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5  
6 **An assessment of the state of nature in the United Kingdom: a review of findings, methods and impact**

7  
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60 **Abstract**

61 Clear, accessible, objective metrics of species status are critical to communicate the state of biodiversity and to  
62 measure progress towards biodiversity targets. However, the population data underpinning current species status  
63 metrics is often highly skewed towards particular taxonomic groups such as birds, butterflies and mammals,  
64 primarily due to the restricted availability of high quality population data. A synoptic overview of the state of  
65 biodiversity requires sampling from a broader range of taxonomic groups. Incorporating data from a wide range of  
66 monitoring and analysis methods and considering more than one measure of species status are possible ways to  
67 achieve this.

68

69 Here, we utilise measures of species' population change and extinction risk to develop three species status metrics,  
70 a Categorical Change metric, a Species Index and a Red List metric, and populate them with a wide range of data  
71 sources from the UK, covering thousands of species from across taxonomy. The species status metrics reiterate the  
72 commonly reported decline in freshwater and terrestrial species' status in the UK in recent decades and give little  
73 evidence that this rate of decline has slowed.

74

75 The utility of species status metrics is further improved if we can extrapolate beyond the species sampled to infer  
76 the status of the community. For the freshwater and terrestrial species status metrics presented here we can do  
77 this with some confidence. Nevertheless, despite the range and number of species contributing to the species  
78 metrics, significant taxonomic bias remained and we report weighting options that could help control for this.

79

80 The three metrics developed were used in the *State of Nature 2016* report and indications are they reached a large  
81 number of audience members. We suggest options to improve the design and communication of these and similar  
82 metrics in the future.

83

84 **Keywords**

85 Metric; Indicator; Index; Biodiversity; Species; Great Britain

## 86 1. Introduction

87 Across society people receive many varied nature conservation messages, ranging from success stories through to  
88 warnings about the imminent extinction of species. The frequency, variety and often contradictory nature of these  
89 messages may obscure an understanding of the overall state of nature and, importantly, the role of human actions  
90 in determining this state. Clear, objective, overarching metrics of the state of the natural environment can provide  
91 this understanding, facilitating informed decision making and supporting educational campaigns. This information  
92 also allows us to measure our progress towards conservation targets at global (e.g. Convention on Biological  
93 Diversity, 2010), European (e.g. Marine Strategy Framework Directive, European Union, 2008) and national scales  
94 (JNCC, 2017a).

95  
96 The UK has some of the longest-running and best-supported biodiversity recording and monitoring in the world,  
97 with the majority of data being collected by skilled volunteers. Biological monitoring and recording programmes  
98 are well developed for many taxonomic groups (Barlow et al., 2015; Dennis et al., 2013) and these are used to  
99 report on species status (Fox et al., 2010), population trends (Holt et al., 2015), and conservation projects (Ellis et  
100 al., 2012), either for individual species or taxonomic groups.

101  
102 Where volunteer-based monitoring of flora and fauna is well-developed, data are strongly skewed towards those  
103 groups that are popular to record, relatively easy to identify or accessible to observe, or those especially  
104 endangered and requiring close surveillance (UK NEA, 2011). As a result, we are able to assess population trends  
105 for only a small percentage of species overall. Recently, analytical techniques for accounting for some of the biases  
106 present in opportunistically collected biological records have developed into robust tools for detecting trends in  
107 species' status (Isaac et al., 2014; Van Strien et al., 2013). This has enabled data from a much broader taxonomic  
108 set to contribute to multispecies metrics (Outhwaite et al., 2018; Van Strien et al., 2016).

109  
110 A group of the UK's leading wildlife organisations have synthesised data on species status across taxonomy and  
111 habitat types, with the ambition of moving closer to a goal of clear, consistent and objective assessment of  
112 biodiversity. The findings are published in two '*State of Nature*' reports (Burns et al., 2013; Hayhow et al., 2016).  
113 The primary aim of these reports was to develop a robust synthesis of the state of species in the UK, Overseas  
114 Territories and Crown Dependencies, making the most of available data, and to increase the level of awareness and  
115 understanding by target audiences (policy makers, conservationists, conservation supporters, and the wider public)  
116 of the current state of nature and how and why it is changing.

117  
118 The State of Nature 2016 ('the report' subsequently) brought together recent measures of species status for a far  
119 wider range of taxa than had previously been possible, and presented a series of metrics summarising species  
120 status and how it has changed over time. Since species monitoring across taxa in the UK is incomplete, the  
121 assessment aimed to maximise the sample size based on data availability, rather than on a preselected random

122 sample of species' data. Consequently there was variation between measures of species status in the time period  
123 covered, the method of data collection, the aspect of species status measured, and the statistical techniques used  
124 to assess trend. It is important therefore, to investigate whether the non-random species sample and the variation  
125 in assessment methodology had a significant impact on our results.

126

127 In this paper, we:

- 128 1. Provide a full description of the species status metrics used to assess the State of Nature and the  
129 underpinning biological data used, in order to facilitate their interrogation and reproduction;
- 130 2. Subject the metrics of species status to tests of robustness and representativeness of the entire species  
131 community and explore methods to control for observed biases;
- 132 3. Identify measures to improve the design and communication of the species status metrics and similar  
133 studies in the future.

134

## 135 **2. Materials and methods**

136 The methods below describe the process used to collate measures of species status and how these were combined  
137 into three metrics: 1. A Categorical Change metric, which describes the distribution of species among five  
138 population change categories based on their *average annual rate of change* over a *long-term* and a *short-term*  
139 period; 2. A Species Index, which charts average species' change over time, and 3. A Red List metric, which presents  
140 the proportion of species at risk of extinction from Great Britain. In order to maximise the taxonomic and  
141 ecological breadth of the species sample in the Categorical Change metric and the Species Index, we combined  
142 information from a diverse range of datasets, treating as equivalent different measures of population change, for  
143 instance changes in species abundance, occupancy or distribution. The three metrics use data from the United  
144 Kingdom only: the limited data available for the UK Overseas Territories are covered in the Discussion.

145

### 146 **2.1 Data collation**

147 We collated as many datasets as possible describing population change of native UK species in order to populate  
148 the first two metrics (Table 1; Tables A2:A4). The majority of these datasets were species time-series derived from  
149 statistical models, rather than raw counts or observations (Table 1). A small number of datasets consisted of  
150 biological records or periodic counts or estimates of species abundance, occupancy or range. For species with  
151 more than one dataset available, we gave precedence to assessments of change in abundance, as this is thought to  
152 be the most sensitive measure (Chamberlain and Fuller, 2001), and then the most robust dataset, based on the  
153 survey method subject to the fewest known biases, and maximising the sample size and time period covered. Each  
154 population change dataset contained two or more comparable estimates of species abundance or distribution  
155 made between 1960 and the present, had a broad geographical coverage across the species' UK range; the results  
156 or the methodology for data collection and/or analysis is published and start and end dates for estimates of status

157 for each species are at least ten years apart. In addition to datasets of species population change, we collated  
 158 national IUCN Red List assessments.  
 159  
 160 Assessments of population change in many terrestrial and freshwater species were based on unstructured  
 161 biological records, meaning records were collected outside a formal monitoring framework. It can be difficult to  
 162 use datasets of opportunistic records to assess change over time, as recording effort varies spatially and temporally  
 163 (Hill, 2012; Szabo et al., 2010). Several statistical techniques are available to help account for these biases; here we  
 164 used a hierarchical Bayesian occupancy modelling approach that has been shown to be robust to numerous biases  
 165 associated with biological records (supplementary material; Isaac et al., 2014; Van Strien et al., 2013). We fitted an  
 166 occupancy model to the records for each species (see supplementary material). The outputs from these models  
 167 are annual estimates of the proportion of occupied sites (henceforth occupancy).

