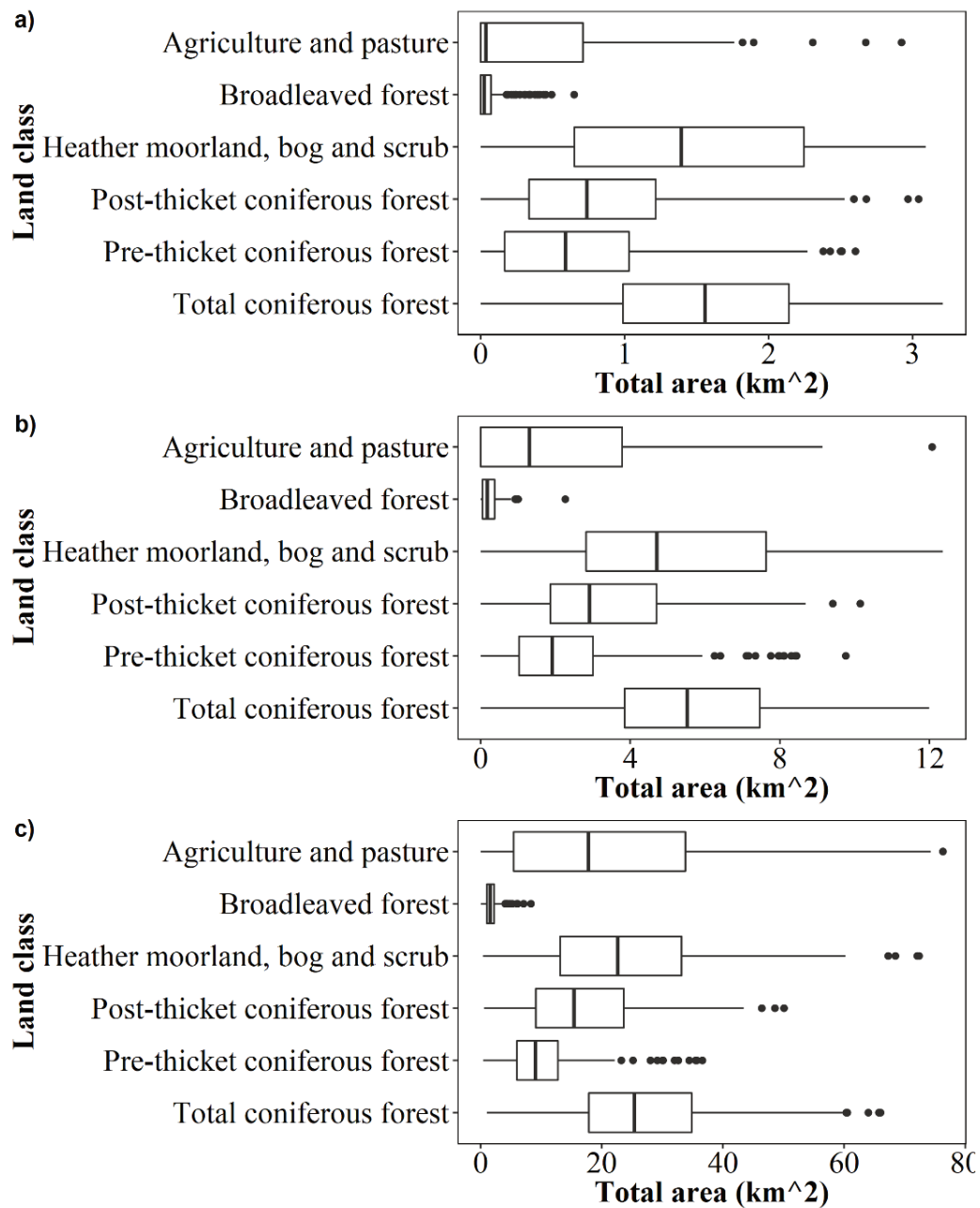
A total of thirteen forest management options described in the Plan for Forests & Freshwater Pearl Mussel in Ireland: Consultation Document 2018 (DAFM, 2018b) were identified as having particular relevance for the conservation of breeding Hen Harriers (Tables 2 and 3). These included options related to forest growth and regeneration, such as standard afforestation, reforestation for wood production and other reforestation options. Options that conceptually support the

creation and maintenance of open spaces in the uplands included no afforestation, no thinning, clearfell, permanent forest removal and fire (Table 3).



