

Forum

The Red-billed Leiothrix (*Leiothrix lutea*): a new invasive species for Britain?

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Invasive non-native species (INNS) are one of the major threats to global biodiversity. Climate change and garden bird-feeding may facilitate the establishment of INNS. The Red-billed Leiothrix *Leiothrix lutea* is a small woodland passerine, native to subtropical Asia, that is an INNS in several parts of the world, including Europe, following escapes from the aviculture trade. Recently, populations of Red-billed Leiothrix have established in Spain, Portugal, Italy and France. Previous studies have shown that much of Europe is suitable for the species, including southern Britain. The Red-billed Leiothrix has not previously been considered as at high risk of establishment in Britain, but we document recent records, including a cluster in southern England, suggesting that establishment may already be underway. We discuss the potential negative impacts of this invasive species on local ecosystems, and how a warming climate and garden bird-feeding might assist their establishment in temperate Europe. We also highlight the importance of improved recording to monitor the potential

establishment of INNS, such as the Red-billed Leiothrix, in Britain.

Invasive non-native species (INNS), also known as invasive alien species, are one of the major threats to global biodiversity (Early *et al.* 2016). INNS are those species that have been introduced by humans to novel environments outside their natural range, and which can have negative impacts on native species and ecosystems through resource competition, disease transmission, hybridization, predation and habitat modification (Simberloff 2013).

Worldwide, more than 200 bird species have become established outside their native range (Lever 2005, Martin-Albarracín *et al.* 2015), and some have serious impacts as INNS. Examples within Europe include the Ruddy Duck *Oxyura jamaicensis* and African Sacred Ibis *Threskiornis aethiopicus*, which have both had significant negative effects on native birds (Lever 2005, Martin-Albarracín *et al.* 2015). Climate change can assist the spread of INNS, by improving the suitability of new regions (Hellmann *et al.* 2008, Baquero *et al.* 2021). Other human activities can also benefit invasive birds, such as Ring-necked Parakeets *Psittacula krameri* exploiting supplementary bird food in European gardens (Le Louarn *et al.* 2016), which may then harm native bats (Hernández-Brito *et al.* 2018).

In addition to waterbirds and parrots, several non-native songbirds have also become naturalized in Europe, resulting from the trade in wild-caught birds from Asia and Africa throughout the 20th century, which was only ended in 2005 (Cardador *et al.* 2019, Keller *et al.* 2020). The Common Myna *Acridotheres tristis* is a high-risk INNS (Nentwig *et al.* 2018) because of its potential for rapid spread and competition with native birds (Grarock *et al.* 2012). Meanwhile, the non-native Common Waxbill *Estrilda astrild* seems to have a negligible impact in its marginal ecological niche in Iberia (Batalha *et al.* 2013). Nevertheless, both climate change and supplementary feeding can contribute to the local environmental favourability for these invasive songbirds (Galbraith *et al.* 2017, Baquero *et al.* 2021).

The Red-billed Leiothrix *Leiothrix lutea* is an invasive songbird that is spreading rapidly in Europe (Keller *et al.* 2020) and that could potentially benefit from climate change and garden bird-feeding. This subtropical Asian species is a small (15 cm in length), active and agile passerine with colourful plumage (Fig. 1), and a rich song that resembles the Eurasian Blackcap *Sylvia atricapilla*, Common Blackbird *Turdus merula* or European Robin *Erithacus rubecula*. It is also a popular cage-bird, and releases and escapes from captivity have led to several naturalized and expanding populations, with further regions of high suitability across large parts of Europe (Pereira *et al.* 2020a). As such, detection and

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monitoring of the Red-billed Leiothrix, and of the impacts that it may have, are important for formulating risk assessments and a possible management response in their current and future European range.

In this paper, we summarize the Red-billed Leiothrix as an example of an invasive songbird in several parts of the world, and raise awareness of its recent occurrence in Britain. In particular, we highlight a cluster of recent records that suggest a risk of establishment that could already be underway in southern England. We discuss the potential for climate change and garden bird-feeding to facilitate the range expansion of this subtropical invasive species into temperate Britain. Finally, we underline the need for recording and monitoring of INNS, including the Red-billed Leiothrix in Britain, where conditions are conducive for establishment.