*Table 1: Characteristics of the datasets contributing to the State of Nature analyses, showing the aspect of population status measured (Data Type), the format in which the data were collated and the number of species each data type contributed to the three metrics of species status. A full list of the datasets and the number and proportion of species included from each taxonomic group is given in Tables A2: A4 and A11. \* Includes population time series at a higher taxonomic level than species.*

	Data type	Format of data at collation	Taxonomic groups represented	Categorical Change	Species Index	Red List	Example of contributing dataset
TERRESTRIAL AND FRESHWATER	Annual population estimates	Annual counts	birds	29	29		Rare Breeding Birds Panel (Holling, 2015)
	Relative annual abundance from structured monitoring	Model derived annual estimate	birds, mammals, amphibians, lepidoptera	555	555		Breeding Bird survey (Harris et al., 2015)
	Relative abundance or range from periodic but comparable surveys	Abundance/ range observed or estimate from each survey	birds, mammals, reptiles	19	19		Otter surveys (e.g. Strachan, 2007)
	Occupancy from opportunistic recording data	Model derived periodic estimate	Moths	309	309		National Moth Recording Scheme (Fox et al., 2014)
		Biological records	arthropods, bryophytes, lichens	1589	1589		
	Range change between periodic atlases	Change Index	vascular plants	1315			Plant Atlas (Preston et al., 2002)
	<b>TOTAL</b>				<b>3816</b>	<b>2501</b>	

	National Red List Assessment		arthropods, molluscs, vascular plants, bryophytes, lichens			79 66	
MARINE	Annual Catch Per Unit Effort from structured sampling	Average catch per hour per survey area	fish, zooplankton*, phytoplankton*	73	73		North Sea International Bottom Trawl Survey (ICES, 2015)
	Relative annual abundance from structured sampling	Model derived annual estimate	birds, grey seal	12	12		Seabird Monitoring Programme (JNCC, 2015)
	Relative abundance or range from periodic but comparable surveys	Observed or estimated abundance from each survey	cetaceans, harbour seal	4	4		SCANS Small Cetacean national survey (Hammond et al., 2013)
	Categorical abundance from periodic surveys	Model derived average annual rate of change	algae	14	14		Brown seaweed surveys (Yesson et al., 2015)
	Phytoplankton colour index		Phytoplankton*	1	1		Continuous Plankton Recorder (Johns, 2015)
	<b>TOTAL</b>				<b>104</b>	<b>104</b>	



## 169 2.2 Producing metrics of species status

170 For each of the three species status metrics developed we presented the results overall (across all species  
171 assembled), by higher taxonomic group (vertebrates, invertebrates and plants and fungi), and by lower taxonomic  
172 group where possible. Additionally, we produced habitat specific metrics based on status data for species assigned  
173 to seven broad terrestrial and freshwater habitat types: Farmland, Woodland, Freshwater and Wetland, Upland,  
174 Coastal, Grassland and Heathland, and Urban (defined in Table A5). Species were classified to habitats by  
175 extending the method used by Redhead et al. (2016) (see supplementary material).

176

177 The nature and quantity of data for marine species was different from that for terrestrial and freshwater species,  
178 with robust data available for a limited set of taxa (Table A3). We did not include marine data in the metrics  
179 described above, but constructed separate Categorical Change metrics and Species Indices for marine species (see  
180 supplementary materials for further details on the limitations of the marine metrics).

181

182 Species were weighted equally in the terrestrial and freshwater species metrics. Each higher taxonomic group was  
183 weighted equally in the equivalent marine metrics given the taxonomic bias and variation in the taxonomic level at  
184 which measures of species change were available.

185

### 186 2.2.1 The Categorical Change Metric

187 In order to provide a simple synthesis of the available species trends, we assigned each species to one of five  
188 categories: *Strong increase*, *Moderate increase*, *Little change*, *Moderate decrease*, *Strong decrease*. Categorisation  
189 was based on the estimated magnitude of each species' population change, not its statistical significance, as the  
190 latter is determined by sample variance and thus influenced by sample size and, in relation to population change,  
191 by species' life history. Using the magnitude of the species' population change helped to reduce interspecific  
192 variance in our ability to detect change where it was present. We categorised species' population change over two  
193 time periods: a *long-term* period (~1970–2013 or closest available time period) and a recent *short-term* period  
194 (2002–2013).

195

#### 196 2.2.1.1 Categorisation based on changes in species' abundance and occupancy

197 In order to allow a comparison of species' trends across methods, we calculated the *total change* then the *average*  
198 *annual change* over the two time periods. We used published values where possible, otherwise they were  
199 calculated as follows (see Tables A3:A4 for exceptions). In general, *total change* (**t**) was the abundance (or  
200 occupancy) estimate in the final year expressed as a proportion of that in the first year. Smoothed time series were  
201 used when available to reduce the influence of unusual annual fluctuations. Here, **t** was calculated using the  
202 abundance estimate of the penultimate year as opposed to that of the final year, as the final year of smoothed  
203 time-series can be erratic (Buckland and Johnston, 2017). For most species *annual average change* (**a**) was

204 calculated using Equation 1, where duration is the difference between the first and last years of species' time-  
 205 series. For estimates of population change derived from Bayesian occupancy modelling **a** was calculated following  
 206 Isaac et al. (2015).  
 207

$$\mathbf{a} = \left( t^{\frac{1}{\text{duration}}} \right) - 1 \quad (1)$$

208 We placed each species into one of the five categories based upon the *average annual change* in relative  
 209 abundance or occupancy; defined as follows: *Strong increase*: a rate of change that would lead to a population  
 210 doubling or more over 25 years ( $\mathbf{a} \geq (2^{(1/25)}) - 1$ ), *Moderate increase*: change that would lead to an increase of  
 211 a third or more but less than doubling in 25 years ( $((4/3)^{(1/25)}) - 1 \leq \mathbf{a} < (2^{(1/25)}) - 1$ ), *Little change*: change  
 212 that would lead to an increase of less than a third or a decline of less than a quarter over 25 years ( $(0.75^{(1/25)}) -$   
 213  $1 < \mathbf{a} < ((4/3)^{(1/25)}) - 1$ ), *Moderate decrease*: change that would lead to a decline of greater than a quarter but  
 214 less than a half over 25 years ( $(0.5^{(1/25)}) - 1 < \mathbf{a} \leq (0.75^{(\frac{1}{25})}) - 1$ ), *Strong decrease*: change that would lead  
 215 to a population halving or more over 25 years ( $\mathbf{a} \leq (0.5^{(1/25)}) - 1$ ). These categories are very similar to those  
 216 used in other conservation assessments (e.g. Eaton and Noble, 2017). In addition, we presented a binary split of  
 217 the proportion of species with positive and negative trends, regardless of magnitude.  
 218

#### 219 2.2.1.2 Categorisation based on change in the distribution of Plants

220 Annual estimates of abundance or occurrence were not available for vascular plants. However, two atlases have  
 221 been produced and for each species an index – the Plant Atlas Change Index– was calculated, assessing the change  
 222 in distribution between the first atlas and the second at the scale of 10-km grid squares (Hill et al., 2004). Changes  
 223 were assessed relative to the change in the average species, as a way to partially control for recording effort by  
 224 assuming that it has changed equally across species (Telfer et al., 2002). As this index is a relative measure of  
 225 change it does not tell us how much a species' distribution has changed in absolute terms. Similar change indices  
 226 are available between each repetition of the Countryside Survey (Carey, 2008) and the one following it (1978-1990,  
 227 1990-1998, 1998-2007), allowing overall change between 1978 and 2007 to be calculated. We used Countryside  
 228 Survey data for the species for which it was available (generally more common and/or widespread species), and  
 229 otherwise used the Plant Atlas Change Index. We placed each plant species into one of five categories using the  
 230 definitions below. The cut-offs at  $\pm 0.5$  follow Preston et al. (2003). *Strong increase*: *Change Index (CIn)*  $\geq 0.5$ ,  
 231 *Moderate increase*:  $0.5 > CIn \geq 0.25$ , *Little change*:  $0.25 > CIn > -0.25$ , *Moderate decrease*:  $-0.25 \geq CIn >$   
 232  $-0.5$ , *Strong decrease*:  $CIn \leq -0.5$ . As above, we also included a simple binary positive/negative split.  
 233

