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Breeding ecology and habitat selection of Merlin *Falco columbarius* in forested landscapes

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Abstract

Capsule: Long-term trends in Merlin *Falco columbarius* breeding performance remained stable during a period of extensive afforestation in Ireland, where Merlin predominantly select conifer plantations for nesting.

Aims: To determine breeding performance and habitat selection of Merlin in a landscape significantly altered by afforestation.

Methods: We compiled data on Merlin to determine long-term trends in breeding performance and to examine habitat selection in a country with one of the fastest rates of afforestation in Europe.

Results: Merlin predominantly nested in trees (99.5%; $n = 183$ pairs), with a strong preference for conifer plantations, which accounted for over 12 times more nests than expected by random selection. Moors and heathland were strongly selected as land-uses adjacent to nest sites. Most nests were located within 10 m of the forest edge, and in forests aged between 31 and 40 years. Merlin showed positive selection for moors and heathland, peat bogs and natural grasslands within breeding territories, and breeding success was positively related to the proportion of these land-uses surrounding nests. Breeding was successful for 74% of nests ($n = 300$), and mean productivity was 2.1 young per breeding attempt ($n = 265$) between 1982 and 2014. Breeding parameters remained constant over the 33-year study period, despite an increase of more than 75% in forest cover during this time.

Conclusion: Merlin breeding performance showed no long-term effects of increased afforestation. Although Merlin predominantly nested in conifer plantations, the presence of nearby open suitable foraging habitats influenced nest site selection and breeding success. The nesting preference of Merlin makes them vulnerable to disturbance from forest operations, which requires mitigation.

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Throughout their breeding range across northern latitudes of Europe, Asia and North America, Merlin *Falco columbarius* use a wide variety of open habitats (Sale 2015, Ewing *et al.* 2011). Due to their widespread distribution, low population densities in remote areas and secretive breeding behaviour, Merlin are a challenging species to monitor (Bibby & Nattrass 1986, Ewing *et al.* 2011, Lusby *et al.* 2011, Sale 2015). This is reflected in the limited information available on their status, population trends and breeding ecology. As a raptor that specializes on hunting open country passerines, Merlin may be especially vulnerable to land-use changes, particularly the loss or degradation of open suitable habitats (Orchel 1992, Rebecca 2006). Afforestation of open habitats is a major, on-going cause of land-use change throughout Europe (Hansen *et al.* 2013). However, there is conflicting evidence on the impacts of afforestation on Merlin populations (Bibby & Nattrass 1986, Orchel 1992, Little & Davison 1992, Parr 1994, Little *et al.* 1995, Rebecca 2006).

Typically, afforestation results in declines of open habitat bird species, while benefitting generalists and forest specialists (Allan *et al.* 1997, Dias *et al.* 2013). For Merlin, this relationship is more complex, as afforestation may provide increased opportunities for nesting (Norriss *et al.* 2010, Lusby *et al.* 2011, Rebecca 2011), while simultaneously reducing the availability and suitability of habitats for foraging (Newton *et al.* 1978, Orchel 1992, Rebecca 2006). Since the late 1970s, Merlin populations in parts of Britain have switched from ground nesting in heather moorland to nesting in trees in conifer plantations, in response to long-term degradation of moorland habitats and increased forest cover (Newton *et al.* 1986, Parr 1991, Little & Davison 1992 , Orchel 1992, Hardey *et al.* 2009, Rebecca 2011). Not all forests are suitable however, and previous work

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has found that Merlin tend to breed in mature conifer plantations and frequently select the tallest trees, leaving them potentially vulnerable to disturbance from forest management operations (Orchel 1992, Norriss *et al.* 2010). The net effect of this shift in nesting behaviour remains unclear, as varying breeding success rates have been recorded for ground nesting compared to tree-nesting Merlin populations (Newton *et al.* 1986, Parr 1991, Little & Davison 1992, Little *et al.* 1995, Williams & Parr 1995).

At the landscape scale, Merlin preferentially hunt avian prey in open and semi-open habitats (Cade 1982, Fernández-Bellon & Lusby 2011) and the spread of afforestation is generally thought to have had a negative impact on their populations (Orchel 1992, Rebecca 2006). Although the British Merlin population as a whole has increased or remained relatively stable since the 1980s (Bibby & Nattrass 1986, Ewing *et al.* 2011), regional declines over this period have occurred, the drivers of which are poorly understood (Ewing *et al.* 2011). Some regional studies, for example in the northeast and southwest of Scotland, have linked declines in Merlin densities to increased afforestation (Orchel 1992, Rebecca 2006). In contrast, afforestation in Wales and northeast England appears to have had little effect on Merlin, possibly because moorland habitats have remained extensive in these areas (Petty *et al.* 1995). Thus, the overall effect of afforestation on breeding Merlin across Britain remains unclear and there is a need to investigate the influence of this land-use change across their range.