THE RED-BILLED LEIOTHRIX AS AN INVASIVE SPECIES

The Red-billed Leiothrix is native to Southeast Asia, spanning from the Himalayas across northern India and Nepal, over much of China and into Myanmar and Vietnam, where it occupies subtropical, humid forests with a dense understorey, and also dense thickets and shrublands (Collar *et al.* 2020, Hart 2020).

To date, the Red-billed Leiothrix has been successfully introduced to Hawaii, Japan, Réunion Island and parts of Europe, including Portugal, Spain, France and Italy (Collar *et al.* 2020). Deliberate releases or free-living birds have also been recorded in Australia, Tahiti, Colombia, Cuba and Malaysia (Hart 2020). Populations first became established in Europe in the late 20th century, and, by 2017, Red-billed Leiothrix were present in 37 distinct regions at least 50 km apart (Pereira *et al.* 2020a). The largest European populations, with



Figure 1. Presumed adult Red-billed Leiothrix at a garden bird-feeder in Horningsham, Wiltshire, UK, on 4 May 2020. (Photo: P. Mumby). [Color figure can be viewed at wileyonlinelibrary.com]

several thousand birds each, are in southwest France and northern Italy (Keller *et al.* 2020). Smaller populations are established in regions as diverse as the outskirts of Barcelona city, rural central Portugal and woodland north of Paris. Furthermore, 128 records occurred between 2009 and 2017 in an arc across northern France, Belgium, The Netherlands and into western Germany, possibly representing a future focal area for establishment (Pereira *et al.* 2020a).

In Europe, Red-billed Leiothrix prefer deciduous or mixed woodlands and shrublands with dense understorey thickets (Herrando *et al.* 2010, Farina *et al.* 2013, Ramellini *et al.* 2019, Pereira *et al.* 2020a), especially those close to water (Cordier 2002, Keller *et al.* 2020, but see Ramellini *et al.* 2019, Wilcox & Tarwater 2022). Pairs occupy breeding territories in spring/summer, which are often grouped together (Cordier 2002, Herrando *et al.* 2010, Farina *et al.* 2013). Breeding densities in naturalized populations averaged approximately 10 pairs per linear km in Portuguese and Italian woodlands (P. F. Pereira, S. Ramellini, our unpubl. data), up to seven pairs/ha in Hawaii (Ralph *et al.* 1998) and 350–400 pairs/100 ha in mountainous forest in Japan (Tojo & Nakamura 2004).

In autumn and winter, Red-billed Leiothrix may disperse to more open, lowland landscapes, such as woodland–farmland mosaics (Ramellini 2017). Dispersal distances are poorly known, but may be up to 10–20 km, including crossing at least 2 km of open ground between habitats (Herrando *et al.* 2010, Ramellini 2017, P. F. Pereira, S. Ramellini, unpublished data).

Red-billed Leiothrix can have negative impacts as an invasive species, through competition with native birds and as a vector for the spread of exotic plants and infectious diseases (Martin-Albarracín *et al.* 2015). For example, in Hawaii, Red-billed Leiothrix preferentially feed on non-native fruits, helping to disperse their seeds (Vizentin-Bugoni *et al.* 2019, Wilcox & Tarwater 2022). Additionally, Red-billed Leiothrix seem largely unaffected by some diseases, such as avian malaria, that seriously affect native Hawaiian birds (Ralph *et al.* 1998), and they can also host avian influenza, which is a risk to poultry (Lee *et al.* 2019).

The Red-billed Leiothrix can be vocally dominant, accounting for 37% of an entire bird community soundscape in northern Italy (Farina *et al.* 2013). In Portugal and Italy, Red-billed Leiothrix influence the singing behaviour of native Eurasian Blackcaps and European Robins in particular (Ramellini 2017, 2021, Pereira *et al.* 2020b). Trophic competition for fruits and invertebrates may also exist, with Red-billed Leiothrix dominating other passerines with similar diets (Pagani-Núñez *et al.* 2018, Pereira *et al.* 2018). As such, native songbirds occupying dense wooded habitats are most exposed to potential impacts from invasive Red-billed

Leiothrix (Farina *et al.* 2013, Pereira *et al.* 2017, Ramellini 2017, Pagani-Núñez *et al.* 2018).

