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Global extinction of Slender-billed Curlew (*Numenius tenuirostris*)

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In the current biodiversity crisis, conservation efforts are often focused on extinction prevention. However, it can be difficult to determine if a species is extinct, especially if the species has an extensive range, including being a transcontinental migrant, or is poorly known. The breeding range of the migratory Critically Endangered Slender-billed Curlew *Numenius tenuirostris* is uncertain, and the species has an extensive non-breeding range that spans central Asia, eastern Europe, the Middle East, the Mediterranean basin and the northwest African coast. There have been no incontrovertible sightings since 1995. In this time, extensive and intensive searches for the species have continued. Using an IUCN extinction probability framework, we incorporate potential threats to the species, search effort and past records (museum specimens and confirmed and unconfirmed sightings, all of which are primarily from its non-breeding range) to assess the probability of extinction. The model indicates that there is a 96.0% probability that Slender-billed Curlew is no longer extant, classing it as Extinct according to IUCN Red List guidelines. Posterior probability Bayesian extinction date estimation modelling suggests an extinction year around the time of the 1995 sighting. Although several threats to the species have been suggested, those that definitively drove the species to extinction will never be known. Other species of *Numenius* are under a range of pressures, and many are recognized as globally threatened. To ensure the continued survival of all shorebird species, we advocate flyway-scale concerted, coordinated action, and caution against complacency even for widespread but threatened taxa in Europe.

Keywords: citizen science, extinction probability, IUCN Red List, lost species, shorebirds.

Biodiversity faces a crisis, with global extinction rates estimated to be orders of magnitude greater than background rates (de Vos *et al.* 2015). The actual annual extinction rate of species is unknown because of the number of species that are undescribed or have not had their status explicitly evaluated. Even when species have been described by western science, their status is often uncertain (Cazalis *et al.* 2023). Vertebrates are comparatively well covered by IUCN Red List assessments, meaning uncertainty is often lower for these classes (Cowie *et al.* 2022). Birds are among the best monitored and studied taxonomic groups (Moussy *et al.* 2022), something facilitated by their visibility and considerable interest to non-scientists (Greenwood 2007). Despite this, many species are known from a small number of specimens, and/or have not been documented in the wild for many years

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(Martin *et al.* 2023). Some bird species have been rediscovered after more than a century without observation (e.g. Black-browed Babbler *Malacocincla perspicillata*; Akbar *et al.* 2021), and hence the absence of recent confirmed sightings is not, in isolation, an appropriate criterion for declaring a species extinct. The erroneous classification of a species as extinct can lead to the 'Romeo Error', a circumstance when effort to conserve a species is halted prematurely, resulting in its (otherwise possibly preventable) extinction (Collar 1998). By contrast, the continued allocation of resources to conserve a species that is extinct risks a waste of finite conservation resources (Akçakaya *et al.* 2017, Troy & Jones 2023). Therefore, we need assessments of extinction probability to be consistent, objective and evidence-based.

The IUCN Red List currently assesses Slender-billed Curlew *Numenius tenuirostris* as Critically Endangered, based on a presumed declining, small population (<50 birds; BirdLife International 2023). As far as is known, the species is restricted almost entirely to the Palaearctic, breeding in central Asia and migrating to Europe, North Africa, the Middle East and the Arabian Peninsula (Gretton 1991, Donald *et al.* 2010). The purported breeding sites were to the east of the Ural Mountains around an area near Omsk in southern Russia (Ushakov 1912, 1925, Gretton 1991). Stable-isotope analysis indicated that the main breeding area might have been further to the south in northern Kazakhstan (Buchanan *et al.* 2018), supporting a previous suggestion by Belik (1994). The locations assigned to eggs in museum collections indicate that the species might have also nested to the west of the Urals (Bond & Buchanan 2022). This migratory species had a wide distribution away from the breeding areas (Gretton 1991, Buchanan *et al.* 2010, Donald *et al.* 2010). Birds occurred westwards from central Asia towards the North African Atlantic coast, Mediterranean and Pannonian Plains, and southwards to the Middle East and the Arabian Peninsula. Birds were recorded across much of Europe, including records from the Netherlands and a well-documented record from the 1960s in Brittany, France (Gretton 1991). Most non-breeding season records came from the Mediterranean basin, although the last major known wintering area was on the Atlantic coast of Morocco (Buchanan *et al.* 2010). The last site of regular observation was Merga Zerga, western Morocco, where the species was present until at least 23 February 1995, with undisputed supporting photographic evidence (van den Berg 1995). Slender-billed Curlews were reported at Merga Zerga in 1997/1998 (Thévenot *et al.* 2003), but there are no photographs of these birds (Bergier *et al.* 2000).

There have been reports and records of the species after 1995 (e.g. Oláh & Pigniczki 2010) but there are no records with photographs that show the identity of the bird clearly. This is despite dedicated searches for the species (e.g. Gallo-Orsi & Boere 2001, Crockford & Buchanan 2017) and an almost certain increase in observer effort, with improved technology, over time across the entire range of the species by birdwatchers. In recent years, reviews of sight and specimen records have resulted in a clearer understanding of the species' occurrence in the Middle East (Kirwan *et al.* 2015) and Central Asia (Wassink 2016); as a result, many records have now been rejected or are currently subject to review.