**Plate 2.** Hen Harrier (Shay Connolly).





**Figure 2.** Proportional land cover for key habitat types (see Table 1) within (a) 1 km, (b) 2 km, and (c) 5 km of confirmed Hen Harrier territories. *Pre-thicket coniferous forest* = ≤ 12 years, post-planting. *Post-thicket coniferous forest* = >12 years post-planting.

**Table 3.** Forest management options (under the Forestry Act 2014) with particular relevance to Hen Harrier conservation in Ireland. Adapted from DAFM (2018).

Management option	Description
<i>Afforestation</i>	
No afforestation	Afforestation licenses are not granted. No forestry-related disturbance to the site.
Standard afforestation	Afforestation using conventional techniques. This can include thinning, respacing, shaping, roading, harvesting and reforesting.
<i>Thinning &amp; clearfell</i>	
No thinning, retain indefinitely	All operations are excluded and the crop is allowed to develop and grow indefinitely. There is no on-site disturbance.
No thinning, leading to clearfell	No thinning on site; crop is clearfelled at a future point.
Clearfell at commercial maturity	Crop is harvested at financial maturity.
Pre-mature clearfell	Clearfelling before financial maturity and the site is likely reforested with native species or reverted to open habitat. Allows the restructuring and age-fragmentation of forest blocks.
Over-mature clearfell	Crop is retained past the age of financial maturity. Can be used to break up age structure of forests.
<i>Post-clearfell</i>	
Reforestation for wood production	Standard option for reforesting objectives, where environmentally appropriate.
Other reforestation options	Natural regeneration of commercial and/or native species.
Permanent forest removal	Forest removal on all or part of the site on the grounds of overriding environmental considerations, Natural processes proceed to restore the site to natural habitat(s).
<i>Forest access</i>	
New forest road	Construct new forest road or upgrade existing roads to create or extend network.
Road abandonment	Road abandoned and no longer used.
<i>Ancillary works</i>	
Motor manual felling	Chainsaw operations where the use of traditional harvesting machinery is not suitable.
Fire	Burn off old vegetation to promote new growth

## Discussion

The Irish uplands have been the focus of extensive habitat modification (Huang 2002; Eaton *et al.* 2008), such that traditional upland habitats have now become degraded, fragmented and increasingly scarce. The consequences of this land use change are clearly demonstrated by the results of the current study which show that breeding Hen Harrier territories are associated with a considerable amount of unsuitable habitat, even in close proximity to nest sites. The abundance of post-thicket coniferous forest at all distances (up to 5 km) from the nest site, and an increase in agriculture and pasture at 5 km suggests that many breeding pairs are subject to limited foraging opportunities and prey availability. Hen Harriers are unable to hunt effectively in closed canopy

woodlands or agriculturally improved grassland habitats (Madders 2000; Arroyo *et al.* 2009). In landscapes such as those recorded in this study, foraging birds may be forced to travel further during the breeding season to meet the energetic demands of growing chicks, thus exposing the nest to increased risk from predation and stochastic weather events. The impacts of landscape composition and food abundance on foraging flight distances and the reproductive potential of breeding birds have been demonstrated for several species (e.g. Tremblay *et al.* 2004; Barbaro *et al.* 2007; Hinam & Clair 2008; Evens *et al.* 2018). Hen Harriers in Ireland have been shown to range over greater distances than their counterparts in Scotland (7.5 km, compared with 4 km for females and 11.4 km compared with 9 km for males, respectively; Arroyo *et al.* 2009; Irwin *et al.* 2012). Furthermore, the

reproductive output of Hen Harriers in Ireland is also generally lower than that of those in Scotland (Irwin *et al.* 2011, though some of the Irish population match or exceed UK breeding successes). While the specific mechanisms driving these differences and variations are yet to be determined, it is reasonable to suggest that a lack of suitable foraging habitat and available prey are contributing to the decline of Hen Harriers in Ireland.