THE RED-BILLED LEIOTHRIX IN BRITAIN

Large numbers of Red-billed Leiothrix ('Pekin Robins') were imported into Britain during the late 19th and early 20th centuries as a popular cage-bird, and captive breeding was recorded from the 1890s (Farrar 1898). There were at least four attempts to introduce Red-billed Leiothrix at different locations in southern England in 1900–39, involving up to 40 birds each (Finn 1907, Ezra 1933, Bedford 1949, Boosey 1956). These releases were unsuccessful, although free-living birds persisted for up to several years, including successful breeding in the wild at Foxwarren Park (Surrey) in 1932 (Ezra 1933).

Red-billed Leiothrix continued to escape from captivity, with 28 published records during 1995–2009, mostly in southern England (British Trust for Ornithology 2017). However, in 1997, the Red-billed Leiothrix was added to Appendix II of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES), and in 2005 the European Union banned bird imports, which ended the legal supply of wild-caught birds.

By 2003, the number of captive Red-billed Leiothrix in Britain was declining, as a result of low rates of importation and captive breeding (Coles 2003). An average of 39 (range 20–71) fledglings were produced annually in 2007–10 (Foreign Bird Federation 2021), with birds in at least 16 British mainland zoo collections (<https://www.zootierliste.de/>), and unknown numbers in private collections. Red-billed Leiothrix remain available in captivity, but are not abundant, with advertised prices of £350 (€420) per pair in January 2022 (c. 14% of the average UK monthly household income: <https://www.ons.gov.uk/>). The species is easy to maintain in captivity and can withstand the southern British climate in outdoor aviaries (Coles 2003).

RECENT RECORDS IN SOUTHERN BRITAIN

In view of the reduced abundance of Red-billed Leiothrix in captivity in Britain since the import ban of 2005, a recent cluster of records in southern England is alarming, because it may indicate a nucleus of establishment. The records were collected after searches of social media during 2020–22, including Facebook and Twitter, with search terms of 'Pekin Robin', 'Peking Robin' and 'leiothrix', and also image searches on the Google search engine. We then contacted observers to ask for further details where possible. Between February 2019 and May

2021, our internet searches found 10 records of Red-billed Leiothrix over a 37-km span across the counties of Wiltshire and Somerset (Fig. 2, Table 1). Eight records were documented with photographs. Eight of the 10 records were within a 70-km² area around the town of Warminster (51°12'N, 002°10'W), ranging from 2.6 to 14.8 km apart. The remaining two records were around 20–28 km to the east of this area (Fig. 2). We refer to these 10 records as the 'Wiltshire–Somerset cluster'. It is possible that all 10 records are part of the same nucleus.

Six further sightings of Red-billed Leiothrix have occurred elsewhere in southern Britain, overlapping with the Wiltshire–Somerset cluster (Table 1). Between October 2020 and March 2021, a single bird was reported from two neighbouring locations in the town of Brecon, in south Wales, 110 km northwest of the Wiltshire–Somerset cluster. In June 2021, a photograph of a Red-billed Leiothrix at a garden bird-feeder was posted on an online message-board. The location could not be traced, but information in the post suggested that it was probably in southeast England, at least 50 km from the Wiltshire–Somerset cluster. In November 2021, a bird was recorded in Sandwich (Kent, southeast England), with the same or another bird being recorded 4 months later in Deal, 4.6 km away; these two records are 240 km east of the Wiltshire–Somerset cluster. Finally, in January–February 2022, two Red-billed Leiothrix wintered in a garden on Merseyside (Wirral), 240 km north of the Wiltshire–Somerset cluster.

In total, therefore, there have been 16 records of up to 16 individual Red-billed Leiothrix in the wild in southern Britain during 2019–22 (Table 1), including at least two cases of successful wintering (Brecon and Wirral, and possibly in Kent if both records refer to the same bird). This is likely to be an underestimate of the number of birds present in wild Britain at this time. Almost all of the records involved single birds in town or village gardens, where they were attracted to bird-feeders and supplementary food. Additionally, almost all of the records were close to a river (within 1.4 km). A notable exception was a bird caught in a mist-net during ringing operations on Salisbury Plain, approximately 2 km from villages and gardens, and 4.5 km from a river.

Most of the records were in the first half of the year, especially February–May. Most records also involved multiple sightings of a bird in the same location over several weeks or months, although there were sometimes gaps of days or weeks between sightings. In two separate locations (Longleat and Horningsham), a bird was reported twice in the same garden, 1 year apart. These records could refer to two returning individuals coming back to the same gardens.

