Outcome Indicator Framework for England's 25 Year Environment Plan: 2022

Technical background document for:

D5 Conservation status of our native species

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Report details

Authors

Tim Wilkins

Richard Wilson

Andy Brown

Project Manager

Tim Wilkins

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Executive summary

This report sets out the approach and methods adopted to inform development of the 25 Year Environment Plan Outcome Indicator, D5: 'Conservation status of our native species'. In scope, it covers conception, development, and finalisation of a 'Red List Index for England' as the D5 metric, focusing on the creation of a 2022 baseline but also addressing how it will be reported upon in future. An accompanying spreadsheet includes the full list of species in the baseline Red List Index and its calculation.

The International Union for Conservation of Nature (IUCN) red-listing system is a globally accepted methodology for assessing species extinction risk which can be applied at national scale. Each species is assigned to one of 11 categories (Extinct, Extinct in the Wild, Regionally Extinct, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, Data Deficient, Not Applicable, and Not Evaluated).

A Red List Index is based on the numbers of species in each Red List category and how these numbers change over time as species improve or deteriorate in status. The index is considered to be more informative as an indicator than the simple proportion of threatened species because it excludes Red List category changes owing to improvements in knowledge, revised taxonomy or other so-called non-genuine changes. The index is expressed as a value between zero and one, where 'one' equates to all species assessed as Least Concern (hence none are expected to go extinct in the near future), and 'zero' indicates that all species have gone extinct. In this way, the index can be used to measure overall extinction risk of a large number of species at a specific point in time, and when recalculated at intervals, to provide a trend.

The report charts the development of the index, from early work undertaken by the UK Centre for Ecology and Hydrology, to a preliminary 'England-level GB Red List Index, to its finalisation by Natural England as the baseline 'Red List Index for England'.

The final version of the index is presented here for the first time. All species (taxa) native to England that have been listed in approved GB IUCN Red Lists, and for which a Red List Category is available (excluding Data Deficient), have been included. A total of 36 GB Red Lists produced over a 15 year period (2008-22) were used as the data source.

The overall (aggregate) Red List Index value for the baseline year of 2022 is 0.9070, embracing the status of 8,259 taxa across 23 major taxonomic groups. The index values for individual groups (i.e. Red Lists) ranged from 0.7387 to 0.9747, with a median of 0.8979. Butterflies, birds, and amphibians & reptiles had the lowest index values (highest extinction risk) of 0.7387, 0.7448 and 0.7692, respectively. In contrast, hoverflies had the highest index value (lowest extinction risk) of 0.9747. As discussed in the report, a number of factors can affect comparison of index values across groups, hence caution is advised when doing so.

The index almost exclusively focusses on terrestrial and freshwater taxa, comprising: 49% invertebrates, 29% vascular plants, mosses & liverworts, 18% fungi and lichens and the

remaining 4% vertebrates. Most marine taxa have yet to be Red List assessed in GB, hence very few are included in the index. Only a small fraction of fungal species (other than lichens) are covered, while groups such as moths and the Hymenoptera (ants, bees, wasps, sawflies, etc.) cannot be included because they lack approved Red Lists. The IUCN Red List criteria are unsuitable for the assessment microorganisms, hence a vast number of microscopic species are not in scope. Assuming a total of 40,000 native macro-species in terrestrial and freshwater groups in England, about 20% are covered by the index.

The use of Great Britain scale Red List assessments for an England indicator is investigated and acknowledged as a weakness. A comparison of GB and England Red List categories across four taxonomic groups shows that between 80-92% of statuses align and therefore the aggregate Red List Index is considered a good approximation of extinction risk in England. Nonetheless, GB scale assessments can underestimate or overestimate extinction risk at England scale and, importantly, losses from England of species still present in Scotland or Wales will not be detected by the index.

Change in the Red List Index is expected to be subtle, partly because it is numerically dominated by species of Least Concern, and the index measures net changes in the movement of species between Red List categories. Nevertheless, small shifts in the index can signify substantial changes in the fortunes of threatened species. For example, a 50% reduction in the number of threatened species in the 'Red List Index for England' would result in a rise in the index value of 2.8% (assuming 50% move to Near Threatened and 50% move to Least Concern), and yet this equates to almost 500 species moving to non-threatened categories. Furthermore, the index can exhibit time-lags, due to the implementation of biodiversity policies, resultant improvements in species populations, available data evidencing these and the frequency of Red List assessment. Therefore, the index will be most effective as a long-term indicator.

A technique called 'backcasting' is commonly used to update Red List Indices whereby existing extinction risk assessments are amended in light of new evidence or taxonomic change. Backcasting in the 'Red List Index for England' will only be possible at specific times, when its use will be minimised to preserve indicator continuity. Index data will be managed via a simple spreadsheet system which will capture Red List category changes and the reasons for these. Data will be retained for the whole series, charting change from the 2022 baseline. The whole dataset will be made openly available.

We anticipate the indicator operating over at least a 20 year period (2022-42), with a 10 year update cycle of every GB Red List in the index. An average of approximately four Red List reassessments per year will be required. Reporting at 5 year intervals will be possible, although only a partial set of reassessments will be available in 2027 and 2037, making the aggregate index less precise than in 2032 and 2042 when a full set of reassessments will be used. Interpretation of the indicator will be improved by clearly showing statistical uncertainty, and also presenting individual taxonomic group Red List Indices.

Contents

1. Introduction

This report sets out the approach and methods adopted to inform development of the 25 Year Environment Plan Outcome Indicator, D5: 'Conservation status of our native species'. In scope, it covers conception, development, and finalisation of a 'Red List Index for England' as the D5 metric, focusing on the creation of a 2022 baseline but also addressing how it will be reported upon in future.

As a metric of extinction risk, the indicator has great relevance to the biodiversity crisis, providing the means to track large numbers of England's native species and, specifically, the relative proportion of species with an improving or deteriorating conservation status over time.

The baseline Red List Index spreadsheet (NERR124 Edition 1. OIF D5 Conservation status of our native species – Data Sheet 2022.xlsx) will be published alongside this report; it contains a list of all taxa in the index and their Red List categories, calculation of the aggregate index and component (taxonomic group) indices, also shown graphically, a list of Data Deficient taxa excluded from the index, and references of the Red Lists used.

The report and dataset have been subject to both internal and external peer review.

2. About the indicator

In 2019 the UK Government published an Outcome Indicator Framework for its 25 Year Environment Plan which contained seven wildlife indicators (D1 to D7) (Defra, 2019). This report and the accompanying dataset concern the headline indicator D5 'Conservation status of our native species', and the subsequent proposal by Natural England to develop a simple index to track changes in the conservation status of species using established international Red List categories and criteria (Defra, 2020; OIF progress reports).

The International Union for Conservation of Nature (IUCN) red-listing system is a globally accepted methodology for assessing species extinction risk. Assessments at national or regional scale (geographically or politically defined areas such as a continent, country, state, or province), assign each species to one of 11 different categories (Extinct, Extinct in the Wild, Regionally Extinct, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, Data Deficient, Not Applicable, and Not Evaluated), based on a series of quantitative criteria (IUCN 2012a). Species classified as Vulnerable, Endangered and Critically Endangered are defined as 'threatened' with extinction. The IUCN Red List Criteria were developed following extensive consultation and testing with experts familiar with all kinds of different species from all over the world (Mace et al., 2008), and can be used to assess any species (apart from microorganisms) (IUCN, 2012a; IUCN, 2022). Further details are given at IUCN Regional Red List Assessments.

3. How a Red List Index works

A Red List Index (RLI) is based on the numbers of species within each IUCN Red List category and the changes in these numbers over time resulting from genuine improvement or genuine deterioration in status between assessments (Butchart et al., 2004). Changes in Red List category are largely driven by improvements in knowledge and changing taxonomy. The indicator excludes such changes (termed 'non-genuine change') to yield a more informative indicator than the simple proportion of threatened species (United Nations Statistics Division, 2021). The RLI is compiled from species across the entire spectrum of extinction threat, and uses a weighted scoring system (Table 1).

Table 1. Standardised scores used in IUCN Red List Indices (Bubb et al., 2009). **Note:** (i) the categories 'Extinct' and 'Extinct in the Wild' relate to global losses whereas 'Regionally Extinct' concerns species lost at national scale, e.g. Great Britain, but which survive elsewhere in the world; (ii) CR(PE) and CR(PEW) are defined as CR qualifiers, rather than separate Red List categories (IUCN Standards and Petitions Committee. 2022); (iii) species categorised Data Deficient, Not Applicable, and Not Evaluated are excluded from the index.

Red List category	Index score
Least Concern (LC)	0
Near Threatened (NT)	1
Vulnerable (VU)	2
Endangered (EN)	3
Critically Endangered (CR)	4
Extinct (EX), Extinct in the Wild (EW), Regionally Extinct (RE), Critically Endangered 'Possibly Extinct' - CR(PE), or Critically Endangered 'Possibly Extinct in the Wild' - CR(PEW)	5

The RLI value is simply the sum of scores of all species in the index, expressed as a proportion of the total score assuming all species in the index became extinct (the sum of applying the maximum weighting of 5 to every species), and the result deducted from 1. The resultant index value lies between 1 (all species Least Concern) and 0 (all species Extinct), providing a measure of average extinction risk across the categories. A detailed explanation of RLI use at national and regional scales, including the equation used, is given in IUCN RLI Guidance (Bubb et al., 2009).

An overall (aggregate) RLI can be generated for all taxonomic groups, and/or an RLI for each individual group. Internationally, it has been used to track the changing fortunes of species at a range of geographic scales, and even to monitor the status of habitats (e.g. Juslén et al., 2016).

When the RLI is recalculated at intervals, its value reflects net changes in the numbers of taxa in Red List categories following reassessment. In order to track variation in the actual levels of threat faced by species, category changes resulting from, e.g. taxonomic change or improved knowledge, are excluded (see section 6.1 for full explanation). In this way, the RLI can be used to give a measure of overall extinction risk of a large number of species at a specific point in time, and when repeated at intervals, to provide a trend. The same principles apply to the global IUCN Red List Index.

Generic strengths and weaknesses of RLIs are set out in Appendix 2, and details of the Red List update cycle given in section 6.4.

4. Developing a Red List Index for England

4.1 Preliminary baseline index

Early work was undertaken by the UK Centre for Ecology and Hydrology (UKCEH), including an evaluation of reporting and reassessment cycles (Logie & Isaac 2021). A simple compilation of GB Red Lists was used to generate a draft GB-scale Red List Index which provided the foundation for further work.