There are reports (Gretton 1991) that Slender-billed Curlew was historically common (at least locally) but it may have been on a trajectory towards extinction for much of the last century. As early as 1912 it was suggested that the species was in decline, not long after the first potential nests were documented (Ushakov 1912). Declines of, and concerns about, the species continued, with the possibility of the species becoming extinct raised as early as the 1940s (Stresemann & Grote 1943). Despite this warning, it was not until 1988 that the species was identified as being of high conservation concern and classified as Threatened (IUCN 1988). A species action plan was produced in 1996 (Gretton 1996) following a workshop held in 1994. With a revision to the IUCN Red List categories and criteria in 1994, it was assessed as Critically Endangered, which it has remained since (BirdLife International 2023). Although the absence of acceptable records since the mid-1990s could indicate that the species is extinct, an objective, evidence-based assessment of the probability of extinction is needed. If confirmed, it would join two known Western Palaearctic extinctions of species. The Great Auk *Pinguinus impennis* was last seen alive in 1844 (Fuller 2003), and the Canarian Oystercatcher *Haematopus meadewaldoi* was noted as absent around 1940 (Hockey 2020), although the status of this as a species remains unclear (Senfeld *et al.* 2020). Slender-billed Curlew differs from these two species in that they bred on islands, which tend to have higher rates of extinction (Loehle & Eschenbach 2012).

Given the potential costs and implications associated with inaccurate assessments of extinction, the IUCN Red List Guidelines (IUCN 2022a, 2022b) describe methods for making assessments of extinction consistent across species. The approach combines two models: (1) a threats model (Keith *et al.* 2017), which uses the acuity and spatial occurrence of known and suspected threats to the species; and (2) a records and survey model (Thompson *et al.* 2017), which uses past observation patterns and survey efforts. Both approaches output a probability with confidence intervals that the species is extinct, and these can be combined in the Framework model to produce an averaged probability of extinction, or $P(E)$ (Akçakaya *et al.* 2017). This approach was tested to calculate the extinction probability of 61 potentially or confirmed extinct bird species using data compiled up to 2017 (Butchart *et al.* 2018); however Slender-billed Curlew was not included (though Eskimo Curlew *Numenius borealis* was) and has therefore never been assessed against this framework.

Sightings, especially when supported by evidence that supports the identification such as photographs and survey data, can also be used to estimate the date of extinction, based on the temporal distribution of historical records. Extinction year estimates and estimating an annual probability of persistence can be useful when examining correlates of extinction (Carlson *et al.* 2018, Bond *et al.* 2019, Burgio *et al.* 2022) as well as being needed for the Red List Index (Butchart *et al.* 2007). Here we apply the IUCN guidelines and the Framework model to calculate the probability that the Slender-billed Curlew is extinct. We assess threats to the species, the records and surveys for the species, and the combined extinction probabilities from both models to assess both its extinction probability and year of extinction.

METHODS

Threats

The 'threats model' of Keith *et al.* (2017) requires an assessment of the probability that threats have caused loss of the species at a local and global scale. This assessment is based on a subjective assessment of knowledge, guided by text describing ranges of probability (Keith *et al.* 2017, IUCN 2022a). The proximate causes of the decline of the Slender-billed Curlew remain unknown (e.g. Donald *et al.* 2010) although various threats have been proposed, supported by varying degrees of evidence (Gretton 1991, Donald *et al.* 2010). Our assessment is summarized in Table 1. We suggest the probability that the threats were sufficient to cause local extinction was between 0.95 and 0.99 (best estimate 0.975). This is based on an assessment towards the upper end of that given in table 2 by Keith *et al.* (2017): 'The severity and duration/timing of threats are very highly certain to have caused local extinction, i.e. would cause 49 of 50 to 19 of 20 similar species to experience a local extinction. There is a one in a hundred to one in twenty chance that a population of the taxon may persist despite the threats.' The probability that threats have an impact across the entire range is assessed as between 0.80 and 0.99 (best estimate 0.95) based on the descriptions in Keith *et al.* (2017) table 2: 'It is quite likely that the threats affect or affected the entire range of the taxon, given any possibility that the taxon occurs or occurred outside its known range. There is 1-in-20 to 1-in-4 chance that the taxon persists within its known range or at an undiscovered location outside the known range,' and 'It is very highly certain that the threats affect or affected the entire range of the taxon, given any possibility that the taxon occurs or occurred outside its known range. There is a 1-in-100 to 1-in-20 chance that the taxon persists within its known range or at an undiscovered location outside the known range.'

Records database

Records of Slender-billed Curlew come from multiple sources, including the extensive list of Gretton (1991), and were collated by the Slender-billed Curlew Working Group (SBCWG; established in 1997). A database was established in 2001 and was updated on a regular basis until 2015. It includes records and reports from published studies, grey literature, online databases, submitted records and personal communications. In 2016 it was updated to include records from new museum specimen databases and records.