The birds in the available photographs appeared to be un-ringed, except for one bird (in Deal) that

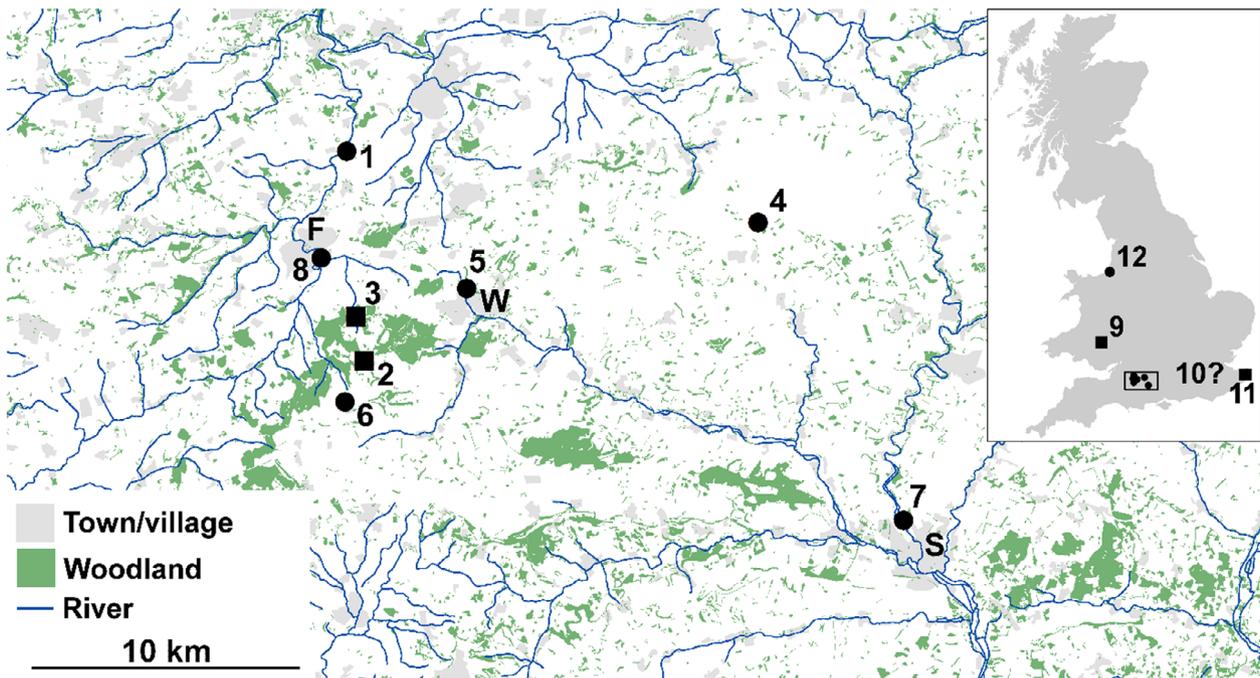


Figure 2. Records of 10 Red-billed Leiothrix sightings (black symbols) in the ‘Wiltshire–Somerset cluster’ between 2019 and 2021. Circles denote a single record and squares denote two records at the same location. Numbers refer to the identity of records in Table 1 (column ID). The towns of Frome (F), Warminster (W) and Salisbury (S) are indicated. Inset: location of the Wiltshire–Somerset cluster in southern Britain, with additional records for 2020–22 also marked. Question mark for record 10 denotes a sighting in 2021 from an unknown location probably in southeast England. See Table 1 for additional detail of all records. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1111/ibi.13090)]

apparently had an avicultural ring, indicating a captive origin. Most birds were described as shy, although the Merseyside birds appeared tame. In gardens, the birds were reported as feeding on peanuts, sunflower hearts (kernels), ‘fat balls’ or suet blocks (tallow/suet mixed with seeds and/or fruits), and apple. Most individuals used bird tables or hanging bird-feeders, although one bird fed on the ground.