A sampling approach to track RLI changes over time was also investigated by UKCEH (Logie & Isaac, 2021). Simulations showed how the sample size of assessed species depended on the subtlety of the true RLI trend. Samples sizes ranged from 86 to 1,367 for a 95% chance of detecting a trend (the difference in RLI values) of 0.01987 to 0.00074 respectively, or from 170 to 1,714 for an 80% chance of obtaining a statistically significant ($P < 0.05$) trend for the same range of trend values. Earlier studies of a sampled RLI approach have shown some variation in recommended sample sizes. Baillie et al. (2008) calculated that a minimum of 900 would be sufficient for birds but 1,500 necessary for taxonomic groups with a high proportion (up to 40%) of Data Deficient taxa. In contrast, Henriques et al. (2020) showed that when re-assessments were conducted every 10 years, 200 species (400 in some cases) ought to be sufficient to detect a trend; it was acknowledged, however, that correct detection of changes in slope still required samples of 900 species (11,000 in some cases). Given an unknown future trend in the D5 index, uncertainties over the most appropriate sample size, and the wider benefits of comprehensive red-listing for conservation, it was decided to develop an RLI using all available data.

Subsequently, a preliminary ‘England-level GB Red List Index’ was developed by Natural England, based on the IUCN RLI guidance (Bubb et al., 2009). Since D5 is an England indicator, consideration was given to using purely England-scale Red Lists but with only four such assessments published to date (plants, terrestrial mammals, amphibians & reptiles, and freshwater fishes) compared to over 30 at GB scale (including birds and many invertebrate groups), the index would have been much less representative (see ‘Geographic scale’ for further discussion).

The preliminary index used an ‘England extant’ criterion to give the indicator absolute relevance to England – i.e. limiting to taxa known to currently occur in England, and removing those either lost from England, or only occurring in Scotland or Wales. Calculation of the aggregate RLI was based on total species counts for all taxonomic groups included (rather than the arithmetic mean of individual group RLIs; no weighting was applied cf. Baillie et al., 2008). This index was published in an evidence report supporting the Environment Act targets (Defra, April 2022). Appendix 1 has full details.

4.2 Revisions and improvements

As set out below, a number of improvements were made to the preliminary baseline index (see ‘Scope for improvement’). IUCN RLI guidance (Bubb et al., 2009) was followed in all aspects except those noted in Table 5 and the subsequent decision to include Regionally Extinct taxa in the baseline index.

Hereafter ‘**eligible status**’ is used to describe any Red List status that is scorable in the index (Table 1). The categories Data Deficient (DD), Not Applicable (NA) and Not Evaluated (NE) are thus ineligible.

4.2.1 Red List coverage

The diversity and currency of Red Lists in the RLI was improved by: 1) replacing three older lists with recent updates (birds, butterflies and bryophytes); and 2) adding seven further Red Lists that were either recently completed, or omitted from the preliminary index (water beetles; pill, fringe-winged, soft-bodied plant, plate-thigh, root-eating and shining flower beetles; rove beetles (macrostaphs or larger staphylinids); hoverflies; non-marine molluscs; freshwater fishes; and the true flies – Lonchopteridae, Platypezidae and Opetiidae).

Two lists were removed from the index (macromoths; and earthstars, puffballs/ stalkballs, chanterelles & tooth fungi) since they still needed formal approval (section 4.2.2).

A table of GB Red Lists used in the finalised indicator is given in Appendix 4 (full references are given in the spreadsheet), and representativeness discussed in section 5.1.

4.2.2 Red List quality

There was a trade-off between biological representativeness and assessment quality. For example, the inclusion in the index of unrepresented but incompletely assessed groups, could cause bias in individual RLIs and therefore also the aggregate RLI.

An issue with some of the Red Lists was treatment of Least Concern, whereby assessors appeared to use a range threshold, e.g. 100 hectads (i.e. 100 x 10km-squares), above which they assumed all taxa would be Least Concern. This mainly affected groups with poor coverage of records and was justified on the basis of inadequate datasets. However, this went against IUCN guidelines which require each taxon to be evaluated against all five

criteria because it will never be clear in advance which criteria are appropriate (IUCN, 2012b). Despite invaluable help from red list authors, we were unable to resolve this issue in every case. To avoid the complete exclusion of the few lists concerned, the following workaround was adopted:

- When such lists are reassessed, authors will be required to retrospectively assess each LC taxon using the IUCN criteria. As a result, a taxon will either remain as LC at baseline or be reclassified to a different category. In cases where baseline LC status is confirmed, subsequent genuine change can be tracked, but where baseline status is found to be different, non-genuine change will be flagged and require correction through backcasting (section 6.2). We expect most of the existing LC assessments to be correct and only a small number to be coded as 'incorrectly assessed at baseline'.

To ensure only complete and IUCN-compliant Red Lists were used in the RLI, each required endorsement by one of the Statutory Nature Conservation Bodies, involving checks by the commissioning organisation and a qualified IUCN Red List Assessor. In addition, checks were carried out during RLI compilation to ensure, for example, the correct treatment of non-native taxa in Red Lists (section 4.2.4).

4.2.3 Treatment of extinct taxa

In accordance with current RLI guidance (Bubb et al., 2009), the preliminary index excluded from the baseline all taxa in extinct categories, including Regionally Extinct and Extinct in the Wild. Thus any subsequent reintroductions, or natural recolonisations, of these would not be tracked in the index. In consultation with the IUCN Regional Office (Cambridge), we adopted the approach taken in Finland which included RE taxa at baseline because over a 10-year period some species were found to have re-established through natural dispersal (Juslén et al., 2013). The authors observed that from a national perspective, it was reasonable to include RE species in calculations because regional extinction is not necessarily irreversible.

Taxa were added to the baseline RLI if they were formerly native to England and classified in GB Red Lists as:

(i) Regionally Extinct (RE);

(ii) Extinct in the Wild (EW);

(iii) Extinct (EX) where the category had been misapplied to Regionally Extinct taxa (in such cases we did not alter the original RL category but suggest it is revised at reassessment).

As a result, 109 taxa were added to the baseline index.

Global extinctions are exceptionally rare at GB level but the following were considered as such and so have been excluded from the index: Great Auk (*Pinguinus impennis*), the true

fly - *Poecilobothrus majesticus*, and the hawkweeds - *Hieracium acamptum*, *H. cambricogothicum*, *H. pycnotrichum*, and *H. subintegrifolium*.

Taxa designated 'possibly extinct', i.e. CR(PE), are defined under IUCN guidelines as those Critically Endangered species that are, on the balance of evidence, likely to be extinct, but for which there is a small chance that they may be extant (IUCN Standards and Petitions Committee, 2022). However, the use of CR(PE) in regional Red List assessments is not clear since 'possibly extinct' could mean regional or global loss. With GB Red Lists we made the reasonable assumption that it means 'possibly regionally extinct', consequently these taxa have been retained in the index.

IUCN guidance advises that the listing of species as Regionally Extinct should embrace only those lost since 1500 AD, though the exact cut-off date is left to the discretion of the Red List assessors (IUCN, 2012a). The list of RE, EW and EX taxa in the index should thus be regarded as the minimum lost. An alternative would have been to introduce a cut-off for the RLI, e.g. post-1800, although this would have involved overriding Red List assessments to which we have consistently given primacy.

Taxa lost from England that remained extant in Scotland and/or Wales were also in scope for the baseline index where: (i) they had eligible GB red list statuses, and (ii) there was reasonable evidence of past natural occurrence in England. Using research undertaken by Natural England (2010), approximately 100 additional taxa were included in the index as a result.

4.2.4 Establishing native status

The finalised RLI aims to comprise species only *native* to England (whether extant or not). Under IUCN rules, non-natives and vagrants should be classed Not Applicable (IUCN, 2012a) or Not Evaluated (IUCN, 2012b) and thus are ineligible for the index. Although this rule had been largely followed in GB Red Lists, it was apparent that in a small number of cases non-natives had been assessed with eligible statuses (LC-EX) either because they were considered native at the time, or ancient introductions, or newly established through dispersal (no evidence of introduction), or perhaps assessed in error.

Evidence sources used to determine natural occurrence in England fell into three main categories:

- National inventories/checklists of non-native species, including invasives (Hill et al., 2005; Roy et al., 2020; Natural History Museum, 2022);
- A wide range of taxonomic group references, including: Red Lists, national and Vice County checklists, atlases, species accounts/dossiers, national (biological records) databases, the NBN Atlas, and floras (not all sources have been listed in the references section);
- Individual species records, in a small number of cases.

The opinion of Natural England species specialists was also sought where evidence was equivocal.

Criteria for determining non-native status can be variable and complex. Appendix 3 sets out the definitions used in the Natural England audit (Hill et al., 2005) and their relevance and application in the RLI. Key aspects of our approach included:

(i) Ancient introductions, e.g. archaeophytes, were excluded;

(ii) Taxa only ever recorded in England sporadically and considered likely vagrants, were excluded;

(iii) Extinct species reintroduced into the wild from populations outside of GB, were included (if non-DD);

(iv) Recent arrivals, only where natural (not introduced) and established (typically for a minimum of 10 years), were included (if non-DD).

Where evidence of non-native status was clear, e.g. plant archaeophytes, these taxa were excluded from the index. However, where there was doubt, conflicting evidence, or a lack of information, we have mainly deferred to assessors' findings.

4.2.5 Proportion of GB populations in England

As discussed in the preliminary indicator (Appendix 1), 'Geographic scale' was key to index development. Any taxon known to naturally occur, or have naturally occurred, in England was included in the RLI (provided it had an eligible status). Alternative approaches were considered that took into account the proportion of GB populations in England, on the basis that species which predominantly only occurred in Scotland and/or Wales were inappropriate for an England indicator.

A range threshold might be applied, e.g. 20% of occupied hectads, below which taxa would be excluded from the index. The global IUCN Red List Index uses a method of geographic disaggregation to determine RLI values for individual regions and countries (Rodrigues et al., 2014). Each country/region is weighted according to the proportion of a species' distributional range it supports. We considered whether a similar system could be adopted to disaggregate the GB RLI to England level. The time-slice chosen to measure distribution to determine weighting would be critical and could lead to perverse outcomes if conservation priorities of rare, or range-contracted, species were weighted against. For example, Corncrake (*Crex crex*) once bred in meadows and grasslands in almost all English counties but a protracted decline since the early 20th century led to its near extirpation and it now persists largely through a concerted reintroduction effort (Natural England, 2008, 2010; P. Grice, pers. comm.). Selecting any one year to determine the weighting for such a species would be problematic.

In summary, these approaches were rejected on grounds that they could inadvertently weight against, or exclude, taxa from the baseline that were:

(i) England conservation priorities – e.g. species with contracted ranges that had once been widespread in England;

(ii) Currently rare in England but might increase in future such that England would have a greater share of (and responsibility for) the GB population.