In Ireland, at the western and southern limit of the breeding range of Merlin in Europe (Sale 2015), afforestation has progressed at one of the fastest rates in the world (Forest Service 2013). There has been an increase from 5.9% forest cover in 1985 to 10.5% in 2012 in the Republic of Ireland, with targets set by the Irish government to reach 18% forest cover by 2046 (Forest Service 2013, DAFM 2014a). Breeding Merlin are widespread in Ireland but are sporadically distributed in upland habitats and lowland bogs, where most forest planting has taken place (Norriss *et al.* 2010, Balmer *et al.* 2013). There has also been a shift in the Irish population to nesting in commercial forest plantations since the 1970s, but, in contrast to Britain, tree nesting is probably now the dominant nesting choice in Ireland (Norriss *et al.* 2010). This difference is likely due to the limited availability of ground nesting opportunities in Ireland, where the expansion of planted forest coincided with a more widespread reduction in heather cover (Bleasdale 1998). In Britain there are relatively fewer but larger planted forests, while in Ireland afforestation patterns have been more fragmented, which may also be more conducive to the emergence of tree nesting (Norriss *et al.* 2010). The effects of these changing land-use patterns in Ireland on the fortune of Merlin are not known. Here we compiled the largest and longest running dataset on breeding Merlin in Ireland to (i) identify breeding site selection at the nest site scale; (ii) quantify Merlin breeding habitat selection at the landscape scale; (iii) determine long-term and regional trends in Merlin breeding performance; (iv) identify the risks associated with forest management activities to breeding Merlin.

Methods

We collated Merlin breeding data from published and unpublished sources, from monitoring studies undertaken between 1982 and 2014 (Table 1). We compiled 343 records of individual territories with confirmed breeding Merlin pairs. Active territories across years that were within 3.5 km of one another were defined as the same territory (Rebecca *et al.* 1992). For each breeding territory ($n = 343$) a centre point was identified, which was the position of the nest where this was known ($n = 183$), or allocated based on evidence of breeding activity where the exact nest site was not located ($n = 160$).

All data were standardized and compiled in a database. Breeding territory locations were assigned to

Table 1. List of studies collated for this analysis, including regions, period and data collected.

Regions	Years	No. confirmed pairs	Breeding success (pairs)	Productivity (pairs)	Nest habitat Recorded (pairs)	Published Source
Antrim Hills & Sperrins	1990–2014	163	155	151	125	n/a
Inishowen/north Donegal, Kildare, Mayo, South Donegal & Wicklow	1982–1992	141	107	78	19	Norriss *et al.* (2010)
Connemara & Mayo	2005–2014	27	26	26	27	n/a
Wicklow	2000–2014	11	11	9	11	n/a
Inishowen/north Donegal	2004	1	1	1	1	n/a
All regions	**1982–2014**	**343**	**300**	**265**	**183**	

Notes: Breeding territory records varied in the detail which ranged from the confirmation of a breeding pair (based on observations of both adults and/or breeding behaviour which included courtship display, copulation, defence of a nesting area, prey delivery or visual confirmation of an active nest) to more detailed information on the outcome of breeding, the specific location of the nest site, and nest site characteristics including the nest habitat type, adjacent habitat to the nest and distance to the forest edge for forest nests.

a 10 km × 10 km square (henceforth, 10 km square) using the Irish Transverse Mercator coordinate system. The 10-km square sampling unit was selected to include suitable habitats, as well as habitats and land-uses likely to be avoided by breeding Merlin, to allow for assessment of nest site selection. All confirmed breeding territories ($n = 343$) were contained within 56 10 km squares (of 1019 10 km squares on the island of Ireland), henceforth referred to as the study area (Figure 1). The study area was divided into eight regions to determine any spatial variation in habitat selection and breeding parameters. The regions were defined based on geographic location, and the discrete nature of these upland areas as well as land-use and habitat similarities (Figure 1).

Mapping of nests and territories

Breeding Merlin territories were mapped using ArcGIS-ArcMap® 10.2 (ESRI Inc., Redlands, CA). All land-use types in each of the 10 km squares that contained breeding Merlin territories ($n = 56$) were assigned to 1 of 22 land-use categories, using CORRINE Land Cover (CLC) maps from 1990, 2000, 2006 and 2012 as appropriate. Forest plantations were further classified using the Forest Inventory Planning System (FIPS) (Forest Service 1999) to determine the proportion of forest cover, patch size and age of forests within the study area. The elevation above sea level (m, asl) of the centre point of breeding Merlin territories was determined using ArcGIS.

Using ArcMap, buffers of 500 m, 2 km and 5 km were drawn around territory centre points. As the home range size of breeding Merlin in western Europe is not known, these distance bands were selected to determine land-use selection at scales which are likely to influence Merlin breeding performance, habitat and nest site selection.