Table 1. Summary of potential threats to Slender-billed Curlew causing extinction at a local level and causing declines across the range with threat impact based on Table 2 in Keith *et al.* (2017).

Spatial scale	Justification	Impact
Local	Proven pressures that have scientific evidence to support impact on population do not exist, so assessments of threats are based on inference. *Breeding* 1 Extensive drainage could have been a major threat to the species, and agricultural activity/areas doubled between 1825 and 1858, with extensive areas of agriculture on raised bogs visited around Novosibirsk in the late 1980s (Gretton 1991). 2 There was widespread drainage and agricultural expansion around time of decline in late 19th and early to mid-20th centuries (Klein Goldewijk *et al.* 2011, Kraemer *et al.* 2015, Fluet-Chouinard *et al.* 2023). The impact of these changes potentially was exacerbated by heat waves and drought (Schubert *et al.* 2014). All the above have previously been linked to declines on breeding areas (Belik 1994). *Passage* 3 Drainage, development and agricultural expansion have impacted previously known wetland passage sites across Europe. The Pannonian Plain, from which there are multiple records from multiple sites, has been largely converted to agriculture, with Hortobágy in Hungary one of the few remaining wetlands in the area (Gretton 1991). The Danube delta from which there are multiple records has been significantly altered (Gretton 1991). *Wintering* 4 Multiple wetland sites from which there are records have been drained (Crockford & Buchanan 2017 and references therein). Loss of specific sites, such as Evros Delta and Amvrakikos was noted in Gretton (1991). 5 Almost all of the Maghreb in Morocco has been converted to agriculture, with only the wetlands of Merja Zerga remaining (Gretton 1991). 6 Hunting is also likely to have had an impact. For example, Gretton (1991) details organized hunting trips in the northern part of Merja Zerga in c.1980s that shot multiple Slender-billed Curlew out of a small population. Threats (1), (3), (4), (5) and (6) are likely to have been of highest importance. **The pattern of records and the information on probable threats indicates that it is highly probable that threats operated at an acuity and intensity that drove local extinction**	0.95–0.99

(continued)

Table 1. (continued)

Spatial scale	Justification	Impact
Range-wide (spatial)	*Breeding* 1 The potential breeding area has undergone substantial and widespread agricultural development since the 19th century, (e.g. HYDE 3.1 land use models, Kraemer *et al.* 2015), resulting in probable habitat loss. This includes the widespread loss of wetlands (Fluet-Chouinard *et al.* 2023). *Passage and wintering* 2 Many non-breeding records come from grasslands in coastal wetlands, now a scarce habitat in the Mediterranean basin (Gretton 1991, Buchanan *et al.* 2010, Donald *et al.* 2010), and wetland loss within the species range has been considerable and widespread, with an acceleration in Europe from the beginning of the 20th century (Fluet-Chouinard *et al.* 2023). 3 Hunting across the range was identified as a threat (Gretton 1991) with specimens collected from across the range and there are a number of records of skins from food markets. Some suggestion that the bird was taken in preference to other species as it was tamer (Gretton 1991) and its apparent preference for supratidal feeding areas may have made it more vulnerable to hunting than species using the intertidal areas. 4 There is the potential for hunting and habitat loss to have interacted with hunting pressure potentially increasing on the smaller number of remaining sites used by the species (Gretton 1991). 5 Predation, disease, competition, pollution and climate change could also have affected the species, but the impact is unknown (Gretton 1991). 6 Allee effect has also been proposed as further impacting on the species after the population had been reduced to low levels by other pressures (Gretton 1991). Threat (2) is likely to have been of the highest importance. **Overall, identified likely threats are known to have acted across almost the entirety of what is understood to have constituted this species' range, and hence p(spatial) is assessed as being very high**	0.80–0.99

Slender-billed Curlews can be difficult to identify (Corso *et al.* 2014, Jansen & Corso 2023) making misidentification a real possibility. Additionally, it is possible that European observers could have based their 'search image' on the adult males at Merja Zerga 1987–1995, with black markings on pure white underparts. Females and immatures are much less distinct (e.g. Corso *et al.* 2014). Previously it has been suggested that unconfirmed records (records for which there is no evidence that shows the identity of the bird clearly) outside the species' known range, or after 1990, be reconsidered 'so that only those records that meet the highest standards are accepted' (Corso *et al.* 2014). To indicate the rarity of Slender-billed Curlew, the only photographs of live birds beyond doubt (i.e. that show the features highlighted by Corso *et al.* 2014) are known from Brittany, France, in February 1968 (Brosselin 1968, Duquet 2008), Merga Zerga, Morocco, between 2 December 1987 and 23 February 1995 (van den Berg 1988) and North Yemen in January 1984 (Porter 1984, 2004).

The records in the database were given $P(\text{ci})$ scores (Thompson *et al.* 2017) that reflect the potential for misidentification of the species. The scores were produced based on table 2 of Thompson *et al.* (2017) and reflect the level of evidence associated with each record. The criteria we used are given in Table 2. We have high confidence in the correct identification of museum specimens as 148 of 149 specimens inspected *in situ* by JJFJ were correctly identified as Slender-billed Curlew based on the latest understanding of identification. For sight records we relied upon past assessments by national rarities committees for the scoring. National rarities committees have previously been asked to review the pre-1980 records and re-assess documentation and reliability of records (e.g. Collinson *et al.* 2014). We also used results of published reviews of records (Kirwan *et al.* 2015, Wassink 2016) to inform scores.