4.2.6 Taxon level

The IUCN Red List criteria may be applied to any taxonomic unit at or below the species level, although taxa below the rank of variety (e.g., forma, morph, cultivar), are excluded from the IUCN Red List of Threatened Species, with the exception of assessments of subpopulations (IUCN, 2012b; IUCN Standards and Petitions Committee, 2022). The regional guidelines (which cover assessment of subpopulations within countries or regions) leave the eligibility of lower taxonomic level to the regional Red List authority to determine (IUCN, 2012a). To date, it appears no such limitation has been applied to GB Red Lists. In addition, infraspecific assessments should always be accompanied by 'parent' species-level assessments (IUCN Standards and Petitions Committee, 2022).

Undescribed taxa are generally excluded from the global IUCN Red List, e.g. undescribed infraspecific taxa, or undescribed species assessed as Data Deficient or Least Concern (unless certain conditions are met); also excluded are taxa above the species level (IUCN Standards and Petitions Committee, 2022).

Infraspecifics

On revision, the RLI contained 243 infraspecific taxa of which 52% were vascular plants and 43% lichens. A total of 207 (85%) were Least Concern, 18 (7%) Near Threatened, 1 Regionally Extinct and the remaining 17 (7%) threatened. The majority (65%) were subspecies.

Our aim in creating the RLI has been to strike a balance between representativeness (including as many taxa from as wide a range of groups as possible) and avoidance of bias (e.g. towards taxonomic groups with higher proportions of infraspecifics). All taxa included had equal weighting, therefore a species represented by more than one infraspecific assessment had more weight in the index.

We adopted the following approach to alleviate the effect of infraspecifics:

(i) Where a species had an eligible status, this was used in preference to related infraspecific statuses.

(ii) In the absence of a species-level assessment, subspecies statuses were used.

(iii) In the absence of both species and subspecies assessments, infraspecific statuses could be used to infer the species-level status but only under the following circumstances:

- The infraspecific was the sole taxon representing the species in GB.

- All infraspecifics were LC, or one was LC and another NT, therefore it could be inferred that the species was LC, (LC/NT combinations were individually checked).

(iv) All remaining infraspecifics, and by implication the parent species they represented, were excluded from the RLI.

In so doing, representation in the index was maintained, duplication of assessments was avoided, and differences across taxon groups were reduced (Table 2). At reassessment, it will be necessary to ensure the rank/qualifier of taxa remains unchanged.

Sensu lato/stricto

Some species appeared twice in the index, with *sensu stricto* and *sensu lato* qualifiers, implying a degree of taxonomic overlap and duplication. *Sensu stricto* gives a more accurate/narrower definition of a species, hence taxa with this qualifier have been used in preference to *sensu lato*. This implies that a proportion of the *sensu lato* 'population' is unaccounted for in the index. Some *sensu lato* taxa remain in the index because these were the sole representation of the species with an eligible status.

Undescribed species

A few taxa lacked identity at species level, e.g. *Orchestina* sp., whilst others had questionable taxonomy indicated by '?' or 'cf.' against the specific name. Although some of these had UKSI recommended taxon keys, they still lacked recommended specific names. All were omitted from the index.

Aggregates

To avoid duplication, aggregate (agg.) taxa were removed from the index if their component species were also listed.

Table 2. Taxa omitted or retained in the index as a result of applying the taxon level rules. The number of species represented by infraspecific assessments is given in round brackets.

Rank or qualifier	Excluded	Included
Aggregates	7	8
Sensu lato	18	4
Sensu stricto	0	20
Subspecies	124 (66)	33 (24)
Sole infraspecific of species in GB	0	3 (3)
Other infraspecifics (more than one per species)	25 (22)	0
Species-level from combined infraspecific assessments	0	29 [a]
Undescribed	6	0
Total	**180 (119)**	**97 (88)**

Note that 29 lichen species ([a] in Table 2) resulted from combining 58 LC and NT/LC infraspecific assessments (these are identified in the accompanying spreadsheet).

We tested how these rules collectively impacted the baseline RLI by comparing before and after RLI values. The original RLI value with all taxa ranks/qualifiers retained was 0.9080 whereas after applying the taxon-level rules, the RLI fell to 0.9070. This was a small but unexpected decrease (rise in extinction risk), and caused by the lower threat levels of taxa excluded: 88% Least Concern and 7% threatened, whereas the proportions for the whole RLI dataset were 80% LC and 12% threatened.

Note that these rules were only applied to the scientific names as they appeared in GB Red Lists at the time of their production. Some taxa may have changed taxonomic rank since, which would affect the outcome.

4.2.7 Breeding and non-breeding bird assessments

The approach taken in the preliminary index ('Treatment of birds with two statuses') differed to the method adopted by others (BirdLife International, 2015; Stanbury et al., 2017) that allocated the highest threat category of birds with two statuses (breeding and non-breeding populations). However, the latter method could elevate the overall threat level such that the RLI for birds would be predisposed to being lower (greater extinction risk) than for other groups.

An alternative method was explored to address this: for species with two eligible statuses that had both breeding and non-breeding populations naturally occurring in England, both population statuses were included in the index. In so doing, the two statuses were effectively averaged by the RLI equation. Otherwise, where only one population was native to England with an eligible status, only that status was included. Sensitivity testing of the two methods, showed that ‘highest status’ gave a bird RLI value of 0.7260, compared to 0.7448 for ‘both statuses’ – i.e. the former indicating a higher extinction risk. To improve comparability across taxonomic groups, the alternative method (‘both statuses’) was adopted in the revised and final iterations of the index (breeding and non-breeding statuses are distinguished in the spreadsheet by the suffixes [br] and [n-br]).

5. The finalised baseline indicator

The final version of the index was built on the preliminary index. Other than revisions covered in section 4.2, the original rationale and methods (Appendix 1) have been retained, including the approach to geographic scale.

The nature of biological recording, data flow, databasing and Red List reassessment, means that RLIs can exhibit time-lags in response (Butchart et al., 2005). Species observations, many of which are undertaken by volunteers in England, can take time to become available via national databases, and GB Red Lists are generally only updated once every 10 years. Furthermore, it can take time for biodiversity policies to be

implemented and for species populations to respond. For these reasons, the 'RLI for England' will be most effective as a long-term indicator.

5.1 Taxonomic scope

All taxa native to England that have been listed in approved GB IUCN Red Lists, and for which an IUCN Threat Category is available (RE/EW through to LC), have been included in the baseline Red List Index (no sampling strategy was employed). A total of 36 GB Red Lists were used, spanning a 15 year period (Figure 1). Lists were only included if: (i) the current (2001) version of IUCN Red List criteria had been used, and (ii) all taxa in groups concerned had been evaluated (but see section 4.2.2). Appendix 4 gives a breakdown of the GB Red Lists, including the proportion of taxa included in the final index.

Representation across the major taxonomic groups varied from zero to 100%. The best represented groups were vascular plants, bryophytes, lichens, birds, amphibians and the non-marine mammals and reptiles and a majority of largely terrestrial and freshwater invertebrate groups (including a high proportion of English beetles, true flies and true bugs) for each of which assessments were available for all English species (Figure 2).

However, some terrestrial and freshwater groups were not represented at all, including numerically large groups such as moths, lice and the Hymenoptera (ants, bees, wasps, sawflies, etc.). Furthermore, fungal species (other than lichenised fungi) and truly marine taxa have very low levels of representation. Marine mammals, fish, molluscs and algae, plus an unknown number (but likely tens of thousands) of marine invertebrates, were not included in the index.

The IUCN Red List criteria are unsuitable for the assessment of microorganisms (IUCN, 2012b) which meant a vast number of microscopic species were not in scope, e.g. 10,000 microfungi, and an unknown number of protists, archaeans and bacteria.

Whilst we cannot know exactly how representative the index is of England's biodiversity as a whole, nor how close 'assessed' extinction risk is to the 'true' extinction risk, assuming a total of 40,000 native macro-species in terrestrial and freshwater groups in England, about 20% (n=8,259) are covered by the index.

Figure 1. Cumulative number of GB Red Lists produced after 2001 that are used in the final baseline RLI. The number for 2022 includes two *in press* lists.