We inspected photographs for clues as to how many individuals may be involved, or for any breeding evidence. Ageing and sexing Red-billed Leiothrix is not straightforward (Kawano *et al.* 2000, Pagani-Núñez *et al.* 2013, Paxton *et al.* 2016), but none appeared to be juveniles. One series of records involved an apparent adult female photographed in a garden in Horningsham in July 2019 and again in May 2020, and then a female photographed 2.6 km away in Maiden Bradley in March 2021, which could all possibly refer to the same bird over a 2-year duration (Table 1). The bird caught on Salisbury Plain was an adult male, and the two birds on Merseyside were possibly a pair. Nevertheless, none of the observations were indicative of recent breeding in the wild.

The origin of the recent British records is unknown, but some probably involve recent escapes or deliberate

releases, although a wild-bred origin cannot be ruled out for others. The records from 1995 to 2009 were widely scattered, and probably all involved individual escapes/releases from captivity (British Trust for Ornithology 2017). The recent (2020–22) Brecon and Merseyside records may also involve recent escapes, and at least one record from Kent certainly involved a captive origin, as shown by an avicultural ring. However, the pattern of records in the Wiltshire–Somerset cluster since 2019 appears different, involving multiple birds in the same region over several years. Despite their loud song, Red-billed Leiothrix are elusive and easily overlooked, and experience from previously colonized areas of Europe suggests that they can go largely unnoticed for some years (Pereira *et al.* 2020a). As such, the cluster of records in Wiltshire–Somerset could be an underestimate of their presence in the landscape.

Natural dispersal into Britain from Red-billed Leiothrix populations in France seems unlikely. The closest population to Britain contains approximately 200 individuals north of Paris (Dubois & Cugnasse 2015). There are also five records on the coast of northern France (Pereira *et al.* 2020a), including a singing bird in October 2017 in a wood near Audresselles (<https://observation.org/observation/145165689>), just 37 km

Table 1. Records of Red-billed Leiothrix in Britain during 2019–22, including the cluster of records in the Wiltshire–Somerset area (shown in bold font), and the duration over which the individuals were seen after the first date of observation (period until the last observation, allowing for short gaps in observation).

ID	Location	First date	Duration	Grid Ref.	Habitat
1	Rode	10/02/2019	1 day	ST803539	Garden
2	Horningsham	?/07/2019	1 week	ST810416	Garden
3	Longleat	10/04/2020	9 weeks	ST808441	Garden
2	Horningsham	04/05/2020	<1 week	ST810416	Garden
4	Salisbury Plain	30/05/2020	1 day	SU046497	Shrubland
5	Warminster	01/11/2020	1 day	ST874458	Garden
6	Maiden Bradley	03/03/2021	3 weeks	ST802391	Garden
7	Salisbury	30/04/2021	1 day	SU132321	Garden
3	Longleat	03/05/2021	2 days	ST808441	Garden
8	Frome	05/05/2021	1 day	ST788476	Garden
9	Brecon (Wales)	15/10/2020	2 weeks	SO044283	Garden
9	Brecon (Wales)	?/12/2020	12 weeks	SO062283	Garden
10	SE England	16/06/2021	1 day	?	Garden
11	Sandwich (Kent, SE England)	11/11/2021	1 day	TR330581	Garden
12	Wirral (NW England)	15/01/2022	5 weeks	SJ338849	Garden
11	Deal (Kent, SE England)	29/03/2022	1 day	TR376524	Garden

Grid references to 100-m accuracy are in the Ordnance Survey Great Britain national grid coordinate system. The ID column refers to the numbered records in Figure 2. Date format used is Day/Month/Year.

from southern England. Despite this, the minimum sea crossing of 33 km is probably a major barrier for Red-billed Leiothrix. As such, escapes or deliberate releases are likely to be the ultimate source of British records.

A PLAYBACK SURVEY IN ENGLAND

Based on the distribution of records in the Wiltshire–Somerset cluster, we carried out a playback survey of woodlands within this region on 17 and 19 April 2021, to check whether Red-billed Leiothrix could be found. The survey involved searching a total route of 16.3 km through four woodlands, during the morning and in warm, dry weather. Along the routes, an mp3 recording of Red-billed Leiothrix song was broadcast every 50–100 m to try to elicit a response from any birds present (see Supplementary material, Appendix S1, for full details). All responses from singing birds were followed up, but these all turned out to be Eurasian Blackcaps or European Robins, which both sometimes responded vigorously to the playback (particularly Eurasian Blackcaps). No Red-billed Leiothrix were detected.