The database of all records and their $P(\text{ci})$ scores is given in Table S1. We calculate the maximum $P(\text{ci})$ value per year and these yearly summary data are analysed using RecordsSurveyModel (Thompson *et al.* 2017), following IUCN (2022a) and IUCN (2022b) to generate $P(E)$ scores from the records and sightings.

Surveys

Survey effort for Slender-billed Curlew breeding areas has been relatively well reviewed in the literature. A summary of breeding area surveys was presented by Gretton (1991), Gallo-Orsi and Boere (2001) and Gretton *et al.* (2002). Buchanan *et al.* (2018) summarized areas where surveys for Sociable Lapwings *Vanellus gregarius* took place in northern Kazakhstan. The effort put into surveys on non-breeding areas was more difficult to quantify. We used grey literature and unpublished reports from a series of dedicated searches for Slender-billed Curlews to quantify dedicated survey effort (summarized by Gallo-Orsi & Boere 2001, Gretton *et al.* 2002, Crockford & Buchanan 2017). However, there is also unstructured, unrecorded coverage of many of these areas by birdwatchers, amateur and professional. This includes regular and dedicated survey efforts to Merja Zerga in the years since the bird was last photographed at that site. It is likely that extensive areas have been covered intensively each year. In addition to this effort there are structured International Waterbird Census surveys (https://www.wetlands.org/knowledge-base/international-waterbird-census/) in many areas that were formerly occupied by Slender-billed Curlew. Therefore, we estimate the passive survey effort to be between 0.7 and 0.8, with a best estimate of 0.75.

The outputs of these models were combined (mean of the best estimates) and compared with suggested reference values for Red List categories described in Akçakaya *et al.* (2017) and applied in Butchart *et al.* (2018). Specifically, we used the threshold that species for which the probability of extinction was >0.5 should be listed on the IUCN Red List as Critically Endangered (Probably Extinct) or CR (PE), and those for which the probability is greater than 0.90 as Extinct (EX). There are no Slender-billed Curlews in captivity, so we did not consider Extinct in the Wild (EW).

Extinction date assessment

To estimate the most likely date of extinction, we used Bayesian models developed by Solow and Beet (2014; model 2), which are detailed in Carlson *et al.* (2018) and Bond *et al.* (2019). Records were classified based on the level of evidence: confirmed specimens ($P(\text{ci}) = 0.99$) were scored 1,

Table 2. Criteria used to score likelihood index, *P*(ci) for Slender-billed Curlew records; min, minimum; max, maximum. Adapted from Thompson *et al.* (2017).

Record type	*P*(ci) min	*P* (ci)	*P*(ci) max
Specimen currently in a museum collection	0.95	0.99	0.99
Observation with photo showing identification criteria of Corso *et al.* (2014)	0.90	0.94	0.94
Record without evidence (including shot birds with no known specimens) that have support (e.g. accepted by a national rarity committee)	0.60	0.70	0.80
Record without evidence (including shot birds with no specimens) that have no support (e.g. no assessment by a national rarity committee)	0.10	0.25	0.40
Observation that is classed as not accepted by a national rarity committee or on review is not convincing or unconfirmed such as by Kirwan *et al.* (2015) or Wassink (2016)	0.10	0.10	0.15

supported records ($P(\text{ci}) = 0.94$) were scored 2 and unsupported records ($P(\text{ci}) < 0.94$) were scored 3 (Boakes *et al.* 2015, Kodikara *et al.* 2018). Extinction year was calculated following Solow and Beet (2014) where:

$$p(E|t) = \frac{p(t|E)p(E)}{p(t|E)p(E) + p\left(t|\overline{E}\right)(1-p(E))}$$

where E is the event when the species went extinct; $\overline{E}$ is when it did not; and t is the complete sighting record ($t = t_1 < t_2 < \ldots < t_n$). We used Model 2 from Solow and Beet (2014) because some of the 'uncertain' observations are from uncertain sources and Model 2 better accounts for invalid sightings (Kodikara *et al.* 2018). This model modifies the above equation as follows (from Solow & Beet 2014; equation 9):

$$p(t|\tau_E) = p(t_c|\tau_E)p(t_u|\tau_E)$$

where t_c and t_u are the sets of certain and uncertain sighting times, respectively. The model produces a posterior probability of extinction for each time step (τ_E) scaled by the area under the entire likelihood curve that starts in the first year after the last specimen record (i.e. 1983). The probability of persistence in 2024 can also be calculated as 1/Bayes Factor. For further details, see Carlson *et al.* (2018) and Bond *et al.* (2019). The slope of the exponential decline was defined by setting γ to six (Solow & Beet 2014, Carlson *et al.* 2018, Bond *et al.* 2019).