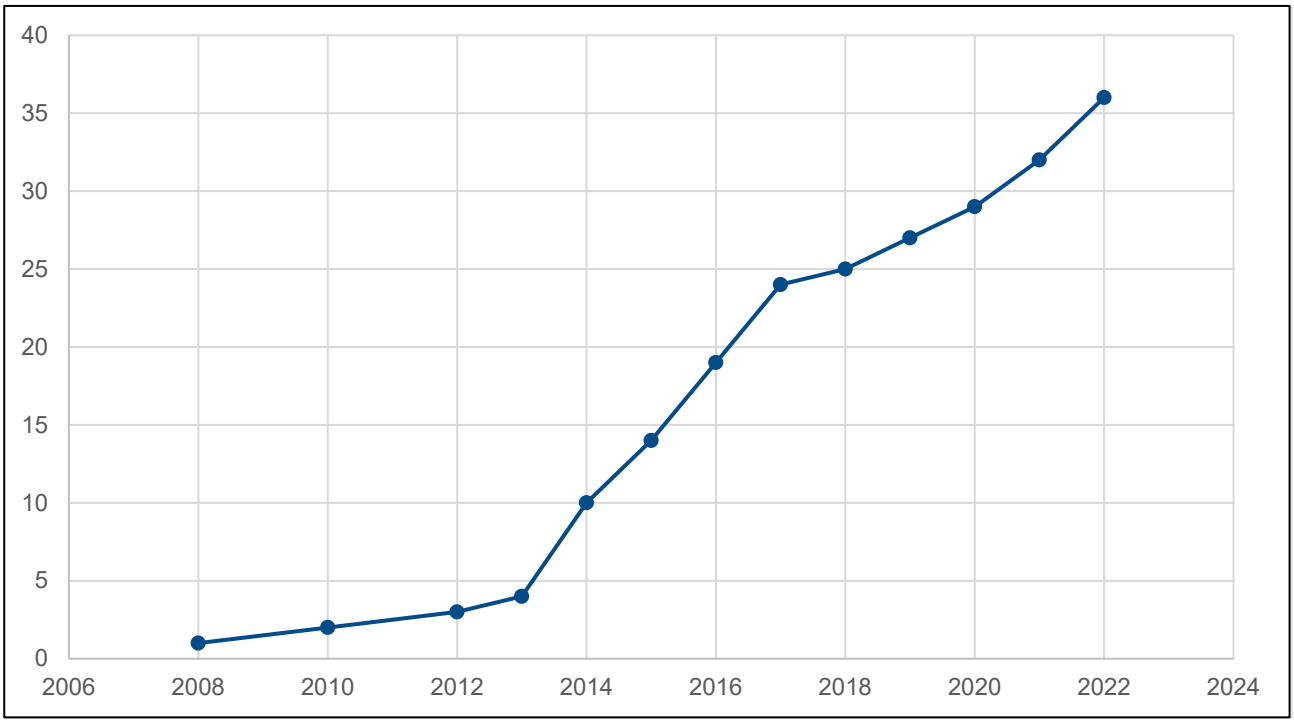
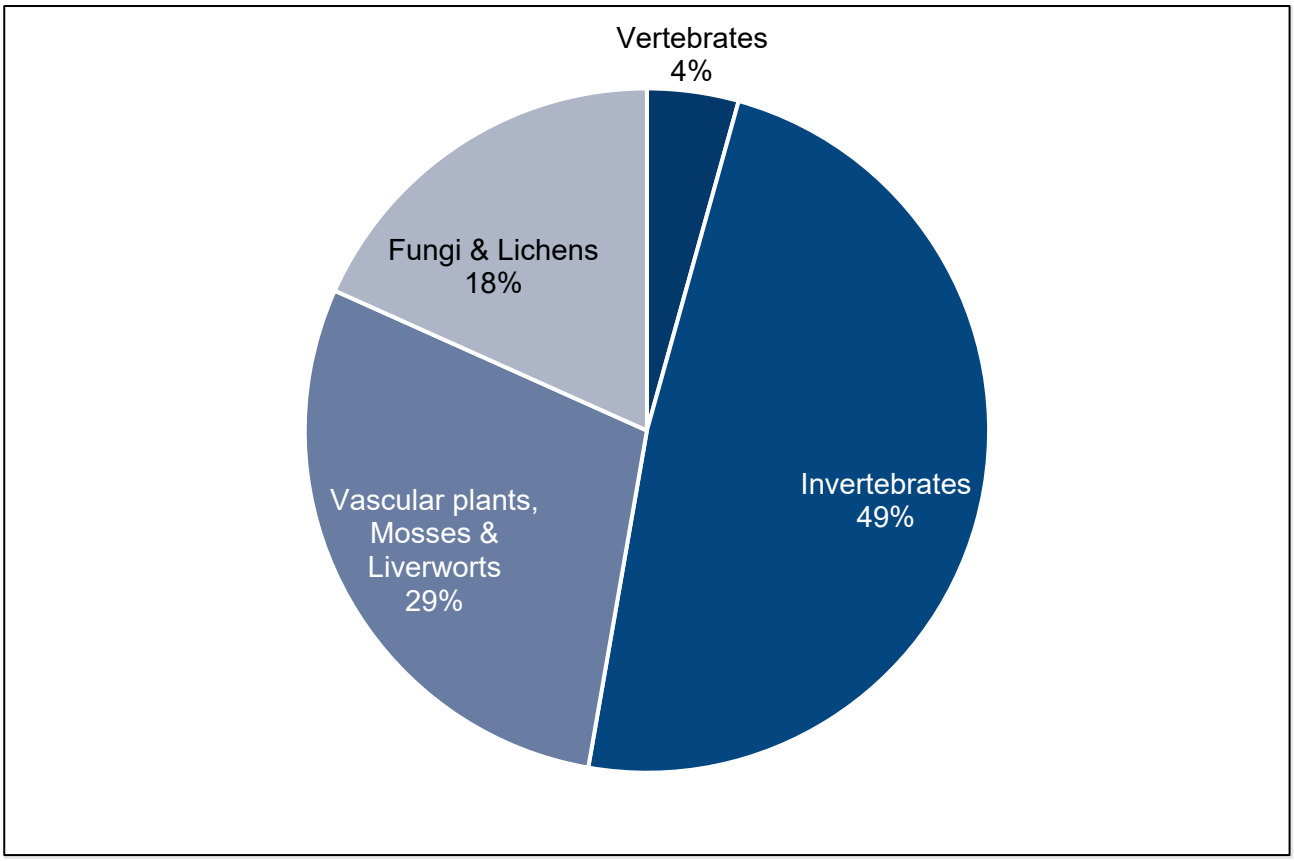


Figure 2. Composition of the final baseline RLI.



5.2 Baseline year

The baseline year of 2022 is intended to align with enactment of secondary legislation of the Environment Act (2021) in which it is anticipated biodiversity targets will be set. Specifying an earlier baseline year was technically feasible but would have decreased the diversity of taxonomic groups represented (Figure 1). Of the 36 Red Lists included, 30 have yet to be assessed more than once using the 2001 IUCN criteria, hence it was not possible to establish an aggregate RLI trend of all groups that could be extrapolated/ interpolated to an alternative baseline year.

5.3 Red List Index

The finalised baseline indicator is shown in Figure 3. An aggregate RLI value of 0.9070 was calculated, embracing the status of 8,259 taxa across 23 major taxonomic groups. The index values for individual groups (i.e. Red Lists) ranged from 0.7387 to 0.9747, with a median of 0.8979.

Within these, butterflies, birds and 'amphibians & reptiles' had the lowest RLI values (highest extinction risk) of 0.7387, 0.7448 and 0.7692, respectively. This tallied with the relatively high proportion of taxa threatened in these groups, 30-41% (Table 3). In contrast, hoverflies had the highest RLI value (lowest extinction risk) of 0.9747, correlating with a relatively low 3% of taxa threatened.

Figure 3. The finalised baseline ‘Red List Index for England’, with taxonomic groups ordered from higher risk (top of chart) to lower risk (foot of chart). The combined (aggregate) RLI value is shown in yellow.

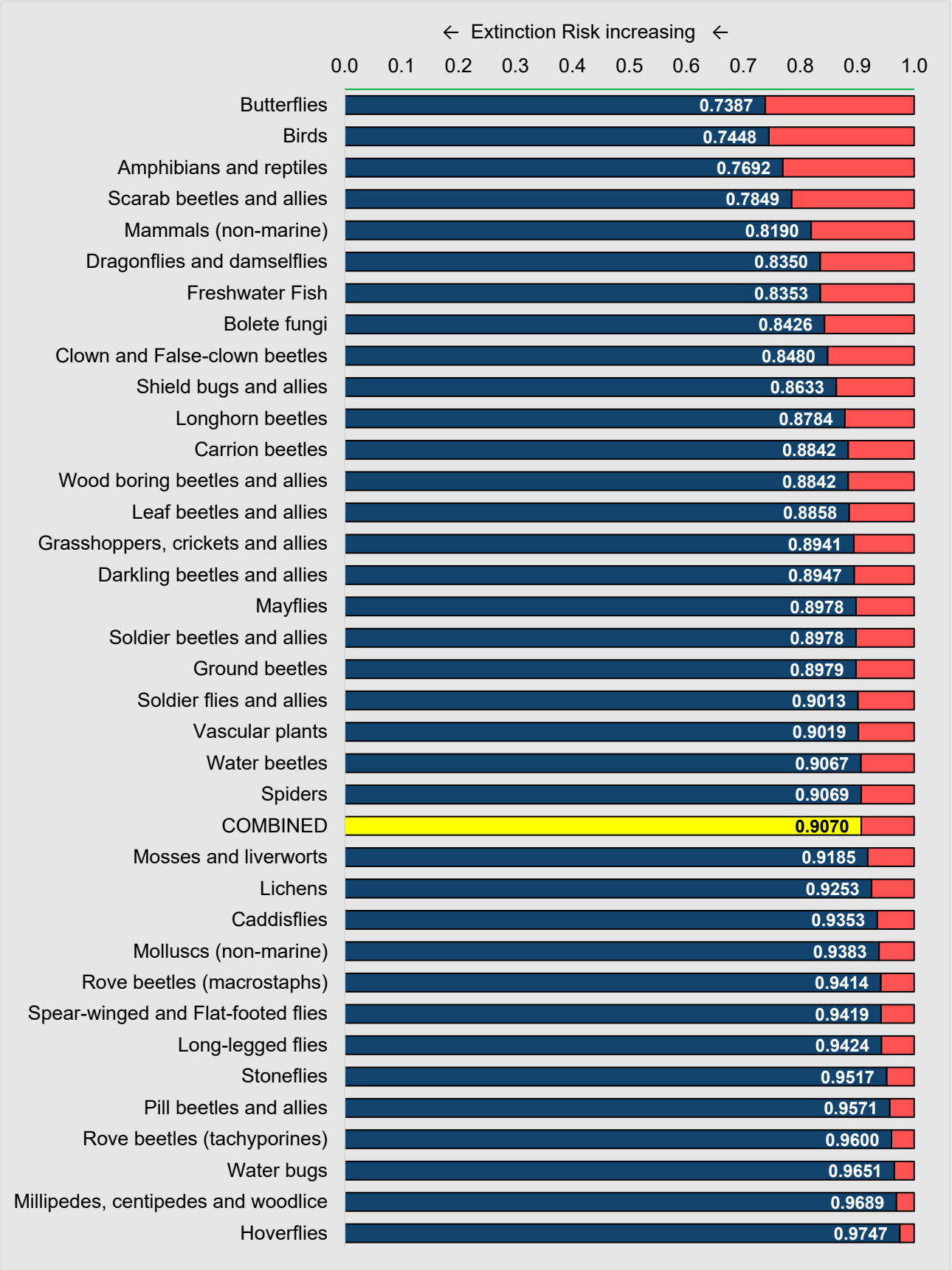


Table 3. Breakdown of the final RLI by taxonomic group, following IUCN conventions (IUCN, 2016). Extinct = sum of taxa in categories EX, EW, RE and CR(PE); Threatened = sum of CR, EN and VU; Non-threatened = sum of LC and NT; DD = Data Deficient; Assessed = total taxa Red List assessed (i.e. excluding taxa in categories NE and NA); RLI = number of taxa included in the baseline index; % Threat = percentage threatened of those extant and evaluated, i.e. the equation (CR+EN+VU)/(Assessed-Extinct-DD) which is considered the mid-point estimate (it assumes DD taxa have the same proportion threatened as data sufficient taxa; see section 5.4). Groups are listed in order of decreasing percentage threatened. A full breakdown by Red List category is given in the RLI spreadsheet.