The failure to find any Red-billed Leiothrix may have been because no settled birds were present in the limited areas searched, or because any birds present did not respond to the playback. However, a response would be expected from any territorial bird present (pers. obs.), although the survey was early in the spring and involved only a single visit to each location to cover as much habitat as possible in the available time. As such, the

survey was perhaps suboptimal for detecting birds at low density. Indeed, three records in the Wiltshire–Somerset cluster occurred after the playback survey, including a bird observed at Longleat, within 2 km of the surveyed area, just a few weeks later in May 2021 (Table 1).

Much of the woodland habitat explored during the playback survey in 2021 seemed generally suitable for Red-billed Leiothrix, comprising broadleaved or mixed woodlands with dense shrub thickets in the understorey (Ramellini *et al.* 2019, Pereira *et al.* 2020a, R.K.B. & M.M. pers. obs.). More widely, the landscape of southern Britain, with its numerous woodlands, hedgerows, wooded rivers and streams, and abundant gardens providing supplementary food, is likely to offer plentiful habitat for Red-billed Leiothrix, broadly similar to habitats occupied in the species' European introduced range (Ramellini *et al.* 2019, Pereira *et al.* 2020a).

CLIMATE CHANGE AND GARDEN BIRD-FEEDING AS FACTORS IN ESTABLISHMENT

Climatic conditions are an important limitation for INNS, including the Red-billed Leiothrix, but the recent climate of southern Britain seems within the species' tolerance. Red-billed Leiothrix appear to do best in mild regions of Europe, with a relatively high rainfall, where winters are not too cold and summers not too dry (Ramellini *et al.* 2019, Pereira *et al.* 2020a). A species

distribution model projected in Europe, based on climatic and habitat variables (Pereira *et al.* 2020a), predicted that much of southern Britain has a moderate suitability for Red-billed Leiothrix occurrence, with the highest values in southeast England.

Climate change homogenizes bird communities by favouring generalists (Davey *et al.* 2012), and can facilitate the establishment of invasive species by improving the suitability of previously marginal or uninhabitable regions, shifting a species' climate envelope poleward (Hellmann *et al.* 2008, Jeschke & Strayer 2008). In the case of the Red-billed Leiothrix, increasingly mild winters resulting from climate change have probably improved the suitability of southern Britain since the failed introduction attempts in the early 20th century (see above). This climatic suitability will probably expand northwards as climate change progresses, as is predicted for other (native) southerly distributed woodland birds (Davey *et al.* 2012, Renwick *et al.* 2012, Massimino *et al.* 2015). Consequently, climate change may increase the risk of INNS from sub-tropical habitats becoming established in temperate regions, such as Britain, and the Red-billed Leiothrix could be an emerging example (Mainka & Howard 2010).

Supplementary bird-feeding also modifies bird communities (Plummer *et al.* 2019), and could be an additional factor in supporting the establishment of Red-billed Leiothrix in Britain. Garden bird-feeding is widespread in towns and villages across many parts of the world, and concerns have been raised over its impacts, including the favouring of generalist and invasive species (Le Louarn *et al.* 2016, Galbraith *et al.* 2017, Shutt & Lees 2021). Up to two-thirds of British households provision 150 000 tonnes of bird food annually, with an estimated average of 100 bird-feeders per square kilometre, providing a wide variety of seeds, peanuts, solid fats, fruit and insects (Cox & Gaston 2018, Plummer *et al.* 2019). This large and widespread resource of supplementary food could assist the Red-billed Leiothrix, and other invasive species, by providing a reliable food source that promotes over-winter survival. Indeed, almost all of the recent Red-billed Leiothrix records in Britain have involved birds readily using a wide range of food provided in gardens, demonstrating their ability to exploit this resource.

Invasive Ring-necked Parakeets in Europe also benefit from garden bird-feeders (Clergeau & Vergnes 2011, Le Louarn *et al.* 2016), although parakeets and leiothrix both appear able to survive away from supplementary food in gardens (Butler 2005, Herrando *et al.* 2010, Farina *et al.* 2013, Ramellini *et al.* 2019). Nevertheless, other INNS of subtropical origin that could exploit the prevalence of garden bird-feeding in temperate regions include the Common Myna, Indian House Crow *Corvus splendens* and Alexandrine Parakeet *Psittacula eupatria* (Roy *et al.* 2014a, Ancillotto *et al.* 2016, Galbraith *et al.* 2017, Shutt & Lees 2021). As such, the homogenizing effects

on bird communities resulting from bird-feeding and climate change, by favouring generalists, could potentially benefit a range of INNS alongside some native species (Davey *et al.* 2012, Shutt & Lees 2021).