#### 234 2.2.2 Composite annual Species Index of abundance or occupancy

235 The Species Index combined annual time series of both abundance and occupancy, as in the Dutch Living Planet  
 236 Index (Van Strien et al., 2016). The species composition of the Species Index was equal to that of the Categorical  
 237 Change metric with the omission of vascular plants, where the population change measure, the ‘Change Index’, was  
 238 incompatible with the indicator format. Additional processing was required for a small number of time series prior  
 239 to calculating the index; missing years were estimated using log-linear interpolation (Collen et al., 2008) but time  
 240 series were not extrapolated before the first available year of counts or after the last. Where genuine zero counts  
 241 were present the time series was included from the year of the first positive count and 1% of the average value of  
 242 the time series was added to each value in the time series of that species (Loh et al., 2005). Where time-series  
 243 ended prior to 2013, they were extended to 2013 by holding the final year’s value constant in all subsequent years;  
 244 49% of time series ended prior to 2013, but only 2% ended prior to 2010. All time series were converted to species  
 245 indices by expressing each annual estimate as a percent of the first year of the time series. On the small number of  
 246 occasions (2% of species indices) where species indices went above 10000 or below 1 they were set to that value as  
 247 extreme index values can have a disproportionate influence (Noble et al., 2004). The Species Index was calculated  
 248 as the geometric mean of the species indices (Gregory et al., 2005). Species’ indices starting after 1970 entered  
 249 the index at the geometric mean value for that year. Confidence intervals (CI) for each Species Index were created  
 250 using bootstrapping by species (Freeman et al., 2001); in each iteration (N=10,000) a random sample of species was  
 251 selected with replication and the index was re-calculated. Short-term change in the Species Index was calculated as  
 252 the geometric mean of species level change between 2002 and 2013, CI were estimated using bootstrapping by  
 253 species. Some species status metrics use bootstrap methods incorporating intraspecific error (Van Strien et al.,  
 254 2016). Although desirable this could not be achieved here as standard errors were unavailable for several  
 255 contributing datasets.

256  
 257 We used a generalised mixed model (function lme, package nlme, R Core Team, 2016) to test whether the rate of  
 258 change in the Species Index differed between the *short-term* period (2002-2013) and the *prior* period (1970-2001)  
 259 (Equation 2). Note the *prior* period is not equal to the *long-term* period.

$$260$$

$$261 \text{lme}(\log(\text{Species Index}) \sim (\text{year} - 2002) + \max(0, \text{year} - 2002), \text{random} = \sim 1 | \text{dummy}, \text{correlation} =$$

$$262 \text{corAR1}(\quad), \text{data} = \text{Species\_Index\_data}) \quad (2)$$

263  
 264 Where corAR1( ) is an autoregressive model of order one, which takes temporal autocorrelation into account by  
 265 using the index value at time t-1 to help predict its value at time t. A uniform single level random effect was also  
 266 included (dummy), which is required in order to include a correlation term. As the *short-term* and *prior* periods  
 267 differed in duration we used bootstrapping to determine the significance of the second explanatory variable, which  
 268 describes the relationship between the rate of change in the index and the two time periods. We re-ran the model

269 (Eq. 2) across the 10,000 bootstraps of the Species Index used to generate its CI and extracted the relevant  
270 coefficient in each case. Significance was indicated if the 95% CI of the model coefficient omitted zero.  
271

### 272 **2.2.3 National Red List assessments**

273 We synthesised all published national Red List assessments for Great Britain, where the risk of extinction was  
274 assessed using current regional IUCN criteria (IUCN, 2012), by presenting the proportion of species in each threat  
275 category. IUCN criteria primarily relate to quantitative changes in population parameters, but also include other  
276 measures, such as an assessment of threats and likelihood of rescue from populations outside the focal area. The  
277 proportion of species considered threatened with extinction is the sum of species in the categories, Critically  
278 Endangered, Endangered and Vulnerable (IUCN, 2016).

279

### 280 **2.3 Understanding sources of bias in the metrics of species change**

281 The species sample underpinning the metrics of species change is based on data availability because it is currently  
282 impractical to use a random sample of UK species within or between taxonomic groups or habitats. This means  
283 that we need to employ caution in extrapolating findings beyond the species assessed. To investigate the  
284 taxonomic representation of our datasets we assessed the extent to which each phylum and kingdom was over or  
285 underrepresented in our datasets relative to the proportion of freshwater and terrestrial species in that group.  
286 Secondly, we explored options for weighting our metrics to take account of taxonomic biases.

287

288 We calculated a weighted ( $w$ ) version of our Categorical Change metric (Equation 3) by assuming that the number  
289 ( $N$ ) of species present in our data ( $N_d$ ) were representative of the taxonomic group ( $N_g$ ) they belong to and  
290 extrapolating our assessment to all UK freshwater and terrestrial species ( $N$ ):

291

$$N_c = \sum_{g=1}^n \frac{N_{c,d,g} \cdot N_g}{N_{d,g}} \quad (3)$$

Where subscript letters denote that the parameter is specific to the population change category ( $c$ ), to those  
species present in the dataset ( $d$ ) and to the group ( $g$ ).

292 We calculated weighted ( $w$ ) Species Indices ( $I$ ) (Equation 4) where each group's weight ( $w_g = N_g/N$ ) was equal to  
293 the proportion of UK freshwater and terrestrial species it represents. Subscript definitions as above.

294

$$wI_t = 10^{\wedge} \sum_{g=1}^n \log_{10} I_{g,t} * w_g \quad (4)$$

295

296 We calculated three different weighted versions of the two metrics, where the group i) represented the three  
297 higher taxonomic groups used (vertebrates, invertebrates and plants and fungi) ii) the three kingdoms of life  
298

299 represented in our datasets (animals, plants and fungi) and iii) the seven phyla represented in our datasets  
300 (Arthropoda, Chordata, Tracheophyta, Pteridophyta, Bryophyta, Marchantiophyta and Lichens; Lichens were  
301 considered a proxy phylum).

302

303 We investigated how ecologically representative our species sample was for two taxonomic groups where range  
304 sizes and habitat associations were readily available (vascular plants and bryophytes (Hill et al., 2007; Hill et al.,  
305 2004)) by assessing whether the species included in our dataset (i.e. those for which trends were available) were  
306 each associated with more or fewer habitat types than those excluded from our dataset, or whether they, on  
307 average, had a larger or smaller range size. Additionally, across all taxonomic groups we assessed whether the  
308 Categorical Change metric varied depending on the number of habitat types species' were associated with (a  
309 measure of how specialised species' habitat requirements are).

