



The movement patterns of two populations of Twites *Carduelis flavirostris* in Ireland

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The Twite *Carduelis flavirostris* is one of only three passerines included on the red list of Birds of Conservation Concern in Ireland. As part of a study on its ecology, we investigated the local movement patterns of two populations of Twites in Counties Mayo and Donegal between January 2006 and July 2008. The breeding populations studied comprised over 40 of an estimated 54–110 breeding pairs in Ireland. Colour ringing was used to identify individual Twites in the field. In the course of this study, 492 birds were ringed, of which 480 were caught outside the breeding season; 57 (12%) were resighted on their breeding grounds. The breeding birds spent most of the winter season within 28 km of their breeding areas. We also describe the size and structure of the home ranges of 11 Twites radio tracked over four periods – March, May, June and August – on the Mullet Peninsula, County Mayo, in the northwest of Ireland. The results of this study suggest that Irish Twites are mainly sedentary and that their populations appear to be augmented by Scottish breeding birds during the winter months.

The Twite *Carduelis flavirostris* has a disjunct world distribution, being found on the coastline and mountains of northwest Europe and, over 2,700km away, in the uplands of Central Asia from eastern Turkey to Tibet and western China (Newton 1972). Twites breeding in Ireland and Britain are regarded by some as a distinct race, *C.f. pipilans*, from the nominate *C.f. flavirostris*, which occurs in Scandinavia (Marler & Mundinger 1975). Twites are listed as a Red Data species, along with being red listed in the Birds of Conservation Concern, in Ireland (Whilde 1993, Lynas *et al* 2007) and in the UK (Eaton *et al* 2009). Their population in Ireland is estimated at between 54 and 110 breeding pairs, which are mainly found along the northwest coast of Ireland (McLoughlin & Cotton 2008).

Ringing studies in Britain have shown that a considerable proportion of the South Pennines breeding population winter on the southeast coastline (Atkinson 1998, Raine *et al* 2006a). Raine *et al* (2006a) also noted that most of the birds that winter on the Cumbrian and Lancashire coasts appear to originate on the west-coast islands of Scotland. Based on field observations, data showing seasonal population variations and ring recoveries, Clark & Sellers (1998) tentatively identified three migration routes in Scotland. Amongst these routes they consider that some breeding Twites of the West Highlands and Western Isles winter in Ireland. However, Brown & Atkinson (2002) suggest that much of the Twite population

of Ireland and Scotland is sedentary, based on a small amount of ring recoveries and population distribution data shown by Lack (1986). Conversely, almost 50% of the Scandinavian breeding population moves south in winter to the saltmarshes of the Wadden Sea (Bernhoft-Osa 1965, Dierschke 1997).

As no data exist on local movements of Twites in Ireland, studies on local movement patterns are important for informing conservation strategies. This investigation is part of a wider study on the ecology of Twites in Ireland. Two wintering populations in the west and northwest of Ireland, on the Mullet Peninsula in Co. Mayo and Sheskinmore National Nature Reserve (NNR) in west Co. Donegal, were targeted as part of a colour-ringing programme. Some post-breeding birds were also ringed near known breeding colonies in Counties Donegal and Mayo. These areas are the strongholds for breeding Twites in Ireland with approximately 40 pairs of the 54–110 pairs estimated to breed in Ireland (McLoughlin & Cotton 2008). The local movement patterns of Twites in these areas are presented in this paper.

Although colour ringing is a very useful tool in determining movement patterns, accurately identifying range size and structure using this means, for example during the breeding season, can be problematic. Twite range size has previously been estimated based on field observations of ringed birds (eg Dierschke & Bairlein 2002). The primary limitation of this method is the

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inability to track an individual bird in the field (particularly a small brown passerine). Radio telemetry overcomes this problem by allowing the observer to identify an animal's location continuously, or at regular intervals. This gives the observer an accurate spatio-temporal picture of the animal's movements and activity for the life span of the transmitter (Kenward 2001, 2004). Location data can then be analysed to gain knowledge of range size and structure, which are crucial elements in determining the ecological requirements of a species at a given time of the year (Johnson 1980). For a small and inconspicuous bird such as Twite, radio tracking is the most effective means of locating the study animal and, therefore, determining its range structure and size.