RESULTS

There was considerable geographical variation in the distribution of specimens and sightings pre-1995, with many more shot, photographed or recorded with support coming from the wintering areas around the Mediterranean basin, than the potential breeding areas (Fig. 1, Table S1).

The temporal distribution of records is shown in Figure 2. The extinction probability from the records and surveys model ranged from 0.970 to 0.999, with the best estimate of 0.994, whereas the threats model produced a range from 0.808 to 0.981, with the best estimate of 0.926. Together this generated a mean probability of extinction $P(E) = 0.960$. The output value of the threats model and the records and survey model both greatly exceeded the threshold (0.5) for Critically Endangered (Probably Extinct). The best estimates exceed the threshold (0.90) for Extinct, even though the range values do span this value. This means that there is strong statistical evidence that Slender-billed Curlew is globally extinct, although statistically the range of values indicate from the threat that there is a small chance that it is extant. The Solow and Beet model for the potential year of extinction found that the probability of persistence declined rapidly during the 1980s, with the highest posterior probability of extinction in 1992. The probability that the species remains extant in 2022 is less than 5×10^{-8} (Fig. 3).

DISCUSSION

Application of the IUCN Red List guidance (Akçakaya *et al.* 2017, Keith *et al.* 2017, Thompson *et al.* 2017) to assess the extinction probability of the Slender-billed Curlew indicates that the species is extinct and we recommend that the species being listed accordingly (EX) on the IUCN Red List should be considered. This is based on putative threats to the species across its entire range, observation history of the species, and known surveys and *ad hoc* observer effort across the range of the species. The Solow and

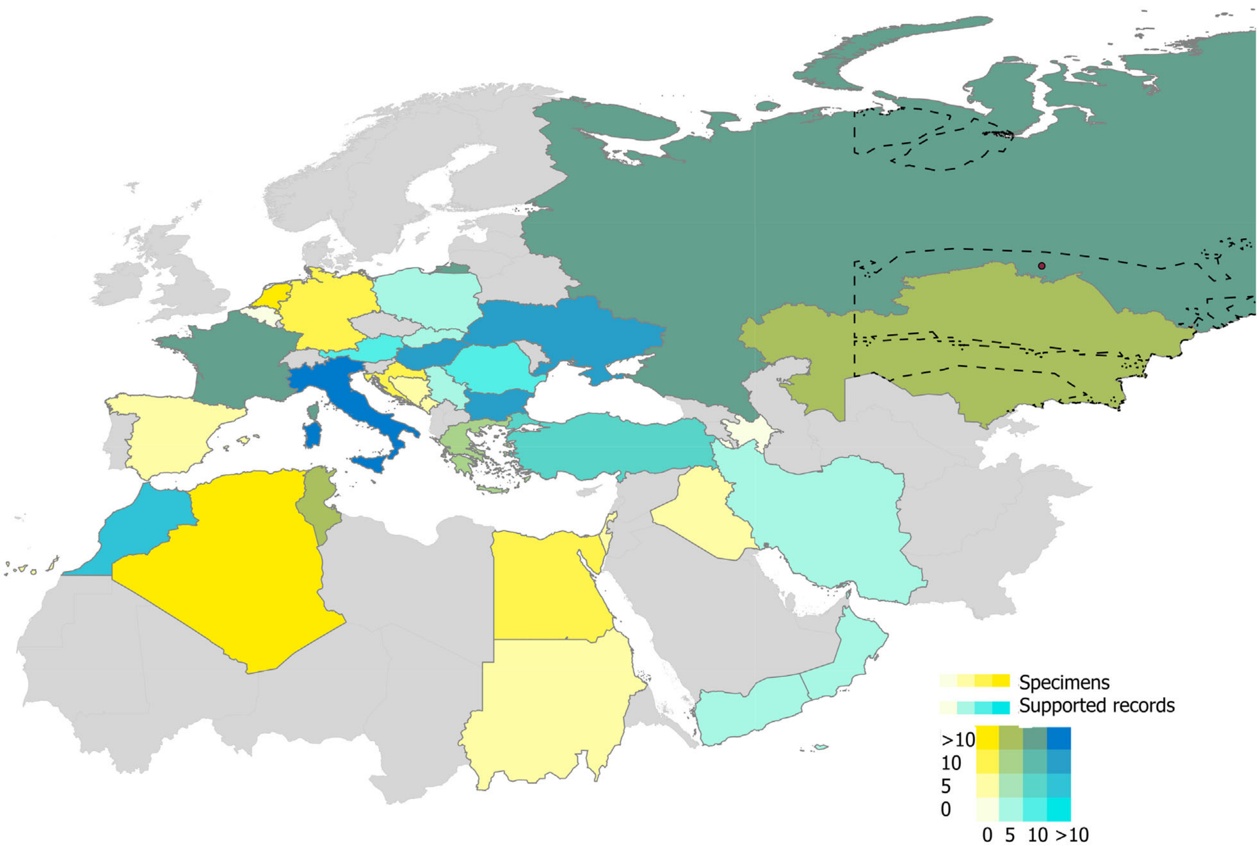

Figure 1. Country-level counts of specimens (yellow scale) and supported records (blue scale) of Slender-billed Curlew. The colour intervals on both axes of the bi-plot indicate counts of 0, 2–5, 6–10, >10 so that strength of yellow increases as the number of specimens increases, and strength of blue increases as number of records increases. High numbers of both are indicated by dark blue. Dotted line indicates the widest possible breeding area by Buchanan *et al.* (2018), and black dot indicates area of breeding identified by Ushakov (1912).