RLI Group	Extinct	Threatened	Non-threatened	DD	Assessed	RLI	% Threat
Butterflies	4	24	34	0	62	62	41.4%
Birds	6	108	154	3	271	268	41.2%
Amphibians and reptiles	0	4	9	0	13	13	30.8%
Bolete fungi	0	13	34	17	64	47	27.7%
Mammals (non-marine)	1	10	31	4	46	42	24.4%
Freshwater Fish	1	8	25	0	34	34	24.2%
Wood boring beetles and allies	1	6	31	6	44	38	16.2%
Vascular plants	10	239	1,250	45	1,544	1,499	16.1%
Soldier flies and allies	0	23	127	1	151	150	15.3%
Spiders	6	89	513	11	619	608	14.8%
Scarab beetles and allies	13	11	69	1	94	93	13.8%
Dragonflies and damselflies	3	5	32	0	40	40	13.5%
Leaf beetles and allies	10	32	212	7	261	254	13.1%
Clown and False-clown beetles	4	6	40	3	53	50	13.0%
Grasshoppers, crickets and allies	1	4	29	0	34	34	12.1%
Darkling beetles and allies	8	15	110	6	139	133	12.0%
Mayflies	2	5	38	5	50	45	11.6%
Ground beetles	9	37	295	2	343	341	11.1%

RLI Group	Extinct	Threatened	Non-threatened	DD	Assessed	RLI	% Threat
Carrion beetles	1	2	16	0	19	19	11.1%
Water beetles	5	32	263	1	301	300	10.8%
Mosses and liverworts	14	90	789	28	921	893	10.2%
Molluscs (non-marine)	0	17	158	9	184	175	9.7%
Spear-winged and Flat-footed flies	0	3	28	6	37	31	9.7%
Shield bugs and allies	5	5	50	0	60	60	9.1%
Long-legged flies	1	22	227	39	289	250	8.8%
Caddisflies	2	15	156	19	192	173	8.8%
Longhorn beetles	3	4	44	1	52	51	8.3%
Lichens	20	115	1,329	138	1,602	1,464	8.0%
Pill beetles and allies	0	4	52	5	61	56	7.1%
Rove beetles (macrostaphs)	8	24	367	26	425	399	6.1%
Soldier beetles and allies	6	5	81	1	93	92	5.8%
Millipedes, centipedes, and woodlice	0	5	117	6	128	122	4.1%
Stoneflies	1	1	27	4	33	29	3.6%
Water bugs	1	3	82	2	88	86	3.5%
Hoverflies	0	7	246	5	258	253	2.8%
Rove beetles (tachyporines)	1	1	53	10	65	55	1.9%
Grand Total	**147**	**994**	**7,118**	**411**	**8,670**	**8,259**	**12.3%**

5.4 Comparing threat across taxonomic groups

Caution is needed when comparing RLI values, or percentage threatened, across taxonomic groups because data availability can influence which Red List criteria are used (Gärdenfors, 2010; Cardoso et al., 2011; Maes et al., 2015). Data-rich groups may have a tendency towards elevated extinction risk because each taxon qualifies under relatively more criteria than data-poor groups, and the highest qualifying threat category is taken. For example, a lack of estimates of population size and changes over time for many invertebrates, fungi, lichens, and bryophytes, limits the ability of assessors to make assessments against 'Criterion A' – *Population size reduction*, whereas this criterion is commonly used for bird and butterfly assessments (Woods & Coppins, 2012; Ainsworth et al., 2013; Stanbury et al., 2021; Fox et al., 2022; Callaghan, in press).

Further differences between taxonomic groups can also confound RLI comparisons:

- Groups that contain higher proportions of infraspecific taxa can potentially introduce RLI bias because each species is effectively represented in the index multiple times, combined with possible differences in threat patterns. Note that the taxon level rules (section 4.2.6) will have reduced this effect in the baseline index.
- Groups that support higher proportions of Data Deficient taxa may result in Red List statistics that underestimate true extinction risk (IUCN, 2016). A recent global study showed that over half of DD species are predicted to be threatened by extinction (Borgelt et al., 2022).
- A consistent cut-off date for extinction may not have been used in every GB Red List (section 4.2.3). This means that the 147 GB losses (including likely losses) listed in the RLI is probably an underestimate.

Although these potential differences need to be taken into account when comparing taxonomic group RLIs, they are less relevant to overall indicator function. Moreover, some of these differences may change over time through backcasting (section 6.2).

6. Evaluating and reporting change

6.1 Genuine and non-genuine change

An accurate RLI trend depends on determining genuine change in the status of taxa and is a requirement of red-listing (IUCN Standards and Petitions Committee, 2022). This means that if, when a species is reassessed, its Red List category changes, only those changes resulting from improvement or deterioration of its population are registered in the index.

A standardised set of reasons will be used to document Red List category changes in the 'RLI for England', so that genuine and non-genuine change can be clearly differentiated for the RLI calculation. For example, those used in the global IUCN Red List A dynamic Red List: reasons for changing status (under Summary Statistics). In accordance with RLI

guidance, a conservative approach will be adopted, and genuine status changes only identified if adequate supporting evidence and justification can be provided (Bubb et al., 2009).

6.2 Backcasting

The formula for calculating the RLI requires that: (a) exactly the same set of species is included in all time steps [or reporting intervals], and (b) the only category changes are those resulting from genuine improvement or deterioration in status. However, in practice, species lists often change slightly from one assessment to the next (Bubb et al., 2009). Red List Indices commonly use a method called 'backcasting' to address this, allowing retrospective amendment of data. As a result, increased amounts of genuine change can be tracked, thereby improving the veracity of the indicator (Butchart et al., 2007).

This is desirable when:

- New evidence/data relevant to a previous Red List assessment, or a new analysis technique applied retrospectively, show that a taxon's past threat status was incorrect.
- A taxon's native status changes due to improved knowledge.
- Taxonomic change invalidates the original taxon; this can happen when, for example, a species is taxonomically split into two species or subspecies, or conversely when two species or subspecies are combined as one species. Name changes can be simply mapped across the RLI but changes in taxonomic scope/identity directly affect threat status.
- Data Deficient species are subsequently assigned threat statuses (LC-EX).
- The IUCN Red List criteria or guidelines are revised, or interpretation of these by assessors has changed.

Future alteration of the baseline dataset (or subsequent data points) will likely affect the RLI value for that time point but, by assuming the taxa concerned have undergone no status changes since, the RLI trend can be preserved. This is achieved by applying the same change/s to all intervening periods, i.e. from the year first amended (e.g. 2022) to the year backcasting was applied (e.g. 2030). An exception is made when evidence shows the taxa concerned have undergone genuine status changes in the intervening period, in which case the index is adjusted accordingly (Butchart et al., 2007).

To test the likely frequency of taxonomic change, we looked at the 943 taxa listed under Section 41 (NERC Act 2006). From 2006 to 2022 (16 years), only 12 taxa had changed taxonomically (excluding name changes). However, DNA sequencing is expected to lead to accelerated taxonomic change in future, especially for some groups.

Backcasting allows the incorporation of Data Deficient taxa when they are reassessed and assigned an eligible status. We tested the impact of adding DD taxa to the index by

looking at the rate of DD status change over time using four Red Lists which had undergone reassessment: birds (Stanbury et al., 2017, 2021), mammals (Mathews et al., 2018; Mathews & Harrower, 2020), plants (Cheffings & Farrell, 2005, updated 2021) and bryophytes (Hodgetts, 2010; Callaghan, in press). Based on the number of DD taxa considered native to England in the GB Red Lists used (n=411), we forecast that 205 (50%) would have scorable statuses by 2042. These could be added to the baseline through backcasting. The pattern of DD movement to other statuses showed that over 20 years, 68% were assigned eligible statuses (48% to threatened or extinct categories (VU-EX), 20% to non-threatened categories) while 32% remained as DD or moved to Not Evaluated/Applicable classes. Simulating backcasting using this allocation pattern, the RLI baseline value was projected to be 0.8993, a decrease of 0.85% on the current baseline of 0.9070, suggesting that the addition of DD taxa would result in a slight increase in overall extinction risk.

A separate worksheet of Data Deficient taxa known to occur in England is given in accompanying spreadsheet. Where there was any question over a GB DD taxon naturally occurring in England, the taxon has been listed.

Backcasting might also be used as a means to increase representativeness of the index by allowing inclusion of further taxonomic groups, as new Red Lists are produced. However, if many species were added, the behaviour of the indicator could be altered. Thus, there is a trade-off between i) making the indicator as accurate, responsive and representative as possible, and ii) maintaining indicator continuity and a meaningful trend.

In conclusion, without backcasting, redundancy would accumulate in the RLI which could eventually limit its effectiveness as an indicator. In the ‘RLI for England’, backcasting will only be possible at specific times, when its use will be minimised to preserve indicator continuity. Reasons for backcasting and details of changes will be fully documented.

6.3 Data management

Index data will be managed via a simple spreadsheet system (structured on the baseline dataset) which will capture Red List category changes and the reasons for these. Data will be retained for the whole series, charting change from the baseline. The whole dataset will be made openly available.

The spreadsheet system will include:

- The aggregate RLI trend (graphical representation)
- Calculation of RLIs (aggregate and for individual taxonomic groups)
- A summary table of species status counts by taxonomic group
- The full list of taxa included in the index with their current & past Red List categories
- The list of Data Deficient taxa excluded from the index
- Red List references – current and past
- A record of the reason/s for category change (genuine vs. non-genuine)
- Details of any backcasting undertaken

6.4 Indicator reporting

6.4.1 Frequency of reporting and reassessment

We anticipate the indicator operating over at least a 20 year period (2022-42), with a 10 year update cycle of every GB Red List in the index. Since the baseline index comprises 36 Red Lists, an average of approximately four reassessments per year will be required.

Reporting at 5 year intervals will be possible although only a partial set of reassessments will be available in 2027 and 2037, making the aggregate index less precise at these times. This is because the RLIs of individual groups can vary considerably in their values and trends (e.g. Gärdenfors et al., 2010; Juslén, 2013). In contrast, reporting in 2032 and 2042 will use a full set of reassessments, hence the aggregate index values then will be more precise but some uncertainty will still exist (see section 6.4.2).

Rationale for reporting interval

A primary constraint on creating and updating RLIs is the frequency of re-assessments; regular assessments are recommended (Bubb et al., 2009). UKCEH investigated the periodicity of reporting and reassessment with regards to D5, which showed that it would not be cost-effective to conduct a reassessment of each group annually because the vast majority of species would not have changed their status (Logie & Isaac, 2021). However, if the time between assessments were too long, then the data would be too outdated to be used as a meaningful indicator. The periodicity of that cycle should be informed by the rate at which species are expected to transition between groups [i.e. categories] (Logie & Isaac, 2021). In Finland, 4.7% of species changed their Red List category due to genuine status changes between 2000 and 2010 (Juslén et al., 2013). Therefore assessing species more frequently than every 10 years would be unlikely to produce much useful information since the vast majority of species would not have changed status (Logie & Isaac, 2021).