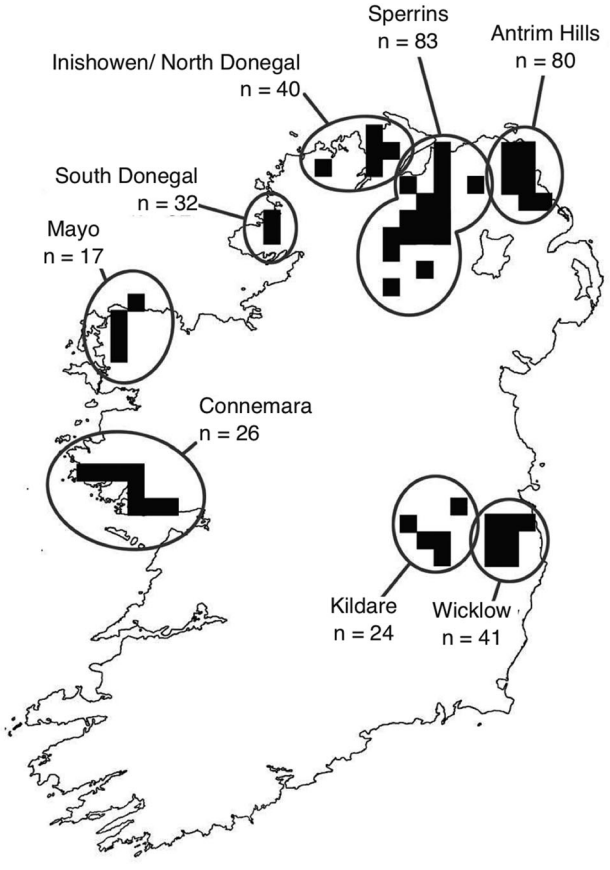

Figure 1. The distribution of all 10 km squares ($n = 56$) containing breeding Merlin territories ($n = 343$) included in this study, showing the number of breeding territories in each region ($n = 8$).

Nest site selection

To investigate nest site selection, two sets of random control points were generated using the Random Point Generator in ArcMap within the 10 km squares ($n = 42$) which contained Merlin nests of known location ($n = 183$). Firstly, five control points were generated at random within each of these 42 10 km squares, hereafter referred to as 'random controls' ($n = 210$). Secondly, to assess in greater detail the nest site selection preferences of tree-nesting Merlin in forest plantations, control points were also randomly generated across all planted forests within these 42 10 km squares, hereafter referred to as 'forest controls' ($n = 890$).

All Merlin nest sites of known location ($n = 183$) were assigned to a CLC category using ArcGIS and CLC maps, or information on nest habitat recorded on original datasets. The adjacent habitat type to Merlin nest sites ($n = 134$) was defined as the land-use type closest to the nest as distinct from that in which the nest was located. This was determined using ArcGIS and CLC maps, or information recorded on original datasets which were assigned to the relevant CLC category. Distance of the nest to the forest edge using three distance categories (<10, 10–20 and >20 m) was determined using ArcGIS ($n = 71$). Forest patch size (ha) ($n = 131$) and forest age ($n = 48$) using six age categories (0–10, 11–20, 21–30, 31–40, 41–50 and >50 years) were determined using ArcGIS and FIPS data. The land-use types of the random controls were determined using ArcGIS and CLC maps. For each forest control the adjacent habitat type, distance of the forest control point to the forest edge, patch size and age of forest which held each forest control were determined using ArcGIS, CLC and FIPS data.

Breeding habitat selection

Two approaches were used to assess Merlin breeding habitat selection. Firstly, all land-use types within the 500 m and 2 km buffer zones were compared with the land-use within all 10 km squares in the study area ($n = 56$) to determine preferences of breeding Merlin for individual land-use types relative to availability. Secondly, the same approach was repeated with all land-uses grouped into three categories: 'forests' (all forest habitats); 'open suitable habitats' (moors and heathland, peat bogs and natural grasslands) and 'other' (all other urban, intensive and enclosed agricultural land-uses) to assess Merlin breeding habitat selection at a broader scale.

Breeding performance

Three measures were used to quantify Merlin breeding performance: (i) breeding success, defined as whether a pair fledged one or more young in a single year ($n = 300$ pairs); (ii) number of fledged young defined as the number of young raised to, or close to, fledging for successful pairs only ($n = 188$ successful pairs); (iii) productivity, the number of fledged young for all breeding attempts with known outcome, including unsuccessful nests ($n = 265$ breeding attempts). We assessed the effects of temporal and regional variation, as well as land-use cover (at the 5 km landscape scale) on Merlin breeding performance.

Data analysis

All data analyses were carried out using R 3.1.2 (R Development Core Team 2015).

Merlin nest site selection was assessed using two-sample Kolmogorov–Smirnov tests to compare the habitat and nest site characteristics to control points, and Welch two-sample t-tests were used to assess nest location within forest plantations. Two-sample z-tests were used to compare the proportions of habitats and land-uses selected for nesting to those available.

Merlin breeding habitat selection was assessed using two-sample Kolmogorov–Smirnov tests to compare the land-use within 500 m and 2 km of territory centre points to total land-use availability in the study area (56 10 km squares).

Breeding performance was modelled with generalized linear mixed models (GLMMs) using the R package glmmADMB lme4 (Fournier *et al.* 2012, Skaug *et al.* 2014). Breeding success, fledging success and productivity were modelled as a function of the fixed effects year, region and land-use. The total amount of open suitable habitat (moors and heath, peat bog and natural grassland) and total forest cover forest within 5 km of territory centre points were included as two separate habitat variables. For breeding success, the response variable was specified as 0/1, thus we used a binomial model. For fledging success and productivity, the response variable (total number of chicks) was count data, thus we started with a Poisson model (log link). The mean number of chicks was fewer than five, so we used Laplace approximation. We fit a region-by-year interaction term to test whether there were region-specific differences in breeding variable temporal trends. We also tried to fit a quadratic year effect but due to sample size the model failed to converge. Our 'full' model used fixed effects (Year + Region + Total forest cover + Total suitable habitat) and accounted for non-independence of data from the same territories across years by including a 'territory ID' random effect. The model estimating productivity including the two habitat variables had a higher Akaike information criteria value, therefore these terms were dropped from the final model. Visual inspection of residual plots did not reveal any deviations from homoscedasticity or normality.