Beet (2014) model gives 1992 as the year when the probability of existence became less than 0.05. This is before the well-documented records from Morrocco in 1995. However, the model provides a posterior probability of a given extinction year scaled by the area under the entire likelihood curve rather than a set value of extinction and gives greater weight to specimens that can be examined and sampled for future analysis (e.g. genetics) than it does photographs and videos. The weight given to specimens recognizes that specimens can be examined and sampled for future analysis (e.g. genetics). Nonetheless, the model suggests that the species was on the verge of extinction in 1995, and the miniscule probability that the species remains extant in 2022 in this model is consistent with the outcome of the IUCN extinction probability framework.

If the IUCN Red List status is changed from Critically Endangered to Extinct, the Slender-billed Curlew will become only the third bird species to spend a large part of its annual cycle in the Western Palaearctic to be known to have gone extinct since 1500, the Great Auk (last seen alive in 1844; Fuller 2003) and the Canarian Oystercatcher (last collected in 1913 and reported as absent in 1940s; Hockey 2020) having predeceased the Slender-billed Curlew in this region.

The pressures that resulted in the species' extinction are mostly unvalidated inference and may never be understood and quantified. Our understanding has advanced little since the Slender-billed Curlew action plan was published (Gretton 1996). At that time, habitat loss on the breeding and non-breeding areas, and hunting, were identified as pressures on the species. Allee

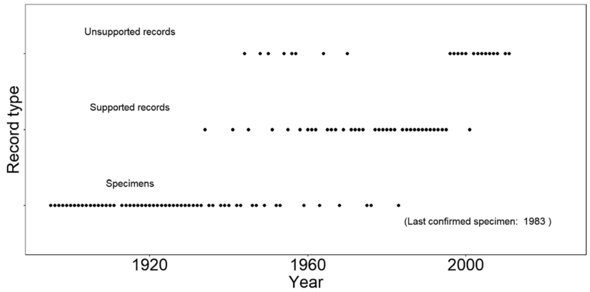

Figure 2. Distribution of specimens and sightings of Slender-billed Curlew since 1895, and 'quality' score based on Thompson *et al.* (2017) criteria.

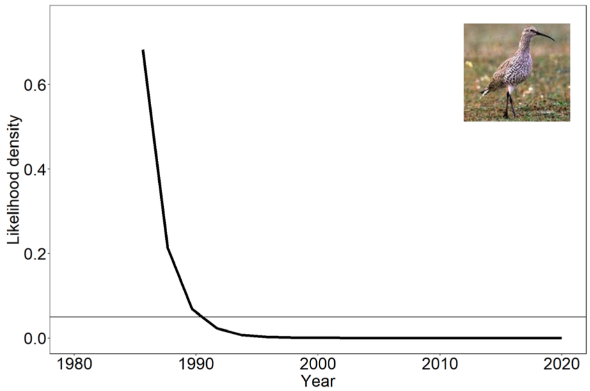

Figure 3. Posterior probability density curve after the last known specimen (skin of known whereabouts) in 1983 indicating the likelihood that Slender-billed Curlew is extant, based on patterns of records. Horizontal line indicates $P = 0.05$. Insert is an adult male Slender-billed Curlew photographed in February 1995 at Merja Zerga, Morocco, by Chris Gomersall. This is the last known bird documented in a photograph in which the identification features of Corso *et al.* (2014) can be seen.

effect was also cited as a potential pressure, with few individuals across a wide area resulting in a reduced probability of finding a mate and breeding. The potential role of the direct anthropogenic pressures (habitat loss and hunting) will probably never be known, as the full range of habitat associations of the species are not documented.

The best information on the species' breeding ecology comes from a small number of nests in boggy forests in southern Russia (Ushakov 1912, Gretton 1991, Gretton *et al.* 2002). If the main breeding regions did lie further to the south into the steppes of northern Kazakhstan (Belik 1994, Buchanan *et al.* 2018), then the habitat associations could differ (the zones identified in northern Kazakhstan, while potentially boggy, would have fewer trees). The conversion of large areas of northern Kazakhstan to croplands in the 19th and 20th centuries could therefore have caused the widespread loss of crucial breeding, and moulting habitat (the only known specimens in active moult come from putative breeding areas; Tom van der Have in litt.) for Slender-billed Curlew. Reconstructions of patterns of land cover change indicate an expansion of cropland throughout the late 19th and on into the 20th century (Klein Goldewijk *et al.* 2011), but the exact extent and time of conversion is difficult to determine retrospectively. Data from Fluet-Chouinard *et al.* (2023), who modelled historical wetland loss, indicate extensive loss of wetlands across the approximate breeding area and non-breeding areas. In the approximate breeding range described by Buchanan *et al.* (2018), loss of wetland was greatest at the start of the 20th century, approximately the time that Ushakov (1912) indicated that the Slender-billed Curlew was declining. This coincides with a period of drought and high temperatures in this area (Schubert *et al.* 2014). The herbivore megafauna extinctions at the end of the last ice age have been linked to a decline in genetic diversity in the genus *Numenius*, including Slender-billed Curlew (Tan *et al.* 2023), although the mechanism(s) responsible remain obscure. It is interesting to note that Saiga Antelope *Saiga tatarica*, a large herbivore, was formerly widespread across the putative Slender-billed Curlew breeding range, but that the population declined rapidly in the second half of the 19th and early 20th centuries (Bekenov *et al.* 1998). This coincides with the proposed decline in purported Slender-billed Curlew breeding populations mentioned by Ushakov (1912). However, as with much about the Slender-billed Curlew, any link must remain speculation.