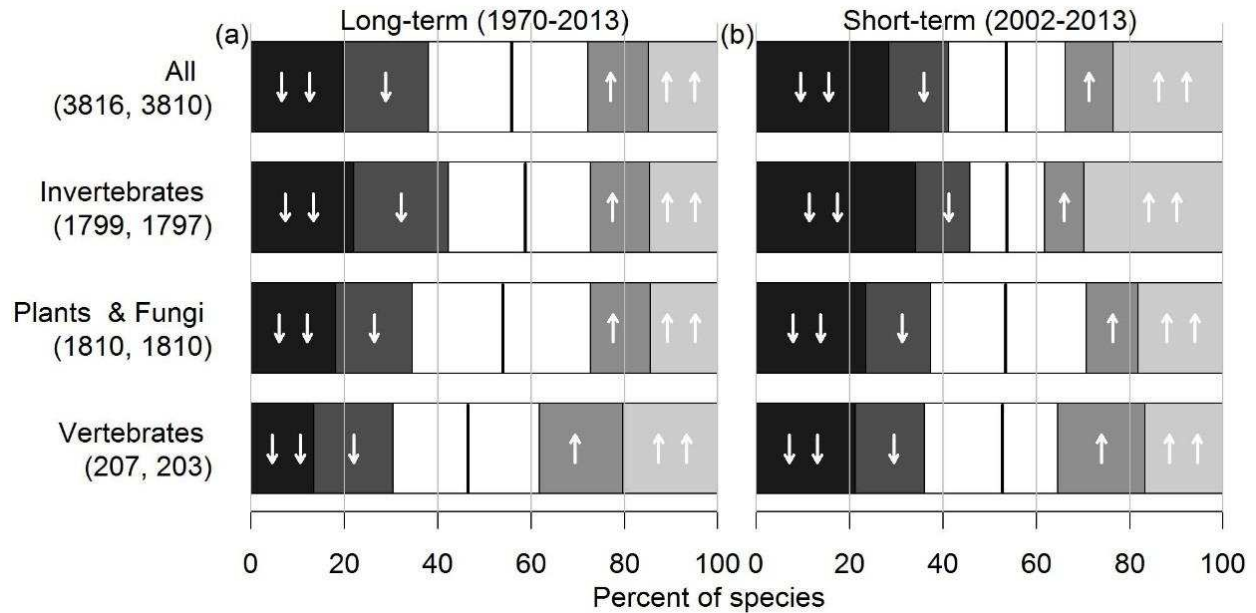
310

### 311 **3. Results**

#### 312 **3.1 Metrics of species change**

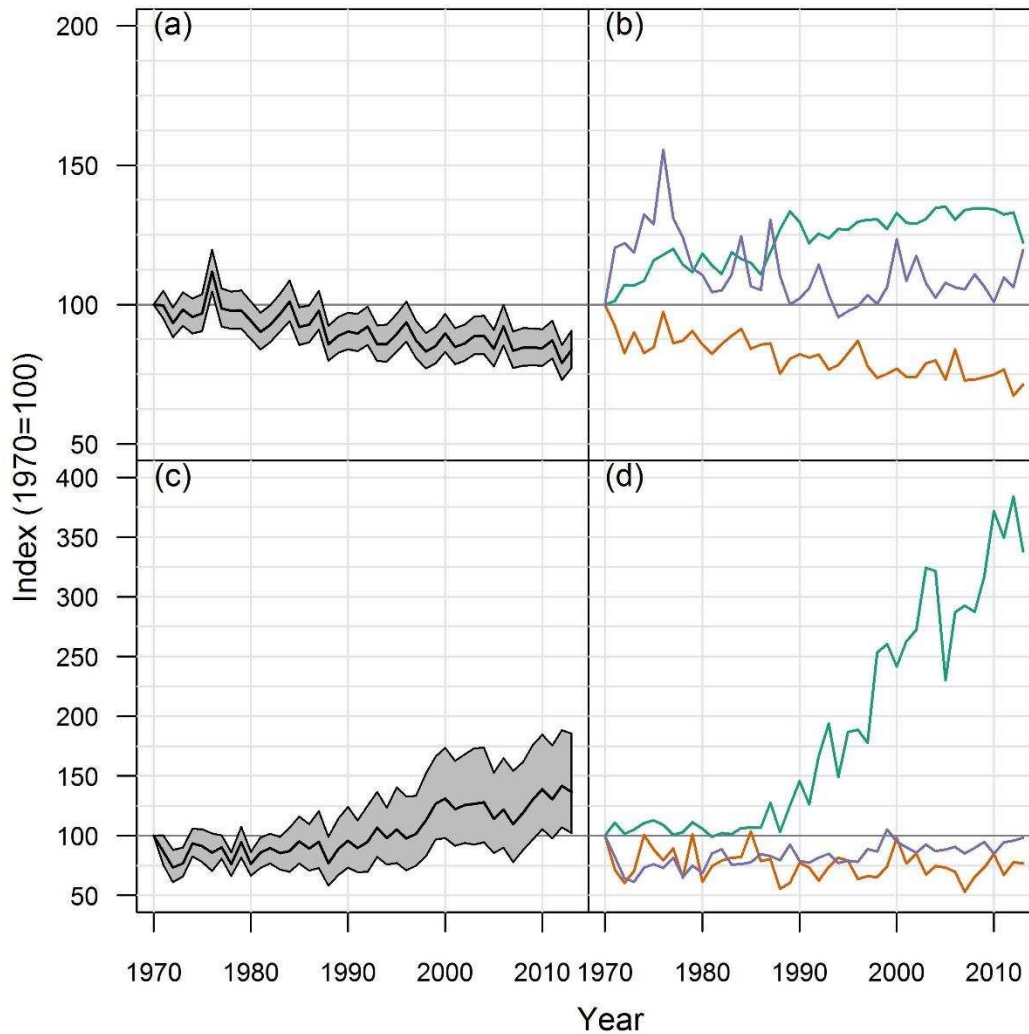
##### 313 **3.1.1 Freshwater and terrestrial species**

314 Of the 3816 species with a *long-term* measure, the Categorical Change metric showed that 2126 (56%) had a  
315 negative population trend and 1450 (38%) were either in the *Strong decrease* or *Moderate decrease* categories  
316 (*decreasing* categories), compared to 1690 (44%) with positive population trends and 1064 (28%) in the *Strong*  
317 *increase* or *Moderate increase* categories (*increasing* categories) (Figure 1a; Table A6). Of the 3810 species with a  
318 *short-term* measure, 2038 (53%) had negative population trends and 1772 (47%) positive and there were 1571  
319 species (40%) in the *decreasing* categories and 1289 (34%) in the *increasing* categories (Fig. 1b; Table A7). There  
320 was variation in the ratio of negative to positive changes between the higher taxonomic groups in the *long-term*  
321 but not the *short-term* (long-term:  $\chi^2_2 = 16.07, P < 0.001$ ; short-term:  $\chi^2_2 = 0.07, P = 0.97$ ), with vertebrates  
322 having fewer species with negative trends compared with invertebrates and plants and fungi.



323  
 324 *Figure 1: The freshwater and terrestrial Categorical Change metric for all species, and by the three higher*  
 325 *taxonomic groups, for the (a) long-term period and (b) the short-term period. The population change categories,*  
 326 *from left to right are: Strong decrease ↓↓, Moderate decrease ↓, Little change, Moderate increase ↑ and*  
 327 *Strong increase ↑↑. The strong black line shows the divide between negative population changes (where change*  
 328 *is below zero) and positive population changes. The number of species is shown in brackets.*

329  
 330 The Species Index (SI) declined significantly by 16% in the *long-term* ( $\Delta SI_{1970-2013}$  with CI = -16 (-23,-9)) and non-  
 331 significantly by 2% ( $\Delta SI_{2002-2013}$  = -2% (-5,2)) in the *short-term* (Figure 2a; Table A8). We found no evidence that the  
 332 rate of change of the overall Species Index differed between the *prior* period (1970-2001) and the *short-term*  
 333 period (2002-2013); change model coefficient (CM) with CI = 1.002 (0.998,1.006) (Table A9). There was substantial  
 334 variation between the Species Indices for the three higher taxonomic groups in the long-term, with vertebrates  
 335 showing no significant change;  $\Delta SI_{1970-2013}$  = 22 (-5,57), plants and fungi increasing;  $\Delta SI_{1970-2013}$  = 20 (3,39) and  
 336 invertebrates decreasing;  $\Delta SI_{1970-2013}$  = -29 (-36,-21) (Fig. 2b; Table A8). None of these Species Indices showed a  
 337 significant change in the *short-term*. The rate of change was significantly less positive in the *recent* period than the  
 338 *prior* period for vertebrates (CM = 0.987 (0.976,0.999)), and significantly more positive for plants and fungi (CM =  
 339 1.011 (1.003,1.018); Table A9).