Results

Nest site selection

Merlin nesting areas ranged in elevation from 12 m asl in Connemara in west Galway to 585 m asl in the Wicklow Mountains (mean elevation was 229 m asl, range 12–585 m asl, $n = 343$). The habitats selected for nesting by Merlin were significantly different to their occurrence in the study area ($D = 0.5$, $P = 0.04$). The majority of nests located ($n = 183$) were in trees (99.5%), most of which were within coniferous forest (80.8%), as well as on densely vegetated islands on water bodies (12.5%), in open woodland (3.8%), isolated trees (1.6%) and a single copse (0.5%) (Figure 2).

Merlin showed a positive selection for coniferous forest ($z = 14.57$, $P < 0.01$) which accounted for over 12 times more nests than expected if selection were random. Densely vegetated islands on inland water bodies were the next most important nest site habitat ($n = 23$), with 23 times more nests than expected by random selection ($z = 4.75$, $P < 0.01$). Ground nesting was actively avoided with only a single ground nest (0.5%) recorded in moors and heathland which represented 7% of the available land surface area of the study area. Nests were located nearly 12 times less frequently in moors and heathland than would have occurred at random ($z = -3.18$, $P < 0.01$).

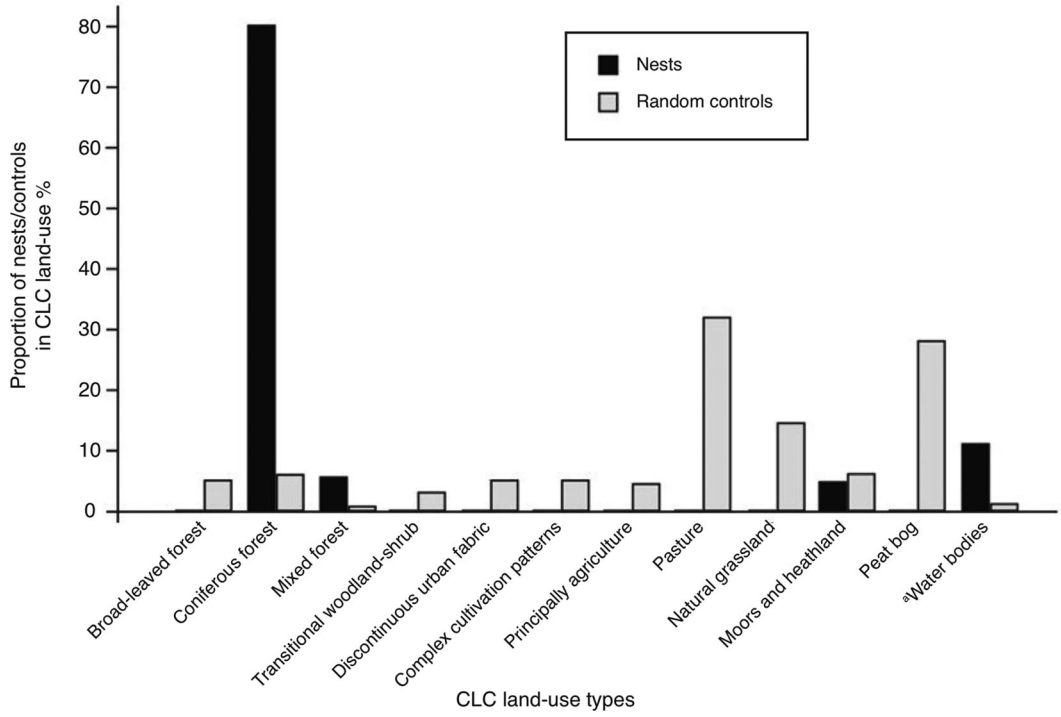

Figure 2. The proportion of actual nest locations ($n = 183$) and random controls ($n = 210$) in each land-use category (CLC). Enclosed land-uses and those associated with cover are shown on the left with more open land-uses on the right. Note: [a]All nests recorded on water bodies were in trees on densely vegetated islands on lakes, these nests were included in the CLC 'Water body' category to reflect the importance of this unique nesting habitat as opposed to within the 'Broad-leaved forest' or 'Mixed forest' category given the fact that the densely vegetated islands on water bodies were not typical of either of these land-use categories.

For Merlin nests in forest plantations, there was a significant difference between adjacent habitat type to the nest ($n = 134$) and to forest controls ($n = 890$) ($D = 0.5$, $P = 0.04$). The majority of nest sites in forest plantations were located adjacent to moors and heathland (5 times more than expected; $z = 12.02$, $P < 0.01$), and peat bogs (4 times more than expected compared to forest controls; $z = 9.08$, $P < 0.01$) (Figure 3).