Although wildlife radio-tracking technology has been used since the early 1960s (Kenward 2001), it is only recently that lightweight transmitters suitable for Twites have become available. Raine (2006) was the first to use radio telemetry on Twites. Through his research he assessed habitat use by Twites in the South Pennines, England, including details of the distance travelled from the breeding colony. In this paper, we present the size and structure of the ranges of 11 birds, which were radio tracked on the Mullet Peninsula during 2007 and 2008. Ongoing work is aimed at investigating the reasons for resource selection, which give rise to the range size and structure. This is the first time that such information has been presented for the Twite.

METHODS

Study area

Winter flocks of Twites at Termoncarragh on the Mullet Peninsula, Co. Mayo (54°15'N 10°04'W), and Sheskinmore NNR, Co. Donegal (54°49'N 8°28'W), were trapped for ringing at artificial feeding stations between October and April from January 2006 to June 2008. During the breeding season, birds were ringed near breeding colonies at Maghera, Co. Donegal (54°45'N 8°31'W), and Glenlara on the Mullet Peninsula (54°17'N 9°59'W) (Figs 1 & 2).

Twite movements

The birds trapped at these locations were fitted with colour rings, which enabled identification in the field. The first 30 birds were given a cohort colour combination. However, on account of the relatively small number of wintering birds in Ireland (the minimum winter population is estimated at 650–1,100 birds: McLoughlin & Cotton 2008), it was decided to mark each bird with unique colour-ring combinations. These birds wore two colours on the left leg with a third colour above or below a metal BTO ring on the

right leg. Birds were trapped at feeding stations provisioned with Niger *Guizotia abyssinica* seed using a whoosh net and drop-trap as described by Redfern & Clark (2001). A mist-net and tape lure were used at the other sites to target post-breeding flocks.

Range size and structure

Range size and structure were estimated using radio telemetry. Twelve Twites were fitted with a Biotrack Pip transmitter with Ag317 cells weighing 0.5 g. The battery life was approximately 18 days. Birds were trapped using the same method as for colour ringing. Radio tags were glued to the base of the central tail feathers, taking care to avoid the preen gland, and secured by tying dental floss around the tag and feather shaft. The antennae protruded beyond the tip of the tail feathers. The previous radio-tracking study on Twites by Raine (2006), along with our own observations of tagged birds, found no adverse effects on any aspect of the behaviour of the birds. They were observed to fly at the same speed, perform the same territorial displays, and forage in the same manner as the untagged birds.

Data analysis

Analysis and graphical presentation of data were made using Ranges7 (Anatrack, UK), ArcGIS Desktop (ESRI, USA), Excel (Microsoft, USA) and SPSS (SPSS Inc., USA). Range size was estimated using Minimum Convex Polygon (MCP) analysis for each individual as this method is widely used to give a broad estimate of animal ranges (eg Aebischer *et al* 1993). As these polygons often include large areas unvisited by tracked individuals (Kenward 2001), we used concave polygon analysis to minimise the unused areas. Cluster analysis was used to estimate range patchiness (Kenward 2001). Range span, the distance between the two furthest locations in an individual's range, was also estimated.

RESULTS

Twite movements

A total of 492 new birds were colour ringed between January 2006 and June 2008, of which a considerable proportion (26%) were either trapped or resighted at least 7 km from the original point of ringing (Table 1).

County Donegal

For the breeding-season ringing area at Maghera we ringed three juveniles and nine pulli from two broods in one of the three breeding colonies shown in Fig 1 between June 2006 and July 2007. As pulli were given a cohort colour combination, it was not possible to identify individuals. However, a minimum of two from each brood were noted

Table 1. Total number of Twites colour ringed (new birds); the number of retraps; and the number of controls for the four ringing sites from January 2006–June 2008.