340  
 341 Figure 2: Species Index for UK species. Freshwater and terrestrial species: (a) All species plus 95% CI, N=2501; (b)  
 342 Vertebrates (Green, N=207), invertebrates (Orange, N=1799), plants and fungi (Purple, N=495). Marine species:  
 343 (c) All taxa plus 95% CI, N=104; (d) Vertebrates (Green, N=80), invertebrate groups (Orange, N=8), plants (Purple  
 344 , N=16). N.B. the y-axis scale differs between plots (a)/ (b) and plots (c)/ (d).

345  
 346 [Greyscale legend for print] Figure 2: Species Index for UK species. Freshwater and terrestrial species: (a) All species  
 347 plus 95% CI, N=2501; (b) Vertebrates (Black, N=207), invertebrates (Black - - - dashed, N=1799), plants and fungi (  
 348 Grey, N=495). Marine species: (c) All taxa plus 95% CI, N=104; (d) Vertebrates (Black, N=80), invertebrate groups (  
 349 Black - - - dashed, N=8), plants (Grey, N=16). N.B. the y-axis scale differs between plots (a)/ (b) and plots (c)/ (d).

350  
 351 We were able to determine habitat associations for 83% (N = 3152) of the 3816 species in the Categorical Change  
 352 metric. The pattern of population change present in the all species metric (Fig. 1a) was similar to that found in  
 353 each habitat, but with Grassland & Heathland (60%) and Coastal (58%) habitats having slightly higher proportions

354 of species with negative population trends than average and Urban habitats having a slightly lower proportion  
355 (47%) (Tables A6 & A7). This could not be tested statistically as the species in each habitat are not independent. Of  
356 the 2501 species in the Species Index, we determined habitat associations for 1837 (73%). The Species Indices for  
357 five of the seven broad habitat types declined significantly in the *long-term*, with Grassland and Heathland showing  
358 the largest decline, of 29% ( $\Delta SI_{1970-2013} = -29$  (-39,-17); Table A10), whereas those for Coastal and Urban showed no  
359 significant change over time. In the *short-term*, only the Species Indices for two habitats, Woodland and Urban,  
360 showed a significant decline. For all habitats apart from Urban and Farmland, we found no evidence that the  
361 average rate of population change differed between the *prior* and the *short-term* period. The  $SI_{Urban}$  was stable in  
362 the prior period, but negative in the recent one (CM = 0.98 (0.97,0.99); Table A9). The  $SI_{Farmland}$  declined in the  
363 *prior* period and became more negative in the *short-term* period (CM = 0.993 (0.986,0.9995)).

364

### 365 **3.1.2 Marine species**

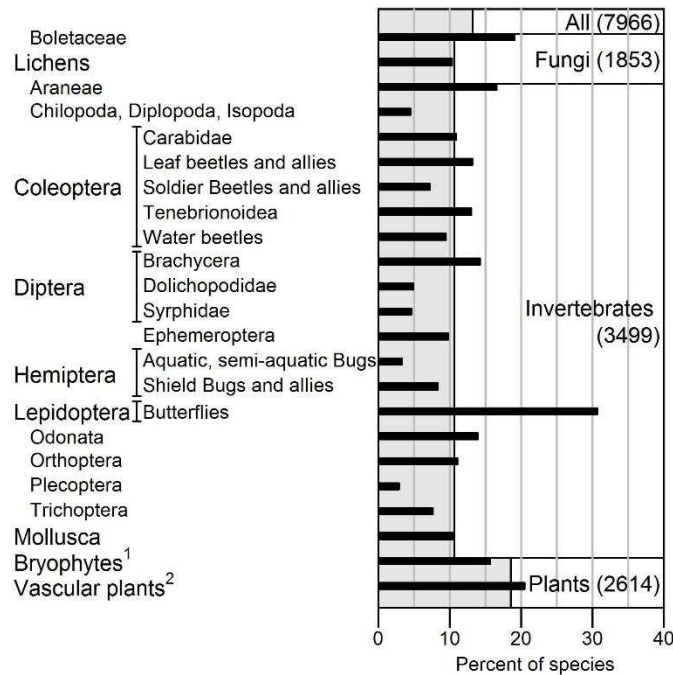
366 Over the *long-term*, 38% (N=39) of the marine taxa assessed had negative population trends and 62% (N=65)  
367 positive, whilst 26 taxa (25%) were in the *decreasing* categories and 51 (49%) in the *increasing* categories (Table  
368 A11). The  $SI_{marine}$  increased by 37% between 1970 and 2013 ( $\Delta SI_{1970-2013} = 37$  (2,85); Fig. 2c; Table A13). Looking at  
369 the trends of marine taxa in more detail, it is apparent that one group was driving the increase. When fish were  
370 excluded from the analysis, 48% (N=19) of the remaining marine taxa have negative population trends and the  
371  $SI_{marine}$  shows a non-significant decline of 11% since 1970 ( $\Delta SI_{1970-2013} = -11$  (-31,13)), whereas 31% (N=20) of fish  
372 have negative population trends, and  $SI_{fish}$  shows an increase of 485% ( $\Delta SI_{1970-2013} = 485$  (147,1310); Fig. 2d). In the  
373 *short-term*, 44% (N=46) of taxa have negative population trends and the  $SI_{marine}$  increased non-significantly by 16%  
374 ( $\Delta SI_{2002-2013} = 16\%$  (-3,41)). There was no evidence that the rate of change in the  $SI_{marine}$  differed between the *prior*  
375 and *short-term* period (Table A12).

376

### 377 **3.2 National Red List assessments**

378 We brought together GB Red List assessments for 7966 species, 15% of UK freshwater and terrestrial species  
379 (invertebrates: 12%, plants: 52%, fungi: 11%; no comparable assessments were available for vertebrates), of which  
380 13% were considered to be threatened with extinction. A higher proportion of plants were threatened (19%,  
381 Figure 3; Table A14) than either fungi or invertebrates (both 11%).