The impact of hunting on the species will likewise remain opaque. Gretton (1996) suggested that hunting was a minor pressure on the species, but Gretton (1991) had previously highlighted it as a pressure on the species in the past, especially on wintering sites. Hunting may nonetheless have been a significant threat, especially when considered synergistically with other pressures. Hunting has been implicated in the extinction of the Eskimo Curlew (Donald *et al.* 2010), which has ecological similarities to the Slender-billed Curlew. There is evidence that birds were traded: for example, there are Italian records from Genova, Rome and Bari, the latter two of which ended up in museum collections (Baccetti 1995). Even from Leadenhall Market, London, a fresh bird was brought from the Netherlands in 1921 (Jansen & Oreel 2020). It is also probable that as the species became rarer, pressure to obtain skins for collections increased, exacerbating the pressures on an already dwindling population. Birds were shot in the 1970s and 1980s, with some ending up in museum collections (data from Gretton 1991, Nowak 1995). Hunting pressure is recognized as a risk to other species that share part of their ranges with Slender-billed Curlew. Sociable Lapwing, a species that also breeds in northern Kazakhstan, and which migrates through the Middle East, has been declining in abundance but with no indications of low breeding productivity (Sheldon *et al.* 2013). Hunting on migration has been identified as a major threat to the species (Sheldon *et al.* 2012), with an estimated 76–630 birds killed annually on the western migration route of this species (Donald *et al.* 2021).

Conservation attention came too late for the Slender-billed Curlew. The potential decline of the species was highlighted at the beginning of the 20th century (Ushakov 1912) and stated more explicitly by Stresemann and Grote (1943). These warnings were not acted on however, and the species was not recognized as being of conservation concern until 1988 (Collar & Andrew 1988). After this, a review of the species (Gretton 1991) and an action plan (Gretton 1996) followed. Our analysis indicates the species was on the verge of extinction or extinct when the action plan was published. The action plan highlighted the enormity of the conservation task but did note that some actions had already been implemented. It also made multiple recommendations to be taken immediately, including preventing further habitat loss and reducing the chance the species could be shot accidentally. By the time the action plan was published the species was listed on Annex I of the EU Wild Birds Directive, Appendix I of CITES, Appendix I of the Convention on Migratory Species and Appendix II of the Bern Convention on European Wildlife and Natural Habitats (Gretton 1996). A Memorandum of Understanding for the conservation of the species was developed during 1993/94 under the Convention on Migratory Species (Gallo-Orsi & Boere 2001). Despite this rapid initial progress, many of the objectives from the action plan were never fully implemented, partly due to the absence of further definite records of the species. For example, wetlands are still at risk and Ramsar wetlands in Europe, as elsewhere, continue to deteriorate in quality (Davidson *et al.* 2019). It is also notable that many of the research aims of the action plan were never completed, for example because the breeding grounds of the Slender-billed Curlew were never located, despite considerable effort.

It is essential that lessons are learned from the extinction of this species. Pearce-Higgins *et al.* (2017) highlighted that the Numeniini Tribe (eight *Numenius*, together with four *Limosa* (godwits) and Upland Sandpiper *Bartramia longicauda*) is a group that contains many species of conservation concern. Including Slender-billed Curlew, which is currently listed as Critically Endangered, five of the eight (62.5%) *Numenius* species are currently considered of conservation concern, compared with 21.8% of all bird species globally (IUCN 2022b). The Eskimo Curlew, which depended on grassland and steppe, as is likely with Slender-billed Curlew, is already listed as Critically Endangered (Probably Extinct), following extinction analysis by Butchart *et al.* (2018).

Species of the genus *Numenius* are long-lived species that take multiple years to recruit to breeding populations, have high survival rates but low reproductive success (Piersma & Baker 2000). These traits are associated with a heightened extinction risk in birds (Owens & Bennett 2000). The causes of declines in these species are often unclear and varied, as well as being spatially and temporally variable within and between species. However, land-use change and development have been identified as threats to *Numenius* (Jensen & Lutz 2007, Roodbergen *et al.* 2012, Douglas *et al.* 2014, Franks *et al.* 2017, Pearce-Higgins *et al.* 2017). Pearce-Higgins *et al.* (2017) further identified seven threats common to many *Numenius* species: disturbance, development, pollution, land-use change, predation, climate change and climate change mitigation actions, and hunting and harvesting. There is overlap between the threats identified by Pearce-Higgins *et al.* (2017) and the threats across the entire former range to Slender-billed Curlew.