Site	2006			2007			2008		
	New birds	Retraps	Controls	New birds	Retraps	Controls	New birds	Retraps	Controls
Co. Mayo									
Termoncarragh	172	101	77	89	45	43	13	5	2
Glenlara	95	39	6	41	25	7	3	5	15
Co. Donegal									
Sheskinmore	11	0	1	56	15	2	0	0	0
Maghera	8	0	0	4	0	9	0	0	0
Total	286	140	84	190	85	61	16	10	17

approximately 6 km to the north at Sheskinmore NNR throughout the winters of 2006/07 and 2007/08. All of the three juveniles colour ringed at Maghera were controlled at the feeding station at Sheskinmore NNR during the winter of 2006/07. Of the total of eight pairs confirmed to breed in the Maghera area, six individuals (38%) were found to have been colour ringed at the Sheskinmore site.

At the winter ringing site at Sheskinmore NNR, a total of 67 birds were colour ringed over six ringing days between November 2006 and March 2007. Six (9%) were observed to breed near Maghera at one of the breeding colonies indicated in Fig 1. One bird was later sighted and photographed at Machrihanish Bird Observatory, Mull of Kintyre, Scotland (see Discussion).

County Mayo

There were two ringing sites (Termoncarragh and Glenlara – both of which are on the Mullet Peninsula) and eight known

breeding colonies in Co. Mayo (Fig 2). Fourteen percent of birds ringed in Co. Mayo were resighted at breeding colonies within 30 km of the ringing site (Table 2).

With 33 (87%) of the Twites observed to breed on the Mullet Peninsula in 2007 and/or 2008 being ringed or controlled at Termoncarragh, it is clear that the birds that bred on the Mullet Peninsula spent much of the winter within approximately 7 km of their breeding area. Forty percent of the breeding birds observed in the 21–25km distance interval, and 25% in the 26–30km band were ringed at Termoncarragh (Fig 2). This shows that a large proportion of the breeding Twite in north Co. Mayo spent much of the winter season on the Mullet Peninsula.

From a total of 139 Twites ringed at Glenlara during the breeding season, 64 (46%) were controlled 7 km to the southwest, at Termoncarragh, during the winter season. These included 15 (11%) individuals that bred at one of the colonies on the Mullet Peninsula. In the

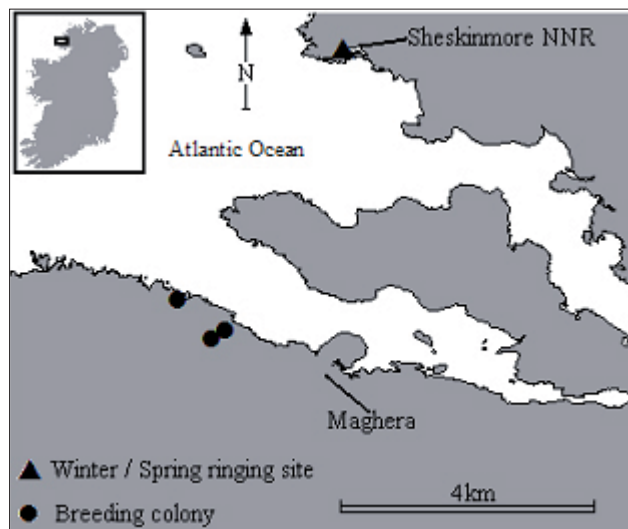


Figure 1. West Co. Donegal: the Sheskinmore NNR winter site, Maghera breeding season site, and known breeding colonies where colour-ringed birds were observed.