Importantly, the RLI measures net change in category movement, so in the case of Swedish Red List between 2005 and 2010, 51 species improved in status, while 50 deteriorated, resulting in a very stable [almost horizontal] RLI trend (Gärdenfors et al., 2010). These 101 genuine changes represented just 0.6% of the overall RLI dataset analysed (n=16,800 species). Few organism groups have sufficient monitoring information to register changes over a period as short as 5 years; significant changes are required to be sufficient, with any degree of certainty, to make changes to the red list status of a species (Gärdenfors et al., 2010). Juslén et al. (2013) also identified the difficulty over 5 year intervals, observing that the frequency of repeated red-list assessments is likely to greatly affect how well genuine changes in species' conservation status are identified.

Aspects of IUCN red-listing also impose constraints. The Red List categories are relatively coarse measures of extinction risk, hence species' populations can decline or increase but insufficiently to warrant a change in Red List category. Furthermore, the IUCN '5-year rule' delays category downlisting until at least five years have passed when the taxon no longer meets the higher threat criteria (IUCN Standards and Petitions Committee, 2022). In

addition, time-lags can affect reassessment, such as the delay between data collection and data availability for assessors, and the time it can take for biodiversity policies to be implemented and take effect.

Life history can also be important. In species with short generation lengths, it can be hard to separate natural variation in population size from an increasing or decreasing trend – e.g. insects (Juslén et al., 2013). Populations may show a clear decline or increase during the assessment period but long-term trends may be different. This can make assessment of genuine change over shorter periods difficult, potentially leading to bias [or uncertainty] in the RLI (Juslén et al., 2013). Conversely, the long generation lengths of some taxa may make it difficult to detect changes at even 10-year intervals. Saiz et al. (2015) found that vascular plants are potentially more resilient to changes in threat level (e.g. due to seed banks or long life spans), suggesting that an RLI based on reassessment every 4 to 5 years might be unrealistic.

Regarding the 'RLI for England', it was concluded that the minimum reporting interval would be every 5 years, and the optimum would be every 10 years.

6.4.2 Expected change in the RLI

Over a 10 year period, national RLIs typically change very little. Saiz et al. (2015) compared the vascular plant RLI-value trajectories from 2000 to 2010 for Finland, Spain, and Sweden, the values in all three countries declined by 1.2%, 0.4%, and 0.1%, respectively (in all cases the number of genuine changes was reported to be very small). The results for the Spanish flora were consistent with previous reports of a slow pace of change in RLI values over a decade (Saiz et al., 2015). Baille et al. (2008) reported that for birds [globally] between 1988 and 2004, the index value went from 0.924 to 0.919, respectively (resulting from 250 genuine category changes). This equates to a decrease in index value of 0.54% over a 16 year period, again a very small change.

Change in the 'RLI for England' is expected to be subtle for all the above reasons, but also because the RLI is numerically dominated by species of Least Concern. Thus, small shifts in the index can signify substantial changes in the fortunes of threatened species. For example, a 50% reduction in the number of threatened species in the 'RLI for England' would result in a rise in the index value of 2.8% (assuming half move to Near Threatened and half move to Least Concern), and yet this equates to almost 500 species moving to non-threatened categories.

6.4.3 Taxonomic group RLIs

Since the aggregate RLI is a high-level metric, it can mask the trends of individual taxonomic groups. In Finland, although the overall [aggregate] RLI value decreased only slightly (by 0.3%) between 2000 and 2010, species groups varied considerably in both RLI values and trends (RLIs of 5 groups decreased, while 6 increased). Hence the overall RLI may be misleading if variation in RLI among species groups is not considered and if RLI

values are not presented separately for each group (Juslén et al., 2013). Similarly, in the Swedish Red List it was reported that the difference between the trends in the RLI from 2000 to 2010 for the different organism groups was apparent despite everything indicating that the trend in the overall RLI was very stable (Gärdenfors et al., 2010).

As well as reporting the aggregate 'RLI for England', it will greatly aid understanding if index values and trends of each taxonomic group (i.e. each Red List) can be presented alongside (e.g. Figure 3).

6.4.4 Uncertainty

Red List Indices have a number of inherent uncertainties, some of which can be addressed through statistical techniques and/or modelling (Butchart et al. 2007, 2010; Rowland et al., 2021). In summary these are:

(i) The unknown extinction risk of Data Deficient taxa

(ii) RLI estimation from use of asynchronous Red Lists

(iii) RLI estimation by linear interpolation and linear extrapolation

Regarding the 'RLI for England', data deficiency is considered below, whilst the effects of (ii) and (iii) depend on the reassessment and reporting cycle and methods. Moreover, two assumptions have been made: (a) no selection bias exists due to the portion of England's biota that has been Red List assessed (see section 5.1); and (b) uncertainties in extinction risk data have been fully considered and addressed during red-listing (Akçakaya et al., 2000; IUCN Standards and Petitions Committee, 2022).

Communicating uncertainty in the RLI trend is seen as important, with clarity over any limitations arising from statistical techniques.

Data Deficiency

Data Deficient taxa are excluded from the index until reassessed with an eligible status when they can be added through backcasting (section 6.2). Although it's anticipated that the number of DD taxa in the index will gradually decline over time (as Red Lists are updated and new survey data are taken into account), the unknown extinction risk of DD taxa, introduces a level of uncertainty into RLI values.

Furthermore, if DD taxa differ in the rate at which their extinction risk is changing, the aggregate Red List Index may give a biased picture. The degree of uncertainty this introduces can be estimated through inferential statistics using a technique called 'bootstrap resampling' to produce confidence intervals (Butchart et al., 2010; Rowland et al., 2021). This could be applied to the 'RLI for England' to communicate uncertainty. In addition, presenting individual taxonomic group RLIs will aid interpretation by providing important context and granularity.

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Appendix 1. Preliminary baseline index

Background to the preliminary index is given in section 4.1. The following is an expanded version of the published evidence report (Defra, 2022) and includes further detail on methods, additional analysis, potential improvements and minor corrections. Importantly, the preliminary RLI dataset formed the foundation of the revised and final RLI. The approach taken here over geographic scale has since remained the same, so is also true of the final index.

Methods

Geographic scale

In the absence of published England-scale Red Lists for a broad range of taxonomic groups, GB Red Lists were used for the indicator. Based on those taxa Red List assessed, about 80% occur in England [Appendix 4 gives a range of between 82-100% of taxa in GB assessed groups naturally occur in England]. Taxa known only from Scotland and/or Wales were rejected on grounds that the indicator was solely for England.

This approach assumed that threat levels at England and GB scales were the same or similar. To test this, we compared England-scale and GB-scale Red Lists for plants (Stroh et al., 2014), terrestrial mammals (Mathews & Harrower, 2020), and herptiles (Foster et al., 2021) which showed that Red List categories agreed in 80%, 88% and 92% of taxa respectively [these are revised figures, limiting the comparison to just RLI-eligible statuses]. Collectively these groups represented 25% of the preliminary RLI (2,006 of total 7,922). Notably, some species had highly contrasting threat categories – e.g. pine marten is Least Concern at GB scale but Critically Endangered at England scale (Mathews & Harrower, 2020). [Since publication of the preliminary index, a Red List for freshwater fishes (Noble et al., in press) has been approved, giving a RL category parity of 88% for GB and England.]

Moreover, differences appeared stronger in some taxonomic groups than in others. For example, the diversity and population sizes of lichens contrasted strongly between Scotland and England (Woods, & Coppins, 2012). Consequently, the GB Red List category for a species can be unrepresentative of its English status.

For the same reason the indicator could be insensitive to changes in England. At worst, the complete loss of a species in England that retained populations in Scotland or Wales would not be reflected in the indicator – e.g. the loss of Golden Eagle from England when it is Near Threatened in the current GB Red List (Stanbury et al., 2021). Conversely, the successful recovery of a species in England could be tempered by ongoing declines elsewhere, potentially resulting in an unchanging threat category.

This was seen as a key shortcoming of the indicator, emphasising the importance of comprehensive RLI reporting, when supplementary data outside of the indicator could be

provided alongside disaggregation of the index to illuminate trends that might otherwise be hidden – e.g. a trend associated with a particular habitat type. An alternative would have been to use only England Red Lists but this would have severely impacted representativeness since just three taxon groups (plants, mammals and herptiles) have published assessments to date [now four with the aforementioned freshwater fishes list].

In conclusion, despite the shortcomings, the above analysis suggested that the majority of statuses at GB and England scales do align and therefore the aggregate RLI is a good approximation of extinction risk in England.

Further analysis of scale

Since publication of the preliminary RLI, a further possibility was investigated. This used the available England assessments (as above, plus Noble et al., in press), supplemented by GB assessments for groups that lacked England assessments. The rationale was to benefit from the accuracy of England assessments without losing the wider taxonomic coverage provided by GB Red Lists. However, this could confound comparison between taxonomic group RLIs (assessed at different geographic scales) and potentially create bias in the aggregate RLI. To test the effect, RLI values for the England and GB assessments were calculated and compared. Collectively (n=1,893) the England RLI was 0.0414 (4.6%) lower (higher extinction risk) than the GB RLI (England RLI = 0.8513; GB RLI = 0.8927). This pattern was the same for each of the four groups tested, suggesting that concerns over this approach were well founded.

Importantly, the lower index values for England could be an artefact of the IUCN Red List criteria and/or application of the regional guidelines, rather than a truly greater extinction risk in England (Gärdenfors et al. 2001; Miller et al., 2007). The Red List criteria use fixed quantitative thresholds which were developed for global rather than national application. The regional guidelines methodology (IUCN 2012a) compensates for potential overestimation of extinction risk at national scale, by incorporating potential 'rescue effects' from neighbouring populations, thus assessors can downgrade threat statuses. Miller et al. (2007) concluded that the effect [of small geographic scale] was not due to a fundamental flaw in the criteria but to the fact that a small country would have small populations, and small populations inherently face a higher risk of extinction. Nevertheless, application within very restricted geographical areas is strongly discouraged, on grounds that assessment of extinction risk becomes increasingly unreliable (IUCN 2012a). However, no specific lower limit is given.

Taxonomic scope

The preliminary baseline index comprised 7,922 taxa, using data from 31 GB Red List assessments (detailed in section 7.1). These Red Lists were not selected but represented all those available with sufficient data to be included. The use of all assessed taxa was considered to be more representative, than taking a sample to reduce the potential pull of more speciose groups on the indicator.