Several Hen Harrier territories examined in this study were found in locations adjacent to tracts of heather moorland, bog and shrub (Figures 2a, b) – habitats that are favoured by the species (Caravaggi *et al.* in press; Fuller 2012; Geary *et al.* 2018). In contrast to closed-canopy coniferous forests and agriculture and pasture, these areas, where present, may provide foraging Hen Harriers with good hunting opportunities close to the nest site, thus reducing the time spent away from the nest and vulnerable eggs or chicks. Heather moorland, bog and shrub can also act as effective foraging corridors in a heavily forested landscape (Bell 2003; Eggers *et al.* 2010; e.g. Figure 2c), facilitating movement and foraging between patches of favourable habitat. During the 20th century, peatlands in Ireland were specifically targeted for afforestation. Reflecting the shift from public to private planting observed in recent decades, fewer forests are now being planted on peatland. At present, 39.2% of forests occur on peatland while the remaining 60.8% occur on mineral soils (Forest Service 2018). However, much of the extant bog and heather moorland in Ireland has been degraded as a result of peat extraction (Renou-Wilson *et al.* 2011) and overgrazing (Stevenson & Thompson 1993). The maintenance and improvement of habitat mosaics that contain areas of heather moorland, bog and shrub across their upland breeding areas will be an important consideration in habitat management for the benefit of foraging Hen Harriers.

The on-going maturation of the existing forest estate will lead to a reduction in the extent, and greater fragmentation, of upland habitats that are suitable for breeding Hen Harriers. In the absence of open heather moorland, Hen Harriers in Ireland typically use pre-thicket coniferous plantations for nesting and foraging (Wilson *et al.* 2009, 2012; Irwin *et al.* 2012; Ruddock *et al.* 2016). These areas may offer nest concealment and protection from predators, though their efficacy in this regard when compared with heather moorland has not been established. Pre-thicket forests are also often lacking the Hen Harrier's preferred avian prey species, Meadow Pipit (*Anthus pratensis*) and Skylark (*Alauda arvensis*), and other open-country passerines (e.g. Wilson *et al.* 2006; AMcC, unpublished data). Hen Harriers in Ireland will also take small mammals, such as bank voles (*Clethrionomys glareolus*) and wood mice (*Apodemus sylvaticus*) (O'Donoghue 2010). However, in contrast to avian prey, small mammals typically prefer areas with dense ground



**Plate 3.** Hen Harrier (Richard T. Mills).

cover (Gliwicz 1989) and occur at higher densities in pre-thicket forest than moorland (AMcC, unpublished data). Research has shown that while Hen Harriers use young coniferous forest areas for foraging, their use of forested habitats declines as the volume of foliage increases towards the end of the pre-thicket forest stage (Madders 2003; Wilson *et al.* 2009; Fuller 2012). Thus, territories that contain a high proportion of pre-thicket coniferous forest cover (e.g. Figures 1d) will become increasingly unsuitable over time as the trees mature. Similarly, breeding Hen Harriers in areas with a greater abundance of heather moorland, bog, and shrub (e.g. Figures 1a vs Figures 1d) may endure further spatial restriction of nesting sites and foraging areas with further forest expansion.

There are a range of forest management options available to decision makers that vary according to the local forestry objectives and the type of development undertaken. Over half of the existing forest estate in Ireland is more than 20 years old (Forest Service 2018), and, hence is unusable by Hen Harriers during the breeding season. Forest management options that allow clearfelling (e.g. clearfell at commercial maturity, premature clearfell, and over-mature clearfell) may be of some utility in providing the species with nesting and foraging habitat, particularly during the subsequent regeneration of dense, complex ground cover. Hen Harriers may not select a nest site until late in the pre-thicket forest growth cycle, if indeed they adopt it at all. Forest fragmentation, age, patch



size, and edge effects can be particularly important considerations for area-sensitive species (Conner & Dickson 1997; Imbeau *et al.* 2001; Loehle *et al.* 2005). Therefore, the maintenance of a balanced distribution of age classes within forested areas with the goal of delivering a continuous supply of pre-thicket habitat that will better support breeding Hen Harriers and their preferred prey than would extensive cover of post-thicket forests.