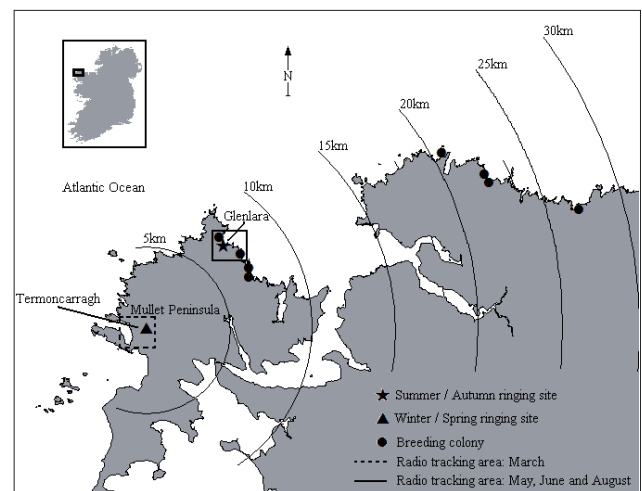


Figure 2. North Co. Mayo study areas with 5-km distance intervals from the winter ringing site at Termoncarragh and all known Twite breeding colonies in Co. Mayo. Also shown are both radio-tracking study areas at Termoncarragh and Glenlara for all tracking periods.

Table 2. Total number of recoveries in each 5 km distance interval of birds that were either ringed or controlled at Termoncarragh. A total of 274 birds were ringed at Termoncarragh between January 2006 and April 2008. The proportion of the estimated breeding population that were colour (cr) ringed in that distance interval is also given.

Distance from ringing site (km)	No. of recoveries from breeding site (% of total ringed)	Proportion of estimated population cr-ringed
0–5	0	0
6–10	28 (10%)	74%
11–15	0	0
16–20	0	0
21–25	10 (3%)	40%
26–30	2 (<1%)	25%
Total	40 (14%)	56%

breeding seasons of 2007 and 2008, 38 breeding birds were observed on the Mullet Peninsula, of which 33 were colour ringed either as juveniles at Glenlara or during the winter season at Termoncarragh. No movements were observed between Counties Mayo and Donegal during the study period.

Site fidelity

At Termoncarragh between January 2006 and January 2008, 274 Twites were ringed over a total of 13 ringing days. Thirty-six percent (73) of these birds were retrapped a number of times (>30 days after ringing) throughout the winter, indicating that they use this area for much of the winter season. Seventeen (8.5%) of the birds ringed at Termoncarragh between January 2006 and April 2007 were resighted or retrapped during the following winter, indicating a degree of site fidelity. Twelve (18%) of the total ringed at Sheskinmore were retrapped at least once, a minimum of 30 days after ringing.

Range size and structure

Eleven birds were radio tracked in two study areas in Co. Mayo to develop a picture of their home-range size and structure (Fig 2). In 2007, one male and one female were tracked in March, three males were tracked in May and three different males were tracked in June. One of the birds tracked in June lost its transmitter on the first day and thus has not been included in the analysis. Only males were tracked during the breeding season as females might have been incubating and would thus have spent long periods on the nest. In 2008, four unsexed juveniles were tracked in August, however, we failed to pick up a signal for one of these birds after the second day. All radio-tracked birds were also individually colour ringed.

The two birds tracked in March had range sizes of 75 and 112 ha. Range patchiness was very low showing that the birds concentrated their activity in a small number of feeding sites. This low range patchiness is also evident in the differences between their concave and convex range sizes (Table 3). These feeding sites were invariably associated with haylage¹ supplementary feed for cattle on machair habitat (pers. obs.). We recorded multiple resightings of colour-ringed birds that used these same feeding sites from October to April each year. The associated flock size in which the birds moved varied between approximately eight and 70 individuals. Both birds roosted in the same flock throughout the study period, but were seldom observed to use the same feeding site simultaneously.