382

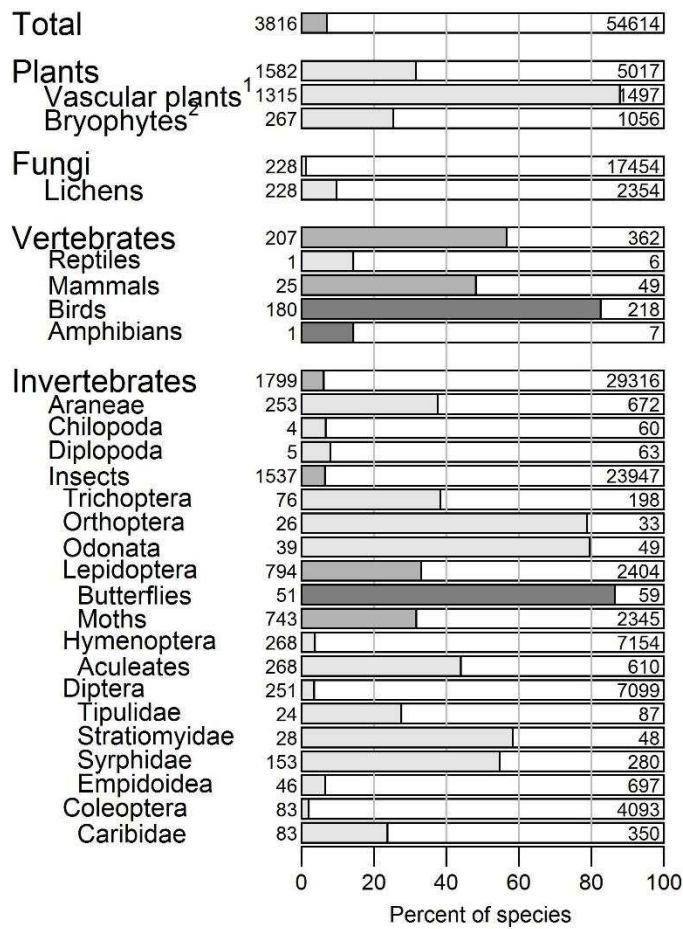
Figure 3: The Red List metric showing the percent of terrestrial and freshwater species threatened with extinction from Great Britain in groups assessed using modern IUCN Red List criteria. Light grey bars show the percent overall and for the three higher taxonomic groups, the black bars show the results of individual group assessments. For paraphyletic groups the families covered are listed in Table A14. 1: Bryophyta, Marchantiophyta, Anthocerothyta; 2: Tracheophyta, Pteridophyta.

383

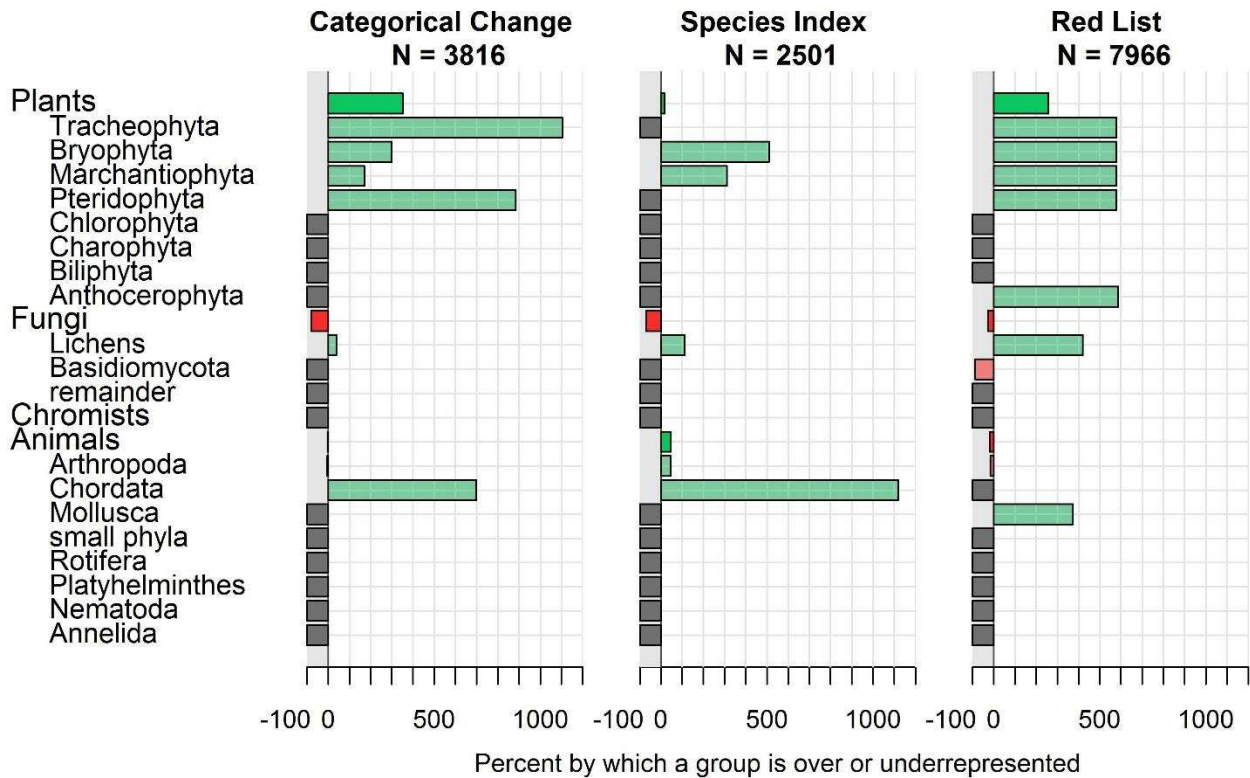
### 384 3.3 Understanding sources of potential bias in our metrics of species status

385 Our three species status metrics are populated by a large and diverse number of the UK's ~55k freshwater and  
 386 terrestrial species from three of the four multicellular eukaryotic kingdoms of life (Tables A2, A14; Figures 4, 5).  
 387 Nevertheless, the proportion of species sampled from each taxonomic group varied considerably. For example, in  
 388 the Categorical Change metric data were available for a substantially greater proportion of vertebrate species (57%;  
 389 Fig. 4), compared to plants (32%), invertebrates (6%), and fungi (1%); although in absolute terms there were fewer  
 390 vertebrate trends (N=207) compared to the other groups (invertebrates, N=1799; plants, N=1582 and fungi,  
 391 N=228). We can quantify this taxonomic bias by estimating the number of species or percent by which each group  
 392 is over or underrepresented in each of the three species status metrics (Fig. 5; Table A15). At a kingdom level fungi  
 393 and chromists (a diverse group of algae including diatoms and kelps) are strongly underrepresented in all three  
 394 metrics, whereas plants are overrepresented. There is considerable variation within the plant kingdom however,  
 395 with only half of phyla represented in the Categorical Change and Red List metrics and only two phyla represented  
 396 in the Species Index. Taxonomic bias for animals varies between the three metrics, but it is notable that only three

397 phyla are represented (Arthropoda, Chordata and Mollusca). The extent of vertebrate data means that Chordates  
 398 are overrepresented in the two population change metrics, whereas they are absent from the Red List metric.



399  
 400 *Figure 4: Percentage of freshwater and terrestrial species occurring in the UK that were included in the Categorical*  
 401 *Change metric and the Species Index (the latter omits all vascular plants), by taxonomic group. The number of*  
 402 *species included is given to the left of each bar and the total number of species in the group is given at the right-*  
 403 *hand side. Groups are colour coded by data type, Key: **Dark grey:** relative abundance, **Light-grey:** occupancy or*  
 404 *distribution, **Mid-grey:** Both. 1: Tracheophyta, Pteridophyta; 2: Bryophyta, Marchantiophyta.*  
 405



406

407 Figure 5: The percentage by which a group is over-represented (Green), under-represented (Red) or not  
 408 represented (Dark grey) in each of the three species status metrics at kingdom (opaque) and phylum (semi-  
 409 transparent) level.

410

411 [Greyscale legend for print] Figure 5: The percentage by which a group is over-represented (Light-grey), under-  
 412 represented (Dark-grey) or not represented (Black) in each of the three species status metrics at kingdom  
 413 (diagonal hatching) and phylum (solid colour) level.