The following groups were covered: Spiders, birds, mosses and liverworts, millipedes, centipedes and woodlice, carrion beetles, clown and false-clown beetles, darkling beetles & allies, ground beetles (carabids), leaf beetles, longhorn beetles, rove beetles, scarab beetles & allies, soldier beetles & allies, wood-boring beetles & allies, soldierflies & allies, true flies (dolichopids), mayflies, boletes, earthstars, puffballs/stalkballs, chanterelles & tooth fungi, lichens, shield bugs & allies, water bugs, amphibians & reptiles, butterflies, macromoths, mammals (terrestrial), dragonflies & damselflies, grasshoppers and crickets, vascular plants, stoneflies, and caddisflies. Full references of the Red Lists used are given in 7.1 and a summary by high level group in Table 4.

Table 4. Number of taxa in the preliminary baseline RLI (excludes taxa in Data Deficient, Not Evaluated, Not Applicable, and all Extinct categories). Threatened comprises the categories: Critically Endangered (including Possibly Extinct), Endangered and Vulnerable, whilst Non-Threatened comprises Near Threatened and Least Concern.

Taxonomic Group	Total in RLI	Threatened	Non-Threatened
Birds	217	84	133
Bryophytes	844	88	756
Fungi	109	46	63
Herptiles	13	4	9
Lepidoptera	775	71	704
Other invertebrates	2,678	327	2,351
Lichens	1,463	114	1,349
Mammals	39	9	30
Vascular plants	1,784	288	1,496
Grand total	**7,922**	**1,031**	**6,891**

Treatment of birds with two statuses

Thirty-four birds had two index-eligible statuses due to separate assessments of breeding and non-breeding populations (in some cases relating to different sub-species). In such cases, precedence was given to breeding status. Where breeding status was ‘Not Applicable’, or the species did not breed in GB, non-breeding status was used.

IUCN methodology

Methods largely followed Bubb et al. (2009), with several exceptions (Table 5).

Table 5. Aspects of method that differed from the IUCN RLI Guidance (Bubb et al., 2009).

Aspect of method	IUCN RLI Guidance	Approach taken & justification
Requirement for repeat assessments	If all species within a particular region or country have been assessed at least twice using this approach [the IUCN Red List Categories and Criteria at regional or national scales], an RLI can be calculated using these data.	Taxa RL assessed only once (lacking repeat updates using the 2001 IUCN categories & criteria) were included. There was no requirement for the baseline index to provide a trend (a value was sufficient). If repeat assessments were available for all groups, it would have been possible to extrapolate to a selected baseline year. However, only six of the 36 Red Lists were reassessments; limiting the index to just these would have greatly reduced the number of taxa and diversity of the index.
Eligibility of taxonomic rank, qualifiers and undescribed taxa	Taxonomic level is not specifically addressed by the RLI guidance. Under red-listing guidelines any taxonomic unit at or below the species level can be assessed, although only certain infraspecifics (subspecies, varieties of plant, and some subpopulations) may be included on the [global] IUCN Red List (IUCN Standards and Petitions Committee, 2022). However, under the regional IUCN Red List guidelines this is left to the regional Red List authority where 'Not Applicable' can be	All individually assessed infraspecific, aggregate, sensu stricto/lato, and undescribed taxa were included. Infraspecifics represented 3% (n=242) of the overall index. Aggregates and sensu lato combined, comprised a further 50 taxa. Only five undescribed taxa were included, e.g. *Orchestina* sp. Inclusion of these taxa maximised representativeness, especially where taxa lacked species-level assessment (e.g.

Aspect of method	IUCN RLI Guidance	Approach taken & justification
	applied to a taxon at a lower taxonomic level (e.g. below the level of species or subspecies) (IUCN, 2012a). [We are not aware of NA being used in this way in GB Red Lists]. The listing of undescribed species on the IUCN Red List is discouraged although it is possible provided a number of conditions have been met (IUCN Standards and Petitions Committee, 2022). An assessment of the full species is required before assessments of taxa below the species level can be included on the IUCN Red List (IUCN Standards and Petitions Committee, 2022).	some lichens). For species with multiple infraspecifics, their statuses were effectively averaged by the index calculation.
Eligibility of partially assessed groups	The RLI should not be calculated from national red lists in which only a subset of species in a particular taxonomic group within the country have been assessed. This is because such a subset is likely to be biased, e.g. in its status, trends or distribution.	Although only a proportion of England's fungi and invertebrates have been RL assessed, those included in the RLI are for groups that have been assessed in their entirety – e.g. bolete fungi. Since the objective was to produce an aggregate RLI for England, the inclusion of such groups was considered highly desirable to maximise representativeness. By considering taxon-specific RLI's during

Aspect of method	IUCN RLI Guidance	Approach taken & justification
		reporting, it will be possible to explain the origins of any pull exerted on the aggregate RLI.
Treatment of Critically Endangered (Possibly Extinct)	Treatment of categories Critically Endangered (Possibly Extinct) and Critically Endangered (Possibly Extinct in the Wild) was not specifically covered by the RLI guidance, hence their weighting in the RLI was unclear.	Following consultation with the IUCN Regional Office, Critically Endangered (Possibly Extinct) taxa were included with a category weighting of 5, in accordance with a recent UN SDG Indicator (United Nations Statistics Division, 2021).

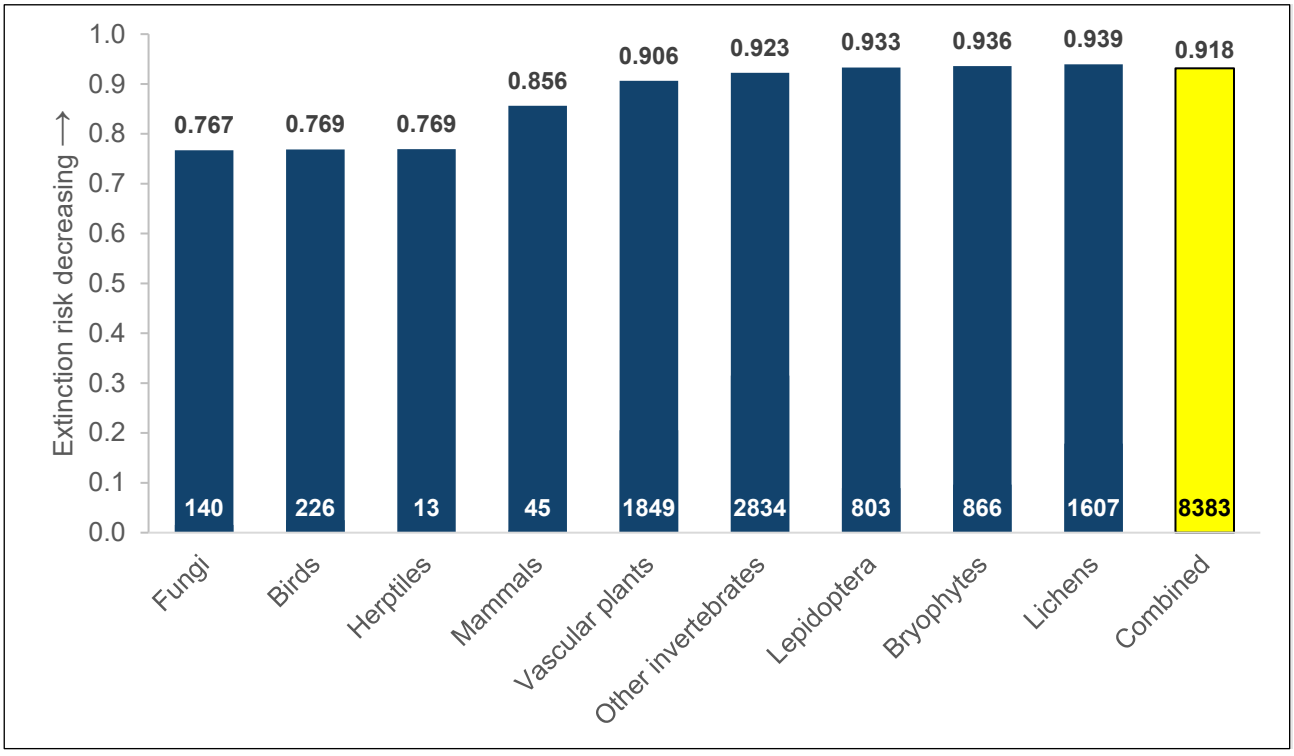
Results

The aggregate Red List Index value for these nine major taxonomic groups was 0.918 (Figure 4). This may appear relatively high (a value of '1' = all species Least Concern) but: i) the preliminary RLI excluded all past extinctions, and ii) over 80% of the taxa were classed Least Concern.

Fungi appeared to be the most threatened taxonomic group in the preliminary indicator, with an index value of 0.767, although only a very low proportion of fungal species in Britain have been assessed so far, hence this value is likely to be unrepresentative.

After fungi, the most threatened groups were birds and herptiles (0.769 in both cases); the least threatened groups were lichens and bryophytes (0.939 and 0.936, respectively). The relatively high index values of Lepidoptera (0.933) and 'Other invertebrates' (0.923) was unexpected but could result from these groups containing a large number of species across a diverse range of habitat types and environments, including terrestrial, freshwater and coastal brackish. Whilst some invertebrate groups appear stable or increasing, others are well-evidenced as in steep decline (Fox et al. 2014, Woodcock et al., 2016; Hallmann et al., 2017; Warren et al., 2021).

Figure 4. Preliminary England-level GB Red List Index for each of the major taxonomic groups, with combined Red List Index in yellow. The Y-axis ranges from 0 (all species extinct) to 1 (all species Least Concern). RLI values are shown at the top of bars, while the base of bars gives the number of taxa assessed within each group.



Scope for improvement

During development it became clear that the preliminary indicator could be improved upon in a number of areas.

1. **Red List coverage** – (i) Some red lists had not been added because there was insufficient time to determine accurate England subsets – e.g. non-marine molluscs, and hoverflies; (ii) recently published new/updated red lists were omitted from the indicator – e.g. freshwater fishes.
2. **Red List quality** – Apart from provisional/draft red lists, the majority of available GB lists were incorporated. Further criteria could be applied to ensure quality standards.
3. **Extinctions** – Initial exclusion of species lost from GB or England meant that: (i) past human-induced extinctions of native species were unaccounted for in the baseline RLI value, (ii) future reintroductions would be undetectable by the index.
4. **Native status** – The preliminary index used a criterion of presence/absence in England, rather than native status. Since D5 concerns *native* species, this was considered a weakness. However, under IUCN guidelines, non-native taxa should not be assessed but classified as Not Applicable (NA) or Not Evaluated (NE) (IUCN, 2012a). Hence all GB non-natives should by default fall outside of the index. Interpretation of this rule varied across taxonomic groups however – e.g. naturalised archaeophytes (ancient plant introductions that have established in the wild) had been assessed (Stroh et al., 2014).
5. **Proportion of GB population in England** – Although parity between GB and England level red list statuses was tested, the indicator might be strengthened by removing taxa with a low proportion of their GB populations in England, on the assumption that recovery would be unattainable through action in England alone. In the extinction risk scenario analysis, a range threshold was used whereby only species with 20% or more of their GB distribution (hectads) in England were included (Defra, 2022).
6. **Taxon level** – No standardisation of: (i) infraspecific taxa, (ii) undescribed taxa, (iii) aggregates (agg., sensu lato, etc), and (iv) eliminating duplication or overlap between (i) to (iii) and species-level assessments.
7. **Birds with two statuses** – The approach taken was different to the first European Red List of Birds (BirdLife International, 2015) and the GB Red List (Stanbury et al., 2017) which assigned the highest threat status from either population assessment. Under our approach, giving breeding status priority resulted in 30 (of 34) species having a higher or equal threat category to non-breeding status. However, four had non-breeding populations that were more threatened than breeding populations: Common Snipe (LC br., NT non-br.), Dunlin (VU br., EN non-br.), Mallard (LC br., NT non-br.) and Ringed Plover (NT br., VU non-br.). The method would be reviewed in light of this.