During the breeding season (May and June), all five tracked birds showed a near-triangular range shape with the apex being the nest site to the east of the range. The notable differences between range-size estimates based on convex and concave polygons indicated that a large proportion of the ranges were not used (Table 3). This is supported by the low range-patchiness estimates (3–13 location clusters per individual). It is important to note that these birds' nests were situated in heather *Calluna vulgaris* on sea-cliffs. The minimum distance travelled from nest to foraging area was 1.06 km with a maximum distance of 1.49 km.

Although four juveniles were tagged in August (Table 3), we failed to pick up the signal of one of the birds after the second day of tracking. Data for the other three birds showed relatively small range sizes of between 24.7 and 30 ha. They were much more widely dispersed within these ranges (eg Fig 3), which are illustrated by the small difference between the convex and concave polygon area estimates. As would be expected from such a case, the range patchiness was high for these three birds, which were tracked for eight days.

The radio-tracking duration (*ie* the number of days and locations recorded) varied between individuals (Table 3) as an effect of variations in cell life and the success of tag attachment. The number of locations is confounded with the number of days, so it was appropriate to test for an effect on range size for only one of these two variables. Spearman rank correlation tests indicated that the number of locations affected range size for concave ($n = 11$, $P = 0.04$, correlation coefficient = 0.609) but not convex ($n = 11$, $P = 0.14$, correlation coefficient = 0.473) polygon range-size estimators. This indicates that a longer sampling period would result in a larger concave range size but would not affect the convex range size.

¹Haylage is a cut forage grass, stored in an airtight plastic wrap, with a moisture content between that of hay and silage.

Table 3. Range-size and structure data for individuals 1 to 11, which were tracked in four separate periods.

Individual	Month	Breeding status	Minimum convex polygon (ha)	Concave polygon (ha)	Span (m)	Range patchiness	No. of days	No. of locations
1	March	Pre-breeding	74.5	29.8	1,752	6	12	3,408
2	March	Pre-breeding	112.2	81.4	1,739	8	12	2,513
3	May	Breeding	48.8	31.3	1,448	7	10	168
4	May	Breeding	29.5	3.6	1,246	12	10	243
5	May	Breeding	25.4	3.7	1,224	3	10	55
6	June	Breeding	70.5	17.3	2,242	13	7	123
7	June	Breeding	45.3	26.8	1,436	7	7	119
8	August	Post-breeding	3.8	2.9	381	4	2	19
9	August	Post-breeding	24.8	24.7	716	21	8	328
10	August	Post-breeding	26.2	25.1	712	21	8	295
11	August	Post-breeding	31.7	30.0	756	29	8	314

DISCUSSION

Ringling of Twites in Ireland

The resighting and ringing effort was concentrated in specific locations (baited ringing stations and nesting colonies) and, due to logistical constraints, very few confirmed records could be obtained from outside these areas. However, as fewer than 25 Twites had been ringed in Ireland in the 35-year period prior to 2005, the results of this study represent a large contribution to the knowledge of Twites in Ireland.

Movement of Twites between Ireland and Scotland

Many of the Twites observed around the coast of Ireland during the winter are thought to be of Scottish origin. This view is based on the proximity of the Mull of Kintyre to the north coast of Co. Antrim (c 25 km) combined with the relatively large Scottish breeding population and the small number of breeding records in Northern Ireland (c 10 pairs: Langston *et al* 2006). The results of this study, together with data from Clark & Sellers (1998), support this view. The confirmed, photographed resighting of a Twite which had been colour ringed at Sheskinmore at Machrihanish Bird Observatory on the Mull of Kintyre highlights the link between Scottish and Irish Twites. The two previous Irish-Scottish movements of Twites were between Longay, an island east of the Isle of Skye, and Lough Foyle, Co. Derry, and between north Co. Down and the Mull of Kintyre (BTO database). Hutchinson (1989) appears to have referred to these movements as being from Inverness to Co. Donegal and north Co. Down to Strathclyde.

In addition to these three known movements, we also know of a probable fourth Ireland-Scotland movement.