Within forest plantations nests were not located at random (df = 103.16, $P < 0.01$) as 91.5% of nests ($n = 71$) were located within 10 m of the forest edge (average for forest control points was >200 m, $n = 890$). The mean patch size of plantations selected was 1347 ha (se = 105.68, range 0.8–4,060 ha; $n = 131$). The age of forests utilized ($n = 48$) ranged from 11 to 20 years ($n = 5$), to forests more than 50 years ($n = 2$), with the majority of nests located in forests aged between 31 and 40 years ($n = 27$; 56.2%; >3 times more nests compared to other forest age groups). There were no nests recorded in the forests younger than 10 years.

Breeding habitat selection

The relative availability of land-use types in the study area was significantly different to the proportion within 500 m ($D = 0.4762$, $P = 0.01$) but not within 2 km ($D = 0.2857$, $P = 0.3$) of Merlin nests. Coniferous forest was the most abundant land-use within 500 m (25% land cover) and 2 km (19%) of nests compared to its availability in the wider study area (6.8%). Pastures were the least abundant land-use within 500 m (4.1%) and 2 km of nests (8%), compared to the availability of this land-use in the wider study area (27.5%) (Figure 4).

The proportion of 'open suitable habitats' (moors and heathland, peat bogs and natural grasslands) were similar within 500 m and 2 km of nests at 60.5% and 64.2%, respectively, which were both greater than the availability of these land-uses in the wider study area (47%), indicating positive selection for these land-uses. The proportion of 'other' land-uses (urban, intensive and enclosed agricultural land-uses) was over 4 times and 3 times less abundant within 500 m (9.4%) and 2 km (13.2%) of nests, respectively, compared with the study area (41.3%), indicating a negative selection of these combined land-use types (Figure 5).

Breeding performance

Merlin breeding success in this study was 74% between 1982 and 2014 ($n = 300$ pairs). An average of 3.0 young fledged per successful pair (se = 0.06, $n = 188$, range

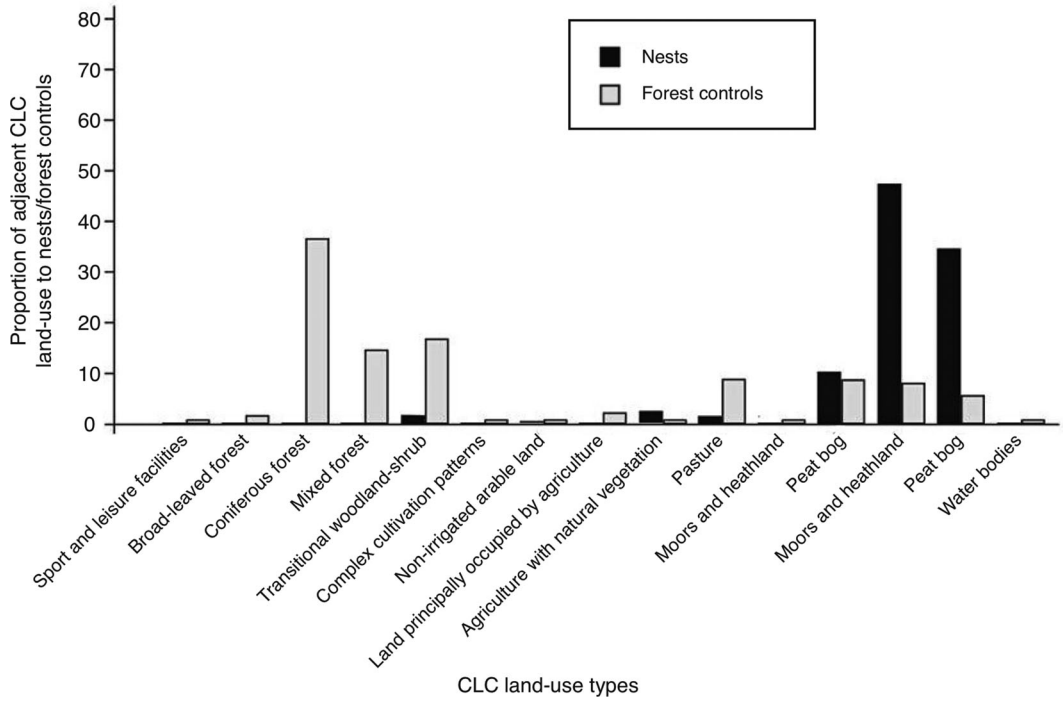

Figure 3. The proportion of available land-uses adjacent to nest sites ($n = 134$) and forest controls ($n = 890$). Enclosed land-uses and those associated with cover are shown on the left with more open habitats on the right.

1–5), with a productivity of 2.1 young per breeding attempt (se = 0.09, $n = 265$, range 0–5) (Table 2).

There was no significant change in Merlin breeding success (GLMM: $P = 0.09$), fledging success (GLMM: $P = 0.48$) or productivity (GLMM: $P = 0.83$) over the 33-year study period. However, there were regional differences in both breeding success and productivity over the years shown by the interaction term region*year (Table 3).