While Hen Harriers across Ireland and the UK typically occupy open ground within new coniferous forests (Petty & Anderson 1986; Jenkins 1988; Madders 2000; Geary *et al.* 2018), the question of how they might use the pre-thicket stage of areas reforested following clear-fell has only recently arisen as much of afforested planted estate has completed its first rotation. Despite a number of reports of their use of second rotation forests in the UK, studies found that the suitability of second rotation conifer forests for Hen Harriers is lower than that of first rotation forests, as the occurrence of small felling areas within large forest blocks restricts access to suitable foraging sites (Petty & Anderson 1986). Furthermore, the ground vegetation in second rotation forests may be poor or absent as a result of canopy shading by mature trees. Thus, pre-thicket second rotation forest may be less suitable as nesting habitat while prey may be less available to foraging Hen Harriers (Madders 2000; Calladine *et al.* 2015). However, these differences in use appear to be confined to the UK; Hen Harriers in Ireland do not show differential use of the pre-thicket stage of first and second rotation (Wilson *et al.* 2009). Management interventions at the post-clearfell stage of plantation forests offer the opportunity to provide areas of suitable habitat, create habitat mosaics and patchworks of different aged stands, and to enhance connectivity with open habitats in forested landscapes, making them more suitable for Hen Harriers.

Forest management activities such as forest roads, manual felling and fire present potential disturbances to Hen Harriers. Intrusive anthropogenic activities have been shown to cause disturbances that negatively impact many breeding birds of prey. For example, breeding Cinereous Vultures (*Aegypius monachus*; Margalida *et al.* 2011) exposed to manual cork harvesting had 20% lower breeding success than those in the same colony that were not exposed to this disturbance. Thus, forest management activities such as harvesting (e.g. motor manual felling) and extraction have the potential to disturb breeding Hen Harriers. Hen Harriers in Ireland have been recorded abandoning nest sites, with 11% of all nests across three study sites being abandoned in 2010 (Irwin *et al.* 2011). While no causal factors for nest abandonment were identified, it is likely that human disturbance was a contributory factor in some instances, as seen with many other birds of prey (McClure *et al.* 2018). Forest activities related to forest access, such as new forest road, can have considerable impacts on

breeding birds of prey, including increases stress levels (Krone *et al.* 2019). For example, Tapia *et al.* (2004) found that roads and tracks that cause the destruction of suitable foraging and nesting habitat are among the most important threats to Hen Harrier populations in Spain. In Ireland, the Nagles and Ballyhours in particular, forest roads and tracks are frequently used by off-road motor vehicles such as scrambler motorbikes and quad bikes, resulting in increased disturbance to wildlife (TN, pers. obs.). The temporal context of 'disturbance' is also variable throughout the breeding season. For example, the aggressive behaviour of breeding Hen Harriers towards conspecifics (Garcia & Arroyo 2002) and consequences of disturbance (García 2003) may vary according to the stage of the breeding season. Aggression increases through pre-laying, incubation and nestling stages; thus, the active disturbance distance for Hen Harriers in response to anthropogenic factors such as forestry operations can be as much as 1 km during the breeding season (Ruddock & Whitfield 2007).

## Conclusions

The protection of Hen Harrier populations and habitats in Ireland is a key national policy objective. In the current study we highlight the high proportion of unsuitable agriculture, pasture and post-thicket forest in habitat mosaics surrounding Hen Harrier territories. Our results suggest that further forest expansion and maturation of the existing forest estate will limit foraging opportunities for breeding Hen Harriers with implications for reproductive output, and potential for population-scale impacts. Forest management planning for Hen Harrier conservation should aim to maintain areas of pre-thicket forest cover and reduce areas of post-thicket forest cover. At the landscape level, heather moorland, bog and shrub habitats should be excluded from future forest planting, as these are critical to maintaining population viability. Forest management aimed at Hen Harrier population consolidation and reinforcement should be focussed on areas around and including known Hen Harrier strongholds in the first instance. Management processes should also embrace strategic, selective clearfelling to create a semi-structured age mosaic within the forest, forest removal, and the restoration of typical upland habitats favoured by Hen Harriers and the small passerines on which they depend. Future research should incorporate Hen Harrier ecology and landscape use outside the breeding season, thus informing conservation solutions that can support the species year-round and across the entirety of Ireland. Finally, we propose that the future of Hen Harriers in Ireland will only be secured if decision makers embrace focussed, adaptive, and long-term solutions that truly reconcile human interests with the conservation of biodiversity.

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