A colour-ringed bird ringed at Termoncarragh on 18 November 2006 was retrapped there on 24 March 2007. Twelve days later a bird wearing the same colour-ring combination was observed in the field at Kilchoman Dunes, Islay, Scotland.

The timing of these movements between Ireland and Scotland suggests that these birds bred in Scotland and spent part or all of the winter season in Ireland. This concurs with the statement by Clark & Sellers (1998) that Twites that breed in Scotland have been known to migrate to Ireland for the winter. As the breeding areas of 88% of the 492 Twites ringed in the study areas are unknown, this suggests that a potentially large proportion of wintering Twites in Ireland may be Scottish breeders. It is important to note that some of these birds will not have survived to breed or may have bred in unknown Irish breeding colonies. Considering the very low Twite ringing effort in Ireland and along the west coast of Scotland, and the relative isolation of their breeding and wintering areas, the three confirmed and one probable movements between Ireland and Scotland are noteworthy.

The movement of Twites in the Irish study areas

Twites breeding in the Irish population strongholds appear to be generally sedentary, with many wintering within 28 km of their breeding areas. A relatively large proportion of breeding birds along the north Co. Mayo coastline spent much of the winter on the Mullet Peninsula. It is important to note that some birds may have moved much further than 28 km from their breeding areas, but due to limited observer effort were not resighted. Although considerably fewer resighting data were generated from Co. Donegal due to a lower ringing effort, a strong link was apparent between breeding birds at Maghera and the winter ringing sites 6 km north at Sheskinmore NNR.

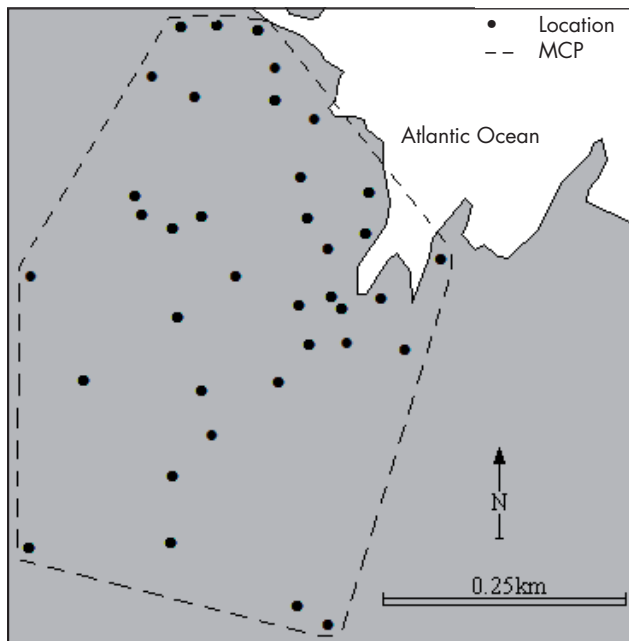


Figure 3. Sample location data and the Minimum Convex Polygon (MCP) for 100% of the locations ($n = 295$) of Individual 10, which was tracked on the Mullet Peninsula, Co. Mayo, in August 2008.

The movement patterns of Irish breeding birds appear to be in contrast with those of the South Pennines and many of the Western Isles of Scotland (Raine *et al* 2006a), but concur with the view of Brown & Atkinson (2002) that Irish birds are sedentary. Population data in McLoughlin & Cotton (2008) show that large flocks are observed each winter on the Mullet Peninsula and in the environs of Sheskinmore, but seldom outside these areas (with the exception of Northern Ireland). This too provides evidence for the sedentary nature of the Twites in the study areas, which account for 40 of the 54–110 breeding pairs estimated for Ireland.

Site fidelity

Twites at the Termoncarragh site showed a degree of fidelity to the winter study area. Atkinson (1998) and Raine *et al* (2006b) also found a degree of fidelity to their wintering sites in the southeast and northwest coasts of England. Ring recoveries in the German Wadden Sea indicate that some individuals show high while others show low winter site fidelity (Dierschke & Bairlein 2002).