The proportion of 'open suitable habitat' within 5 km of nest sites was positively related to breeding success (GLMM: $P = 0.05^*$), but did not affect fledging success

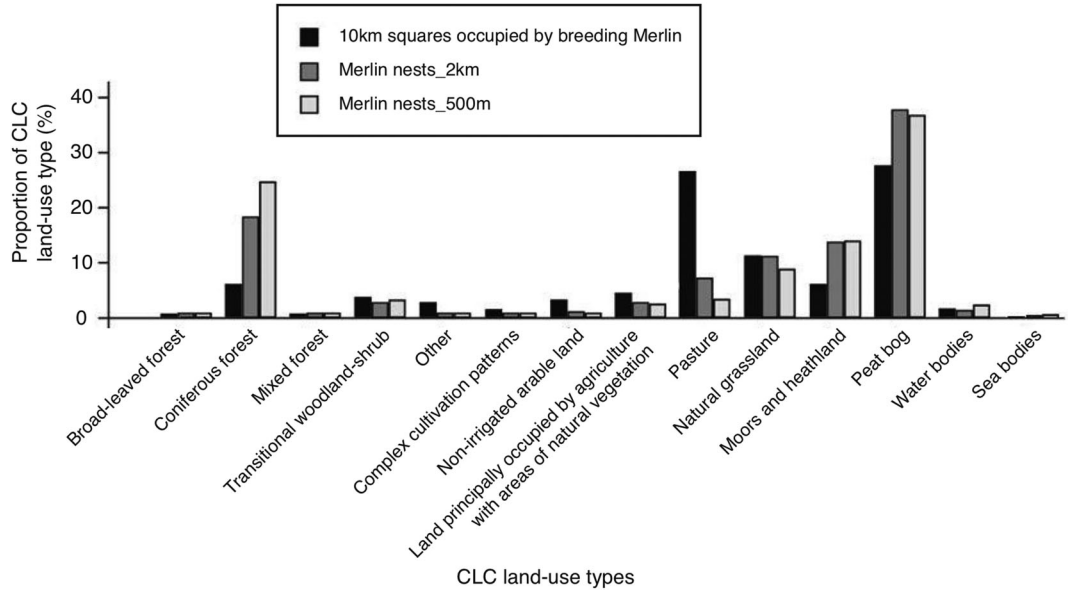

Figure 4. The proportion of land-use types (CLC) within all 10 km squares ($n = 56$) occupied by breeding Merlin pairs, and within 2 km and 500 m of confirmed breeding pairs ($n = 343$). Enclosed land-uses and those associated with cover are shown on the left with more open habitats on the right.

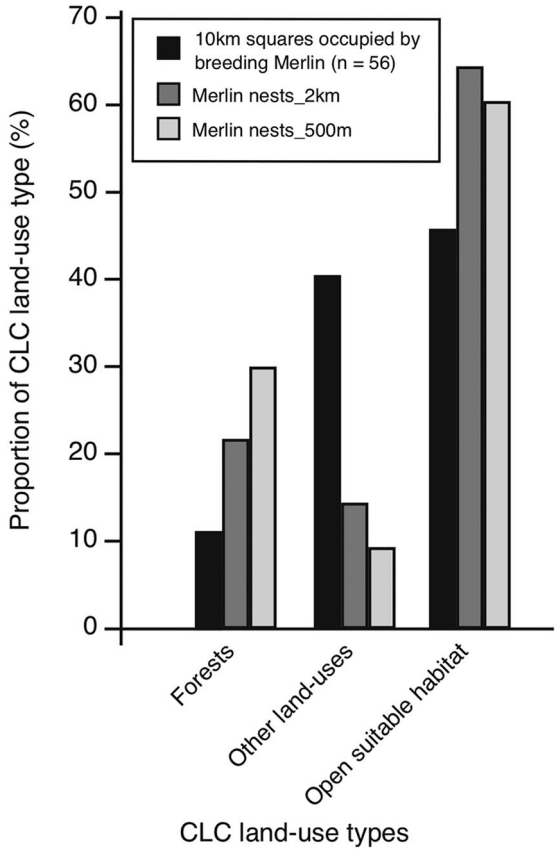

Figure 5. The proportion of grouped habitats (forests, open suitable habitats and other habitats) within all 10 km squares ($n = 56$) occupied by breeding Merlin pairs and within 2 km and 500 m of confirmed breeding pairs ($n = 343$).

or productivity. The extent of total forest cover within 5 km of nest sites did not have a significant effect on Merlin breeding parameters (Table 3).

Discussion

Nest site selection

This study confirms that conifer plantations are now commonly selected by Merlin for nesting in Ireland, and that ground nesting has become rare. There has been a significant decrease in the availability of Merlin's preferred habitats in Ireland over the past century as heather cover has decreased (Bleasdale 1998) and many Irish peatlands are now overgrazed (Fuller & Gough 1999). The national forest estate has increased from just over 1% in 1928 to 10.5% in 2012 (DAFM 2012b) which has been primarily driven by afforestation on peatland habitats which has further reduced the availability of heather moorland. Although favourable ground nesting conditions may still exist in certain upland areas and lowland bogs in Ireland, in general heather cover of sufficient quality is limited and this appears to have had a profound impact on Merlin nesting behaviour over the past 40 years (Norriss *et al.* 2010). The importance of conifer plantations for nesting observed in this study is unlikely to be an artefact of survey methods or bias, as forest nesting Merlin are considered more difficult to find compared with ground nesting pairs (Hardey *et al.* 2009, Norriss *et al.* 2010).