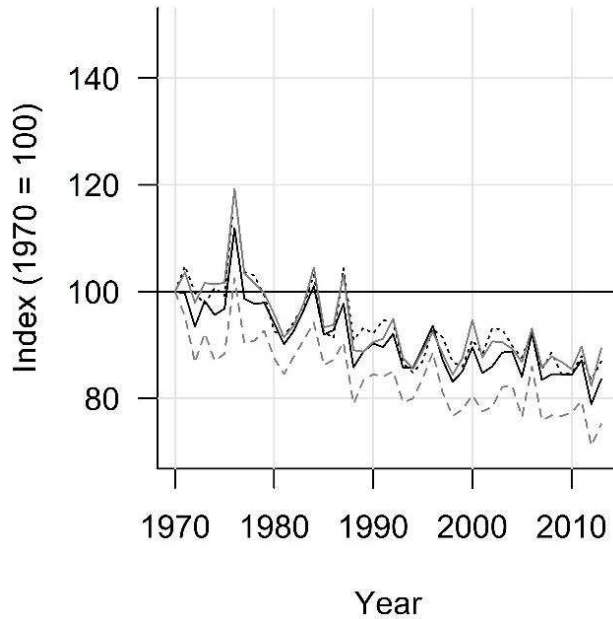
414

415 The proportion of species with negative population trends in the long-term in the weighted version of the  
 416 Categorical Change metric did not differ markedly from the un-weighted estimate of 56%; weighting by higher  
 417 taxonomic group (57%), by kingdom (56%) or by phylum (58%) (Table A16). In comparison to the long-term change  
 418 in our unweighted Species Index of  $\Delta SI_{1970-2013} = -16$  (-23,-9) weighting by higher taxonomic group led to a change of  
 419  $\Delta SI_{1970-2013} = -11$  (-18,-2), by kingdom  $\Delta SI_{1970-2013} = -13$  (-20,-7) and by phylum  $\Delta SI_{1970-2013} = -25$  (-31,-19) (Figure 6;  
 420 Table A16). In both metrics weighting by phylum gave a more negative outcome as the weight of Arthropod  
 421 species, which have a higher percentage of negative trends, was increased.

422

423 The tests for ecological bias (in the sense of ecological specialism) found that bryophyte species included in the  
 424 species change metrics tended to be associated with a greater number of habitats ( $X^2_6 = 303.69, P < 0.001$ ) and  
 425 were more widespread (*Wilcoxon* (*W*) = 16245, *P* < 0.001) than those for which population trends are not yet

426 available. The same pattern, albeit weaker, was observed for vascular plants ( $\chi^2_2 = 7.70, P = 0.021; W =$   
 427  $79118, P < 0.001$ ). However, across all taxonomic groups within our dataset we found no correlation between  
 428 the number of habitats in which species were found and whether their population trend was positive or negative  
 429 ( $\chi^2_7 = 12.28, P = 0.09$ ).



430  
 431 *Figure 6: The weighted Species Index where each group's weight was equal to the proportion of UK freshwater and*  
 432 *terrestrial species it represents. **Black:** Unweighted, **Grey:** weighted by higher taxonomic group, **Black ··· dotted:***  
 433 *weighted by kingdom, **Grey --- dashed:** weighted by phylum.*

434  
 435 Measures of species change were collated for only 104 marine taxa. This included chromists, plants, invertebrates  
 436 and vertebrates, but was biased towards fish (62%, Table A3). We did not find suitable population change  
 437 estimates expressed at a species level for marine invertebrates or phytoplankton; although data were often  
 438 collected at the species level. Given these limitations, we weighted each higher taxonomic group equally in the  
 439 marine metrics (2.2; Figure 2c, d).

440  
 441 **4. Discussion**

442 **4.1 What is the state of nature in the UK?**

443 The two State of Nature reports (Burns et al., 2013; Hayhow et al., 2016) mark a considerable advance in our  
 444 knowledge of the status of species in the UK. Previously, national Red Lists were the only assessment of species  
 445 status available for a comparable number of species, and widely-used biodiversity indicators rely on a far smaller  
 446 species sample with narrow taxonomic breadth (JNCC, 2017a). In our assessment, more than a third of freshwater  
 447 and terrestrial species and more than a half of marine species showed changes in abundance, occupancy or range,  
 448 which we defined as 'strong' over the *long-term* period. For freshwater and terrestrial species the average trend

449 was that of decline, strongly influenced by agricultural management and climate change (Burns et al., 2016).  
450 Human activities are also implicated in the 1057 species classified as threatened with extinction from GB (National  
451 Red Lists, e.g. Macadam, 2016), despite global (Convention on Biological Diversity, 2010) and national (e.g. Scottish  
452 Natural Heritage, 2016) targets to reduce the rate of biodiversity loss.

453

454 By contrast, the average trend for marine species was an increase, although this was based on a small sample of  
455 taxa, dominated by fish (62%). This average increase in fish populations is thought to have been influenced by two  
456 conflicting processes in the *long-term*. Populations of large-bodied fish species have been negatively impacted by  
457 fishing, leading to population declines (Genner et al., 2010; Pinnegar et al., 2010). However, warming sea  
458 temperatures have been associated with population increases for a wide range of small-bodied fish (Simpson et al.,  
459 2011). In the *short-term* some commercially fished species have increased due to improved fisheries management  
460 (JNCC, 2017b) and previous declines in some deep sea fish have stabilised (Neat and Burns, 2010).

461

462 Several studies have observed a recent reduction in the rate of net biodiversity loss compared to earlier in the 20<sup>th</sup>  
463 century. For instance, Carvalho et al. (2013) found a reduced rate of species richness loss and homogenisation  
464 for insect pollinator groups and plants in the late compared to the mid 20<sup>th</sup> century and large declines during the  
465 20<sup>th</sup> century in total nectar provision in GB appeared to stabilise by the late 1970s (Baude et al., 2016). Here, we  
466 found no evidence for a difference in the overall rate of species change between the *prior* and *short-term* periods.  
467 Differences were observed for some groups and habitats, but very few of these related to a reduced rate of decline  
468 or elevated rate of increase in the *short-term*. These different patterns of change between our and other's studies  
469 may be explained by the species sampled or the analytical methods used. However, as each study reported  
470 different measures of population change they may be observing different aspects of the same underlying process.  
471 A recent simulation study found that although observed trends in population abundance were consistent with  
472 simulated population change, observations of species richness showed periods of stability despite changes in the  
473 simulated populations (Hill et al., 2016).

474

475 We were unable to generate species status metrics for the UK's Overseas Territories (OTs), despite the international  
476 significance of the biodiversity found there. Repeated assessments of the state of species, such as those available  
477 for the UK, are almost entirely lacking for the OTs. A recent review of their biodiversity identified over 32000  
478 species, but estimated that there may be another 70000 species yet to be documented, with potentially over 3000  
479 single island endemics (Churchyard et al., 2016).

480

481 **4.2 Do our assessments represent a useful synthesis of the state of UK species and the environment more**  
482 **broadly?**

483 Each of the status metrics was populated by a large number and broad range of taxonomic groups and as such they  
484 are likely to provide a reasonable representation of the state of freshwater and terrestrial biodiversity. The species  
485 samples underlying the two species change metrics largely overlapped, however the Red List metric was  
486 complementary, with half of the species in the Categorical Change metric absent from the Red List metric.  
487 Nevertheless, substantial taxonomic bias remained in each, with important groups like fungi underrepresented (Fig.  
488 5) and vascular plants absent from the Species Index. The taxonomic breadth of the sample of marine taxa used  
489 was considerably lower than that for freshwater and terrestrial biota, and so we should be very cautious about  
490 extrapolating the patterns of change observed. However, we hope that by presenting these interim marine metrics  
491 we will stimulate further progress towards a robust assessment of marine species status. Indeed, across all biomes,  
492 it is likely that data availability (August et al., 2015) and analytical techniques (Dennis et al., 2017; Edgar et al.,  
493 2016; Outhwaite et al., 2018) will continue to increase and improve in coming years, allowing population change to  
494 be estimated for additional species and groups, which may reduce bias in the species sample.