Range size and structure

The highly mobile nature of Twites during the winter season has been well documented (eg Atkinson 1998, Raine 2006). Bub (1976) notes that birds wintering in Germany may move over 50 km from a good feeding site and return to it within a day. In this context, the two birds that were

tracked in March showed a remarkably small range size of less than 150 ha. Although most feeding areas were common to both birds, they generally did not share the same one simultaneously. The low range patchiness for these birds, in addition to their small concave polygon area, shows the use of only a small number of feeding sites within their range. High densities of seed surrounding cattle ring-feeders is mostly likely responsible for focusing the birds in this relatively small number of feeding locations. General observations of Twites in this area showed that the majority of wintering birds also used these feeding locations for much of the winter.

During the breeding season, a large proportion of the area within flying distance of the breeding colonies was open ocean, and therefore unavailable to passerines. This most likely influenced the size and triangular shape of the range of these birds. This range shape is however typical for Irish Twite as all of the known breeding colonies in Ireland are coastal, occurring on steep, heather-dominated slopes within 100 m of the sea.

The relatively small foraging distance from nest sites in the study area (min 1.06 km, max 1.49 km) reflects the availability of suitable foraging habitat. In the South Pennines, Raine (2006) determined the minimum distance travelled of eight radio-tracked Twites from nest to foraging area to be 1.31 km with a maximum of 3.54 km. It is probable that Irish breeding Twites would also travel this distance from their nest site where necessary.

The juveniles tracked in August remained at feeding areas throughout the tracking period and subsequently had smaller range sizes than the breeding birds. The relatively high range patchiness demonstrates the dispersion of birds within their range and reflected the relatively abundant food resources in this area, which was also the main foraging area for breeding birds.

Information from this radio-tracking study shows that Twites on the Mullet Peninsula, which account for up to 15 breeding pairs (McLoughlin & Cotton 2008), use only relatively small areas for foraging and nesting between late April and September. This study would, however, benefit from a larger sample size with greater representation of age, sex and individuals that use alternative breeding and wintering areas. As the number of locations gathered affects the concave range size, a longer tracking duration would be preferable in future studies. Labour and financial constraints limited the sample size in this study; however, knowledge gained on the ecology of Irish Twite should be invaluable in informing national Twites conservation strategies. In addition, this new information and the combination of methods presented provide a pilot study for similar research studies in the future.

Conservation implications

A key finding from this study is that much of the Irish Twite breeding population spent the winter season within

28 km of their breeding area. In their winter range on the Mullet Peninsula, a large proportion of individuals appeared to use an area of less than 150 ha, including their roost site, for much of the winter. From late April to late August radio-tracked birds used an area of less than 75 ha. From a conservation perspective, this leaves Twite populations very vulnerable to changes in land use and farm management practices. However, if adequate conservation measures were put in place within 28 km of breeding areas, this would benefit these populations of Twites during both the breeding season and throughout the winter. These areas must form the core of a targeted action plan for the conservation of Twites in Ireland.