In Ireland, although there is a limited availability of suitable ground nesting conditions, overall it is not known whether the availability of nest sites impacts the population. Because Merlin use the tree nests of other species, particularly corvids, the availability of nest sites for Merlin is dictated by the nest site choice and densities of corvid species. In Ireland, Hooded Crows *Corvus cornix* are widespread and their population has remained stable in recent decades (Balmer *et al.* 2013). A high Merlin breeding success rate (74%) coupled with the fact that the majority of breeding territories were used for more than one year indicates that where there are commercial forest plantations of suitable age, the availability of nest sites is unlikely to be a limiting factor for Merlin. It is likely that the presence of open suitable habitat in proximity to forest plantation, as shown by positive selection for these land-uses together, is an equally important factor which

Table 2. Merlin breeding parameters in Ireland (1982–2014) compared to breeding data for Merlin populations in Britain.

Location	Years	Breeding success	No. sites	Fledged/Successful attempt	No. sites	Productivity	No. sites
Ireland (this study)	**1982–2014**	**74%**	**300**	**3**	**188**	**2.1**	**265**
Orkney[a]	1981–1987	44%	61	2.8	61	1.3	61
Wales[b]	1975–1982	43%	42	3.5–3.8	42	–	–
NE Scotland[c]	1980–1989	65.5%	328	3.5	166	2.2	232
Shetland[d]	1984–1987	71%	86	3.4	61	2.4	86
Yorkshire[e]	1983–1994	85%	82	3.4	82	2.9	82
Northumbria[f]	1961–1976	65–66%	182	3.6	182	2.3	182
Northumbria[g]	1974–1983	–	275	3.3	275	1.9	275
Britain[h]	1983–1984	65%	498	3.4	498	2.2	498
Britain[i]	1993	–	450	3.1	292	2.0	450
Britain[i]	1994	–	451	3.5	324	2.5	451

[a]Meek (1988); [b]Roberts & Green (1983); [c]Rebecca *et al.* (1992); [d]Ellis & Okill (1990); [e]Wright (1997); [f]Newton *et al.* (1978); [g]Newton *et al.* (1986); [h]Bibby & Nattrass (1986); [i]Rebecca (2011).

Table 3. GLMMs showing the influence of year, region, habitat and the interaction between region and year on; (i) breeding success and (ii) productivity.

	Breeding success model				Productivity model			
	Estimate	se	*z* Value	Pr(>*z*)	Estimate	se	*z* Value	Pr(>*z*)
Intercept	1.98E + 02	1.17E + 02	1.7	0.090	0.925	0.263	3.51	0.0004***
Suitable habitat within 5 km of nests	1.88E−08	9.57E−09	1.97	0.049*	–	–	–	–
Total forest cover within 5 km of nests	−3.83E−09	2.02E−08	−0.19	0.849	–	–	–	–
Year	−9.80E−02	5.82E−02	−1.69	0.092	−0.001	0.012	−0.14	0.890
Region Connemara[a]	−1.03E + 03	3.91E + 02	−2.64	0.008**	−7.417	2.096	−3.54	0.0004***
Region Inishowen	−2.08E + 02	3.37E + 02	−0.62	0.537	0.144	0.486	0.3	0.766
Region Kildare	9.96E + 00	4.11E + 02	0.02	0.980	−0.416	0.663	−0.63	0.530
Region Mayo	4.01E + 02	5.61E + 02	0.71	0.475	1.253	0.854	1.47	0.142
Region South Donegal	4.34E + 01	3.27E + 02	0.13	0.894	0.309	0.578	0.54	0.592
Region Sperrins	−2.87E + 02	1.42E + 02	−2.02	0.043*	−0.297	0.364	−0.82	0.415
Region Wicklow	−5.80E + 02	2.11E + 02	−2.76	0.005**	−1.134	0.401	−2.82	0.00475**
Year: Region Connemara	5.13E−01	1.95E−01	2.64	0.008**	0.245	0.070	3.47	0.00052***
Year: Region Inishowen	1.04E−01	1.69E−01	0.61	0.540	−0.003	0.043	−0.08	0.934
Year: Region Kildare	−6.95E−03	2.07E−01	−0.03	0.973	−0.025	0.085	−0.3	0.760
Year: Region Mayo	−2.03E−01	2.82E-01	−0.72	0.471	−0.224	0.115	−1.94	0.052
Year: Region South Donegal	−2.33E−02	1.65E−01	−0.14	0.887	−0.145	0.087	−1.66	0.095
Year: Region Sperrins	1.43E−01	7.11E−02	2.01	0.0441*	0.006	0.017	0.37	0.713
Year: Region Wicklow	2.90E−01	1.06E−01	2.75	0.006**	0.051	0.019	2.7	0.006**

[a]Reference Region is Antrim Hills.

influences nest site selection as well as landscape suitability for Merlin.