Appendix 2. Characteristics of a Red List Index

Red List Indices share several generic characteristics, both strengths and weaknesses (Butchart et al., 2004; United Nations Statistics Division, 2021).

Whilst RLIs are most effective at showing long-term trends, they are less suited to detecting change over shorter timescales and can sometimes appear insensitive to the changing status of species. This is mainly because:

(i) The broad nature of the Red List categories, means that a species' population may need to change markedly before a new Red List category can be assigned; this is especially the case with Least Concern which is broader than the other categories. In addition, the IUCN '5-year rule' delays category downlisting until at least five years have passed when the taxon no longer meets the higher threat criteria (IUCN Standards and Petitions Committee, 2022).

(ii) The index measures net change in extinction risk, therefore improvements in status can be counterbalanced by deteriorations; there is a risk that positive results from targeted recovery effort could be masked because of this.

(iii) Least Concern taxa comprise a large proportion of the index, which is reflected in the large denominator of the RLI equation. This means that small shifts in the RLI value can involve many taxa, representing substantial real-world change.

(iv) Time-lags in data flow and Red List reassessment. Species observations, many of which are undertaken by volunteers, can take time to reach national databases. Red Lists are typically updated every 10 years – e.g. the global IUCN Red List of Threatened Species aims to reassess all taxa every 10 years (IUCN, 2022).

Nonetheless, RLIs give some key advantages over other species indicators:

(i) The IUCN red-listing system underpinning RLIs has been designed to be as widely applicable as possible, with five criteria that enable the assessment of taxa from the complete taxonomic spectrum, with the exception of micro-organisms (IUCN 2012b). This enables the index to track large numbers of highly diverse species, including many that are too poorly monitored to allow the development of more sensitive indicators (e.g. abundance trends).

(ii) The five criteria also capture a broad range of extinction risk symptoms, including abundance decline, range contraction, small population size, fragmentation, and rarity. Species can qualify under one or more of these. This multifaceted sensitivity is carried over into the index.

(iii) Red List category changes are largely driven by improvements in knowledge and changing taxonomy. By excluding such changes, the RLI is more indicative of the status of species populations than the simple proportion of threatened species.

Appendix 3. Use of non-native definitions

English Nature definition (Hill et al., 2005)	Application in baseline Red List Index
Formerly native (extinct as a native but present as introduced populations, commonly called re-introductions; these may be deliberate or accidental and may be genetically distinct from the original population).	Retained since originally native; current status may still include some of the wild population. A potential exception would be the introduction of a non-native subspecies (or other infraspecific) as a proxy for the original species.
Native species with large addition from domestic or non-native stock.	Retained since originally native and includes some of wild population. Note that under IUCN rules, populations introduced outside of native range (e.g. some fish stocks) should be excluded from assessment.
Spontaneous hybrid between native and introduced taxa.	Not applicable (none known in the index).
Introduction (introduction, not present as native in post-glacial period; this includes taxa that have spread naturally to Britain from introduced populations in Europe, e.g. Harlequin Ladybird).	Excluded. Ancient introductions, e.g. plant archaeophytes, and other long-established naturalised species have been excluded.
Native or alien (probably or possibly introduced).	Retained on precautionary principle unless evidence post-dating RL assessment indicates otherwise.
New species derived from a spontaneous hybrid between native and introduced taxa (e.g. as an allopolyploid).	Retained as potentially could apply to new endemic taxa. Only two species known in RLI: York Groundsel and Common Cord-grass; possibly also Interrupted Brome.
Newly arrived (taxa with an unknown history that appear to have arrived since 1950 and from their subsequent behaviour seem likely to be introductions).	Retained on precautionary principle unless categorised as Not Applicable, or evidence post-assessment indicates introduced. Generally, newly arrived taxa are not Red List assessed until their populations have successfully bred in the region for at least 10 consecutive years (IUCN 2012a).

Appendix 4. Breakdown of GB Red Lists used in the final Red List Index

The table below shows the number of taxa in Great Britain Red Lists by taxonomic group and Red List category. 'GB Eligible' is the 'GB Total' minus the number of Data Deficient, Not Evaluated and Not Applicable taxa (see definition of eligible status), 'RLI Total' is the number of taxa included in the baseline RLI for England, and 'RLI %' is the percentage of GB eligible taxa in the RLI, to the nearest whole number (RLI Total/GB Eligible). Full references of Red Lists are given in the accompanying spreadsheet. **Note**: (i) only a proportion of GB 'eligible' taxa are included in the RLI because some are not known from, or not native to, England; (ii) the RLI total given (8,218) is less than the actual total (8,259) because the index includes separate RL assessments for breeding and non-breeding populations of birds; (iii) vascular plant taxa counts are those for England, hence GB totals are underestimates and the RLI percentage an overestimate.

Group (Red List)	EX	EW	RE	CR (PE)	CR	EN	VU	NT	LC	DD	NA/ NE	GB Total	GB Eligible	RLI Total	RLI %
Amphibians and reptiles (Foster et al., 2021)	-	-	-	-	1	3	-	2	7	-	-	13	13	13	100%
Birds (Stanbury et al., 2021)	1	-	7	-	21	41	46	26	99	2	10	253	241	227	94%
Bolete fungi (Ainsworth et al., 2013)	-	-	-	-	-	5	8	6	28	18	2	67	47	47	100%
Butterflies (Fox, et al., 2022)	-	-	4	-	-	8	16	5	29	-	1	63	62	62	100%
Caddisflies (Wallace, 2016)	-	-	-	2	4	3	8	6	153	20	1	197	176	173	98%
Carrion beetles (Lane, 2020)	-	-	1	1	-	-	2	2	14	-	1	21	20	19	95%

Clown and False-clown beetles (Lane, 2017)	-	-	4	-	-	-	6	6	34	3	1	54	50	50	100%
Darkling beetles and allies (Alexander et al., 2014)	-	-	8	1	-	-	19	-	112	6	34	180	140	133	95%
Dragonflies and damselflies (Daguet et al., 2008)	-	-	3	-	-	4	2	6	27	1	13	56	42	40	95%
Freshwater fish (Noble et al., in press)	-	-	1	-	2	3	3	-	25	1	8	43	34	34	100%
Grasshoppers, crickets and allies (Sutton, 2015)	-	-	1	-	1	1	2	2	27	-	4	38	34	34	100%
Ground beetles (Telfer, 2016)	-	-	3	7	3	19	16	33	266	3	17	367	347	341	98%
Hoverflies (Ball & Morris, 2014)	-	-	-	-	4	3	6	10	249	9	2	283	272	253	93%
Leaf beetles and allies (Hubble, 2014)	-	-	3	7	6	17	12	5	208	7	17	282	258	254	98%
Lichens (Woods & Coppins, 2012)	29	-	-	-	45	34	112	227	1,347	243	336	2,373	1,794	1,464	82%
Longhorn beetles (Alexander, 2019)	-	-	3	-	2	1	1	3	42	2	21	75	52	51	98%
Long-legged flies (Drake, 2018)	-	-	2	-	6	5	11	6	221	49	6	306	251	250	100%
Mammals (non-marine) (Mathews & Harrower, 2020)	-	-	1	-	2	4	5	5	26	4	12	59	43	42	98%

Mayflies (Macadam, 2016)	-	-	2	-	-	3	2	-	38	6	-	51	45	45	100%
Millipedes, centipedes and woodlice (Lee, 2015)	-	-	-	-	-	2	4	7	110	10	49	182	123	122	99%
Molluscs (non-marine) (Seddon et al., 2014)	-	-	-	-	4	2	13	10	152	11	23	215	181	175	97%
Mosses and liverworts (Callaghan, in press)	-	-	4	21	40	53	77	39	795	45	23	1,097	1,029	893	87%
Pill beetles and allies (Lane, 2021)	-	-	-	-	1	-	3	2	50	5	4	65	56	56	100%
Rove beetles (macrostaphs) (Boyce, 2022)	-	-	8	1	5	4	19	17	351	30	10	445	405	399	99%
Rove beetles (tachyporines) (Lane, 2019)	-	-	1	-	1	-	1	2	51	10	2	68	56	55	98%
Scarab beetles and allies (Lane & Mann, 2016)	-	-	9	4	2	2	7	7	62	1	6	100	93	93	100%
Shield bugs and allies (Bantock, 2016)	-	-	3	2	2	2	1	-	50	-	9	69	60	60	100%
Soldier beetles and allies (Alexander, 2014)	-	-	5	1	-	3	4	5	78	1	17	114	96	92	96%
Soldier flies and allies (Drake, 2017)	-	-	4	-	4	11	10	10	119	1	2	161	158	150	95%

Spear-winged and Flat-footed flies (Chandler, 2017)	-	-	-	-	1	1	1	-	28	6	5	42	31	31	100%
Spiders (Harvey et al., 2017)	-	-	3	5	13	30	54	29	492	13	19	658	626	608	97%
Stoneflies (Macadam, 2015)	-	-	1	1	-	-	1	-	27	4	-	34	30	29	97%
Vascular plants (in Stroh et al., 2014)	16	4	-	-	40	92	156	87	1,409	45	86	1,935	1,804	1,499	83%
Water beetles (Foster, 2010)	-	-	5	-	5	8	22	36	233	1	-	310	309	300	97%
Water bugs (Cook, 2015)	-	-	-	1	-	-	3	4	79	2	4	93	87	86	99%
Wood boring beetles and allies (Alexander, 2017)	-	-	1	-	1	1	4	2	29	6	66	110	38	38	100%
TOTAL	**46**	**4**	**87**	**54**	**216**	**365**	**657**	**607**	**7,067**	**565**	**811**	**10,479**	**9,103**	**8,218**	**90%**