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REFERENCES

- Aebischer, N.J., Robertson, P.A. & Kenward, R.E.** (1993) Compositional analysis of habitat use from animal radio-tracking data. *Ecology* **74**, 1313–1325.
- Atkinson, P.W.** (1998) *The wintering ecology of the Twite *Carduelis flavirostris* and the consequences of habitat loss*. PhD thesis, University of East Anglia.
- Bernhoft-Osa, A.** (1965) Om bergiriskens (*Carduelis flavirostris*) trekk. *Stavanger Museums Årbok* **35**, 109–118.
- Brown, A.F. & Atkinson, P.W.** (2002) Twite. In *The Migration Atlas: movements of the birds of Britain and Ireland* (eds Wernham, C.V., Toms, M.P., Marchant, J.H., Clark, J.A., Siriwardena, G.M. & Baillie, S.R.), pp 657–659. T. & A.D. Poyser, London.
- Bub, H.** (1976) Flügelmaße und Gewichte des Berghänflings (*Carduelis f. flavirostris*). *Ornithologische Mitteilungen* **27**, 6–12.
- Clark, H. & Sellers, R.M.** (1998) Movements of Twites in Scotland. *Scottish Birds* **19**, 270–279.
- Dierschke, J.** (1997) The status of the Shorelark *Eremophila alpestris*, Twite *Carduelis flavirostris* and Snow Bunting *Plectrophenax nivalis* in the Wadden Sea. *Wadden Sea Ecosystem* **4**, 95–114. Common Wadden Sea Secretariat, Wilhelmshaven.
- Dierschke, J. & Bairlein, F.** (2002) Why did granivorous passerines wintering in Wadden Sea salt marshes decline? In *The avian calendar: exploring biological hurdles in the annual cycle*. (eds Both, C. & Piersma, T.) Proc. 3rd Conf. European Orn. Union, Groningen, August 2001. *Ardea* **90**, 471–477.
- Eaton, M.A., Brown, A.F., Noble, D.G., Musgrove, A.J., Hearn, R.D., Aebischer, N.J., Gibbons, D.W., Evans, A. & Gregory, R.D.** (2009) Birds of Conservation Concern 3: the population status of birds in the United Kingdom, Channel Islands and Isle of Man. *British Birds* **102**, 296–341.
- Hutchinson, C.D.** (1989) *Birds in Ireland*. T & A.D. Poyser, Calton.
- Johnson, D.H.** (1980) The comparison of usage and availability measurements for evaluating resource preference. *Ecology* **61**, 65–71.
- Kenward, R.E.** (2001) *A Manual for Wildlife Radio Tagging*. Academic Press, London.
- Kenward, R.E.** (2004) Radio-tagging. In *Bird Ecology and Conservation a handbook of techniques* (eds Sutherland, W.J., Newton, I. & Green, R.E.). Oxford University Press, Oxford.
- Lack, P.** (1986) *The Atlas of Wintering Birds in Britain and Ireland*. T. & A.D. Poyser, Calton.
- Langston, R.H.W., Smith, T.W., Brown, A.F. & Gregory, R.D.** (2006) Status of breeding Twite *Carduelis flavirostris* in the UK. *Bird Study* **53**, 55–63.
- Lynas, P., Newton, S.F. & Robinson, J.A.** (2007) The status of birds in Ireland: an analysis of conservation concern 2008–2013. *Irish Birds* **8**, 149–166.
- Marler, P. & Mundinger, P.C.** (1975) Vocalisations, social organisation and breeding biology of the Twite, *Acanthis flavirostris*. *Ibis* **117**, 1–17.
- McLoughlin, D. & Cotton, D.** (2008) The status of Twite *Carduelis flavirostris* in Ireland 2008. *Irish Birds* **8**, 323–330.
- Newton, I.** (1972) *Finches*. Collins, London.
- Raine, A.F.** (2006) *The breeding ecology of Twite *Carduelis flavirostris* and the effects of upland agricultural intensification*. PhD thesis, University of East Anglia.
- Raine, A.F., Sowter, D.J., Brown, A.F. & Sutherland, W.J.** (2006a) Migration patterns of two populations of Twite *Carduelis flavirostris* in Britain. *Ringling & Migration* **23**, 45–52.
- Raine, A.F., Sowter, D.J., Brown, A.F. & Sutherland, W.J.** (2006b) Natal philopatry and local movement patterns of Twite *Carduelis flavirostris*. *Ringling & Migration* **23**, 89–94.
- Redfern, C.P.F. & Clark, J.A.** (2001) *Ringers' Manual*. BTO, Theford.
- Whilde, A.** (1993) *Threatened Mammals, Birds, Amphibians and Fish in Ireland*. Irish Red Data Book 2. HMSO, Belfast.

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