POTENTIAL PATTERNS OF ESTABLISHMENT – LESSONS FROM EUROPE

There is clear evidence that the Red-billed Leiothrix is expanding from established population centres in Europe, and has the capability for rapid growth (Herrando *et al.* 2010, Ramellini *et al.* 2019, Keller *et al.* 2020, Pereira *et al.* 2020a). The species' European range almost doubled over the last two decades (Pereira *et al.* 2020a), and some populations showed exponential growth (Herrando *et al.* 2010, Ramellini *et al.* 2019). Other populations expanded across significant distances via habitat corridors, such as in northeast Spain where the species spread over a distance of 17 km in 9 years (Herrando *et al.* 2010). Additionally, the large population in southwest France, apparently established from just a few pairs (Cordier 2002), has spread along the Atlantic coast to northern Spain, occupying at least nineteen 50 × 50 km squares by the end of 2017 (Pereira *et al.* 2020a).

These trends indicate that establishment of Red-billed Leiothrix in Britain could lead to a rapid increase and expansion, probably assisted by climate change and garden bird-feeding. Similar factors may benefit the established population near Paris, which appears to be stable or slowly increasing (Dubois *et al.* 2016, <https://www.faune-france.org>). Meanwhile, milder winters and supplementary food in gardens may also assist the establishment of Red-billed Leiothrix in the arc across France, Belgium, The Netherlands and Germany, where numerous birds have been reported but a breeding population has not yet been confirmed (Pereira *et al.* 2020a).

The avicultural interest in Red-billed Leiothrix has remained high. As such, the multiple populations across Europe have become a potential source to supply an illegal market in wild-caught birds. Indeed, illegal trapping has already been detected near Lisbon in Portugal and in southwest France (Matias 2010, Basly 2018). Trapping wild Red-billed Leiothrix may help to control their populations, but a captive population would represent a continued risk for spread in the wild via trading, escapes or deliberate releases. This commercial aspect remains a potential source of new population nuclei far from established populations.

INCREASING AWARENESS OF THE RED-BILLED LEIOTHRIX AND OTHER INNS

A UK horizon-scanning exercise of potential INNS in 2013 did not identify the Red-billed Leiothrix as an

invasive species with a medium or high risk of establishment in Britain (Roy *et al.* 2014a). Since this analysis, however, the European population has expanded, modelling has shown the suitability of southern Britain for colonization (Pereira *et al.* 2020a) and multiple records have been reported, notably the Wiltshire–Somerset cluster. This all suggests that the Red-billed *Leiothrix* could now be considered at medium to high risk of establishment in Britain, and that increasing the awareness and recording of the species would be valuable.

Britain has a highly developed network of biological recording, coordinated by non-governmental organizations, public bodies and the voluntary sector (Tweddle *et al.* 2012, August *et al.* 2015). Similar networks occur elsewhere, and can be a great advantage for monitoring INNS, such as Red-billed *Leiothrix*, so long as observers and recording schemes are aware of the significance of any records (e.g. Delaney *et al.* 2008, Gallo & Waite 2011). Previously, records of Red-billed *Leiothrix* would have been considered as recent escapes from captivity, but could now potentially represent wild birds. Despite the problem of low public awareness and inconsistent recording of novel INNS (Crall *et al.* 2006), information portals can be designed to address this, thereby improving awareness and recording as a basis for informing management plans (Roy *et al.* 2014b).

Nevertheless, detecting and monitoring INNS in the early stages of potential establishment can be difficult. For example, in densely wooded habitats Red-billed *Leiothrix* can be very elusive. Despite their loud song, its similarity to that of the Eurasian Blackcap, Common Blackbird or European Robin may lead to it being overlooked by birdwatchers. Bird ringers undertaking mist-netting during routine monitoring of bird communities in the British Trust for Ornithology's Ringing Scheme (Walker *et al.* 2020) are therefore well placed to detect Red-billed *Leiothrix* by catching them incidentally.