In 2014, the Convention on Migratory Species published Conservation Statements for Numeniini species (Brown *et al.* 2014). If the actions in these are implemented, further extinctions could probably be averted. Failure to undertake concerted, coordinated, flyways-scale conservation action increases the likelihood of other species in the Palaearctic, and in other flyways, following the Slender-billed Curlew to extinction. Such extinctions are an indicator of the failure of international cooperation on biodiversity conservation as surely as climbing carbon levels currently measure our failure adequately to address climate change. With more advanced technologies than were available even 20 years ago – including optical and photographic equipment, bird-tracking and remote-sensing methods, and an evidence base on methods for protection, management and restoration – there is even less excuse for further failures.

Strategic, evidence-based approaches are needed to minimize the impact of future land use change, including agricultural, afforestation and planning policy and practice, to avoid the destruction of breeding habitat that affects many Numeniini species as well as driving declines of other shorebirds. Likewise, many of the globally threatened migratory shorebirds are dependent on coastal wetlands, so enhanced efforts to scale up concerted, coordinated conservation efforts for these, such as the World Coastal Forum, are to be welcomed.

Beyond Numeniini, populations of shorebirds are in decline around the world, and migratory species appear to be declining at a greater rate than resident ones (Koleček *et al.* 2021). Conservation actions for migratory waders, as with all migrants, must consider their annual life cycle. Actions targeted to just one area or part of the range may ultimately prove ineffective in conserving the species, even if based on sound evidence, if threats driving or contributing to declines are operating elsewhere on the flyway. Hence, action is often needed at the species, site and landscape levels along the entire flyways (Kirby *et al.* 2008). This has long been recognized and a range of mechanisms exist to promote such actions.

Governments and other stakeholders such as conservation non-governmental organizations should continue to engage with, advocate for, and help implement global and regional conventions and other intergovernmental processes that foster international and flyway-scale conservation. Within the range of the Slender-billed Curlew, the regional African–Eurasian Migratory Waterbird Agreement (AEWA), together with the Convention on Migratory Species, supported efforts to conserve Slender-billed Curlew through the working group, among other activities. Site-based networks will be most effective if identified based on objective criteria, and the Key Biodiversity Area initiative (IUCN 2016) could form a vital part of networks of sites for flyway-scale conservation. The inclusion of ecological connectivity data (such as from ringing recoveries and tracking of tagged birds) could help illustrate the connection between sites and hence support enhanced international cooperation for the conservation of such ecological networks in line with the global commitment to ensure ecological connectivity while managing and restoring areas of importance to biodiversity under Targets 2 and 3 of the 2022 Kunming Montreal Global Biodiversity Framework (CBD 2022).

Most avian extinctions have concerned insular taxa, and very few contemporary European species (Hume 2017). The Slender-billed Curlew reminds us, however, that even widely distributed European species are at risk of extinction, which can occur in a relatively short time. There are currently 43 globally threatened species in Europe (IUCN Red List categories VU ($n = 30$), EN ($n = 7$), CR ($n = 6$); IUCN 2022b), and increasing, representing a range of taxa from pan-continental species like Common Pochard (*Aythya ferina*; VU) to localized island endemics like the Gran Canaria Blue Chaffinch (*Fringilla polatzeki*; EN; BirdLife International 2023). In a critical time for biodiversity, we must prevent the 'next Slender-billed Curlew' through enhanced conservation action, coordinated via partnerships, including direct intervention and nature conservation policy. Efforts on the conservation of the Critically Endangered Spoon-billed Sandpiper *Calidris pygmaea* in the East Asian–Australasian Flyway, probably the migratory shorebird that is most at risk of following the Slender-billed Curlew to extinction, are currently being deployed collaboratively at flyway scale, deploying new technologies, having been informed by the history of the Slender-billed Curlew.

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AUTHOR CONTRIBUTIONS

Graeme M. Buchanan: Conceptualization; investigation; writing – original draft; methodology; writing – review and editing; data curation. **Ben Chapple:** Writing – review and editing; data curation; investigation. **Alex J. Berryman:** Investigation; writing – original draft; writing – review and editing; data curation; methodology; conceptualization. **Nicola Crockford:** Funding acquisition; writing – review and editing; project administration; data curation; resources. **Justin J. F. J. Jansen:** Conceptualization; writing – review and editing; data curation; methodology; investigation. **Alexander L. Bond:** Conceptualization; investigation; writing – original draft; methodology; data curation.

CONFLICT OF INTEREST

The authors have no conflicts of interest.

ETHICAL NOTE

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Data Availability Statement

All of the data used in the analysis in this paper are given in Table S1, which contains the location and year of all records on the database.

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SUPPORTING INFORMATION

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

Table S1. Summary by year of the records from the Slender-billed Curlew database that were used for analysis. All records for a given year are given but only year maxima were used in the actual analysis.