Breeding habitat selection

Our analyses showed that breeding Merlin occupy a wide elevation range and diversity of habitats in upland landscapes and lowland bogs across Ireland. Conifer plantations were a dominant land-use type within Merlin breeding territories, second only to peat bogs within 500 m and 2 km of the centre point of breeding territories, and were preferentially selected. This may be influenced by the fact that afforestation in Ireland has traditionally focused on peatland habitats (Wilson *et al.* 2012) and therefore is more likely to occur in close proximity to traditionally preferred Merlin habitats. Although breeding Merlin selected conifer forests at the nest site scale, their use or avoidance of this habitat for foraging is not known. In Ireland, given the limited availability of suitable heather moorland for ground nesting, afforestation may have allowed Merlin to exploit nesting opportunities in areas with open suitable foraging habitat but where preferred ground nesting options are limited. However, once suitable nest sites are available, the extent of forest cover may subsequently have a negative effect on Merlin, as has been reported for some Merlin populations in Britain (Newton *et al.* 1978, Orchel 1992, Rebecca 2006).

In southwest Scotland, it has been estimated that a minimum of 20 km^2 of grass and heather moorland, within a mosaic of approximately 60% moorland and 40% forest within 4 km of nests is necessary for Merlin territories to remain viable (Orchel 1992). In Wales, a proportion of 70–80% moor adjacent to nests was deemed necessary to sustain Merlin populations (Parr 1991). The average proportion of open suitable habitats (peat bog, natural grassland and moors and heathland) within 5 km of breeding territories recorded by this study was 59%, which is slightly lower than UK estimates at the 4 km scale (Parr 1991, Orchel 1992). The average proportion of total forest cover within 5 km of breeding Merlin territories in Ireland was 11%, and did not exceed 35% land cover within 5 km of a nest. Although we did not detect a relationship between breeding performance and the extent of forest cover within breeding territories, it is likely that where forest cover is more extensive than observed within the territories in this study (e.g. over 35% forest cover with 5 km surrounding nest sites), the suitability for breeding Merlin would be reduced.

Breeding performance

Breeding success of Irish Merlin (74%) was higher than reported by most studies in the UK, although the number of fledged young and overall productivity were lower or similar (Table 2). Failed breeding attempts of Merlin can be difficult to detect (Newton *et al.* 1978, Norriss *et al.* 2010, Lusby *et al.* 2011), which may cause bias in estimating breeding success. The recorded productivity of 2.1 young for Irish Merlin in this study was within the range recorded for a population regarded as stable in northeast Scotland, which produced between 1.7 and 2.2 young per pair (Rebecca *et al.* 1992), and greater than a Merlin population in Northumberland which was increasing with a productivity of less than 2 young per pair (Little & Davison 1992). Although the observed productivity of Irish Merlin varied annually, it

remained constant over the 33-year study period. This suggests that increased afforestation has not affected the breeding performance of established pairs, however we did not have data on Merlin density trends over this period. It is clear that further investment in monitoring will be needed to generate rigorous population density estimates sufficient for assessing trends into the future to inform conservation management.

Merlin breeding success and productivity varied spatially in this study. Highest productivity rates were recorded in regions that were also at the highest latitudes (Antrim hills, Inishowen/north Donegal and the Sperrins). Ireland is situated at the southern and western edge of the breeding range of the Eurasian Merlin (Sale 2015), and the breeding bird atlas (2007–11) shows a strong bias in distribution of Merlin towards the northern half of Ireland (Balmer *et al.* 2013). The fact that the Irish population is at the south western edge of the Merlin's range (Sale 2015) may be a factor in their lower productivity relative to populations in the UK. Nest site selection and breeding success of Merlin across the study area were influenced by the availability of 'open suitable habitats' at the 5 km scale. Although we did not detect a relationship between land-use and productivity of Merlin, a more detailed habitat assessment to include data on habitat management and prey availability would be beneficial to better understand any habitat effects on Merlin breeding ecology at a fine scale and at a wider landscape scale, including the regional differences in breeding performance.

Conclusion

The upland landscape within the breeding range of Irish Merlin has been significantly altered through the extensive afforestation of previously open habitats. The majority of breeding Merlin in Ireland now nest in the abandoned nests of other bird species in forest plantations, and, in the absence of other available nesting sites such as deep heather moorland, the population is now largely reliant on this resource. This study demonstrates that Merlin do not use young forests (<10 years) for nesting. Forests from 11 years to those older than 50 years were used for nesting, with most pairs nesting in forests between 31 and 40 years, which is within the age range for felling or thinning operations in commercial forests. This, coupled with the fact that Merlin naturally occurs at low population densities, highlights the importance of ensuring that forest management operations do not negatively impact their breeding performance. Although Merlin nest in forest plantations, the presence of open suitable habitats in proximity to forest influences nest site selection and breeding success. Long-term trends in Merlin breeding performance have not been negatively influenced by increased afforestation. However, in the absence of strategic monitoring, uncertainty over true population densities and trends remain. The information on Merlin nest site selection and habitat use derived from this study should inform conservation efforts for this species, particularly afforestation planning to ensure habitat suitability for breeding Merlin is maintained in important areas for the population. In addition, the information on Merlin breeding ecology should be used to inform a more efficient survey protocol for Merlin which is essential to identify the main threats to the species; to underpin the development of site-specific mitigation and a national conservation strategy; and to monitor the impacts of conservation actions into the future.

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