As with other INNS, gardens are also likely to be a major source of records, as birds will appear in the open at feeding stations and have a good chance of being noticed by one of several million potential observers (Davies *et al.* 2009, Cammack *et al.* 2011). When seen, the Red-billed *Leiothrix* is unlikely to be confused with another species, but may be unfamiliar to many birdwatchers. Indeed, aside from the single ringing record, many of the recent records in Britain appeared after garden observers posted images or comments on social media to request help with identification.

Social media is an excellent medium to promote awareness of invasive birds, with several online forums in Britain that each have thousands of members, including BirdForum (www.birdforum.net), RSPB Community (<https://community.rspb.org.uk/>) and users of the #ornithology tag on the Twitter platform (Dudley & Smart 2016). Mining social media sites is an increasingly

useful strategy for detecting records of invasive species, as shown for the Red-billed *Leiothrix* in Britain, but also demonstrated for invasive turtles (Allain 2019). To aid the monitoring of Red-billed *Leiothrix* and other invasive birds, facilitating the recording of sightings onto national recording schemes, such as the BTO-led Bird-Track (<https://www.bto.org/our-science/projects/birdtrack>) or iRecord (<https://irecord.org.uk/>) platforms in Britain, would provide a central repository of records.

However, aside from promoting the passive recording of Red-billed *Leiothrix*, proactive actions would also be valuable, such as comprehensive playback surveys of wooded habitats to determine whether birds are present and potentially breeding. In Britain, and also in parts of northern France, Belgium, The Netherlands and Germany where records have occurred, surveys of potential habitat throughout the spring and summer could help to monitor whether establishment was underway. Such surveys are valuable in formulating national and regional action plans to manage potential establishment, which is essential in countering any negative impacts of invasive species (Moore & Booy 2010). Ultimately, action plans may involve species removal where this is deemed necessary and feasible (Robertson *et al.* 2015).

CONCLUSIONS

In summary, the Red-billed *Leiothrix* is a woodland generalist that is a highly invasive species in several parts of the world. In Europe, the species has several established and spreading populations, and has the potential to colonize a large part of the continent, including southern Britain. Records since 2009 in northern France, The Netherlands, Belgium and western Germany (Pereira *et al.* 2020a) suggest that this region of Continental Europe is also at risk of establishment of Red-billed *Leiothrix*. Where it becomes established, the species can reach high breeding densities, with potential competition effects for native birds, and its loud and frequent song could significantly alter the soundscape of Britain's dawn chorus.

The presence of a recent cluster of Red-billed *Leiothrix* sightings in southern England suggests that colonization could already be underway. As such, increasing the awareness and recording of Red-billed *Leiothrix* in Britain, but also in Europe, would be valuable in monitoring their occurrence and potential establishment. Further field surveys of suitable woodland habitats in Britain and elsewhere in Europe, in areas where recent Red-billed *Leiothrix* sightings have been concentrated, would be useful to determine the extent of the species' presence and, crucially, to assess any breeding occurrence.

The Red-billed *Leiothrix* is potentially an emerging example of an INNS originating from subtropical regions

that is likely to benefit from human activities, namely climate change and garden bird-feeding, which could facilitate its establishment in temperate Britain. Other subtropical invasive birds may similarly benefit from these factors in temperate regions. Increased public awareness and recording, and the mining and utilization of social media, can be important tools for detecting and publicizing the early stages of potential establishment of Red-billed Leiothrix and other INNS in Britain and elsewhere. Ultimately, action plans are required to assess and manage the establishment of invasive species, such as the Red-billed Leiothrix.

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ETHICAL NOTE

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AUTHOR CONTRIBUTIONS

Richard K. Broughton: Conceptualization (lead); data curation (lead); investigation (lead); methodology (lead); resources (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Samuele Ramellini:** Conceptualization (equal); investigation (supporting); methodology (supporting); resources (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Marta Maziarz:** Conceptualization (supporting); investigation (equal); methodology (equal); resources (equal); visualization (equal); writing – original draft (supporting); writing – review and editing (equal). **Pedro F. Pereira:** Conceptualization (equal); investigation (supporting); methodology (supporting); resources (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal).

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1. Woodlands visited during a playback survey for Red-billed Leiothrix, on 17 and 19 April 2021.