495  
496 In order to control for current taxonomic biases, we explored weighting each taxonomic group in the two species  
497 change metrics relative to its contribution to UK biodiversity, such as is used by the Living Planet Index (McRae et  
498 al., 2017). This method should be considered for future assessments, however, the taxonomic level at which the  
499 weighting is conducted should be chosen carefully or applied hierarchically otherwise the weighting may amplify  
500 bias at lower taxonomic levels. Additionally, weighting by taxonomy may not control for other biases, for instance  
501 representation across the range of species' abundances or contributions to ecological processes. For the two  
502 taxonomic groups tested, there was some bias in data availability towards generalist, widespread species. It is hard  
503 to predict the generality or impact of this pattern, however, given evidence to suggest that specialist species are  
504 more likely to have poorer conservation status than generalists (Davey et al., 2012; Le Viol et al., 2012), our  
505 assessment of the percent of species in declining categories may be conservative.

506  
507 In order to maximise taxonomic breadth, the Species Index combined time series' of both abundance and  
508 occupancy (Van Strien et al., 2016). These two measures of population change tend to be correlated (Van Turnhout  
509 et al., 2007; Zuckerberg et al., 2009), nevertheless changes in abundance may be more pronounced or easier to  
510 detect, in particular for widespread species (Chamberlain and Fuller, 2001). Therefore, this decision may have  
511 introduced additional variance to the indices both due to the different measures of change and to differences in  
512 the data collection process.

513  
514 The Red List assessments summarised here cover a modest percentage of UK species (15%) but represent a major  
515 step forward in our understanding of national extinction risk. Ecological bias is likely to be lower here, as  
516 taxonomic groups are assessed in their entirety, yet significant taxonomic bias remains. Several additional Red List  
517 assessments have subsequently been published (e.g. Lane, 2017) and assessments are in progress for the

518 remaining vertebrate classes and several other insect groups, although fungi remain under-represented. Continued  
519 support for a programme of Red List assessments will likely further improve taxonomic coverage and allow repeat  
520 assessments, as is the case in many countries (Henriksen and Hilmo, 2015; Rassi et al., 2010), in time allowing the  
521 calculation of a Red List Index (Butchart et al., 2007).

522

### 523 **4.3 Future improvements to the design and communication of the State of Nature and similar assessments**

524 The aim of the assessment was to create a clear and objective summary of the state of wildlife in the UK and to  
525 communicate this in a way that increased awareness and understanding of the state of nature and how and why it  
526 is changing. Implicit in this is a requirement for audiences to easily understand the headline metrics and  
527 accompanying statements, and appreciate why they are important. Evidence is lacking to say whether the design  
528 of the species metrics and how they were communicated facilitated this requirement and whether our aims were  
529 met. Here we discuss indirect evidence collated and potential future improvements.

530

531 Effective biodiversity indicators should simplify information, be representative, quantitative, responsive,  
532 susceptible to analysis, policy relevant and easy to communicate (Gregory et al., 2005); the metrics here meet  
533 many of these criteria. Despite this, there remains scope to improve their design to make it easier to communicate  
534 their content and meaning. For freshwater and terrestrial species, the results indicate that more species have  
535 declined than increased and the average species' trajectory is downwards. We do not explicitly give an  
536 interpretation of these patterns, but it is implied that more species decreasing than increasing is undesirable and  
537 remedial action should be taken. But what would our interpretation be if we observed a ratio roughly balanced  
538 between increasing and decreasing, or with more species increasing, as we do for our sample of marine taxa? An  
539 unintended consequence of the current Species Index design is that it implies that population increases for some  
540 species balance out decreases for others. However, what is of more concern is the extent of anthropogenic impact  
541 on species, with focus upon species in decline. Partitioning the metrics by species' ecology to show areas of  
542 concern could aid interpretation. We investigated whether species' status differs by taxonomic group and habitat,  
543 but few strong patterns were seen, although that may be due partly to the simple breakdowns used. It would be  
544 useful to explore a range of other traits, such as rarity, specialism or ecosystem function (Powney et al., 2017).  
545 Another option would be to link species' status directly to the underlying cause, either by developing metrics that  
546 link biodiversity state to an environmental driver (Van Strien et al., 2009) or by developing a linked indicator set  
547 (Sparks et al., 2011). Explaining the reasons underpinning changes in species status helps interpretation  
548 (Blackmore and Holmes, 2013), although that level of knowledge or certainty is often missing.

549

550 We communicated the results of State of Nature 2016 through traditional and social media as well as targeted  
551 communications to policy makers, using members of the partnership as spokespeople. We only have indirect  
552 measures of whether the report succeeded in increasing the awareness and understanding of target audiences.

553 Over 10000 people responded to the 2016 report by individually tweeting about #StateofNature, and we had  
554 >35000 unique page views of an infographic carrying a simplified version of the report's findings. A stronger  
555 indication of increased awareness came from 7500 clicks on the 'how to help' options within the infographic,  
556 although it is unknown to what extent subsequent action was taken. There is some evidence that the two State of  
557 Nature reports have been successfully communicated to policy makers. They have been mentioned 12 times in 10  
558 debates in Hansard, the transcript of the UK parliament, six times in the Scottish Parliament's, and 12 times in the  
559 Welsh Assembly's equivalent reports. A clear recommendation for similar assessments in the future would be a  
560 robust methodology to measure impact on target audiences. Future impact may also be increased by involving a  
561 broader range of people in communicating the assessments, for instance a cross-party group of policy makers or  
562 other audience groups, as people's opinion of a messenger can influence their likelihood of acceptance (Kahan,  
563 2010).

564

565 Successful communication of a conservation message is, of course, only the first step towards pro-environmental  
566 behaviour change (Kollmuss and Ageyman, 2002), however, status reviews such as the State of Nature analyses can  
567 form the empirical basis of long-term communication projects whose ultimate aim is behaviour change amongst  
568 target audiences.

569

#### 570 **4.4 Conclusions**

571 The UK has some of the most comprehensive biodiversity monitoring in the world with tens of thousands of people  
572 contributing their time and expertise to collect data each year. This gives us an unparalleled ability to chart how  
573 nature is changing and to some degree why. The State of Nature analyses have allowed a robust assessment of the  
574 changing status of freshwater and terrestrial species with an initial assessment of marine species. The two State of  
575 Nature reports were communicated widely and we have some indication that the headline messages reached  
576 target audiences.

577

578 Clear, comprehensible and objective assessments of the state of nature are critical to informed decision making by  
579 policy makers, conservationists and individuals. This is particularly important as we approach 2020, when  
580 countries will be assessing their progress towards the Aichi global biodiversity targets (Convention on Biological  
581 Diversity, 2010).

582

583 The State of Nature partnership hopes to continue to work together towards this goal, with a third report planned  
584 for 2019. It is likely the metrics in the 2019 report will have lower levels of taxonomic bias given improvements in  
585 data availability and analytical techniques. Equally important is the continued development of the biodiversity  
586 metrics in order to facilitate communication of their content and meaning to audiences. Work is ongoing to  
587 develop a more rounded assessment of state, pressure and response and to illustrate likely causal links between



588 state and pressure where possible. Finally, we hope to work with audience members to improve our assessment  
589 and better measure its impact.

590

### 591 **Acknowledgements**

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596 Butterfly Monitoring Scheme, operated by the Centre for Ecology & Hydrology and Butterfly Conservation. The  
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598 Forestry Commission, JNCC, NERC, Natural England, Natural Resources Wales, and Scottish Natural Heritage as well  
599 as NGOs have provided funds for wildlife monitoring in the UK.

600

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