Development of a Combined Marine and Terrestrial Biodiversity Indicator for Scotland

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Commissioned Report for the Scottish Government
Project Number SPB/001/18

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The key chapters in this report (3, 4, 5, 6 and 7) close with a short summary of main points. The page number of this summary is given in parentheses after the chapter page number.

Executive summary

This report details work undertaken to produce a single high level indicator to measure trends in biodiversity in Scotland. The Scottish Government commissioned the work, keen to include an appropriate metric within the National Performance Framework (NPF). In the process of developing a single measure which combined data on both terrestrial and marine species' abundance and terrestrial species' occupancy (distribution), the authors raised concerns about whether such an approach could produce a meaningful indicator.

Following completion of the report, but prior to its publication, the Scottish Government has taken account of the concerns raised. With the exception of data on seabirds, it was noted that the data available for marine species abundance are largely restricted to seabed species fished commercially and that these species are subject more to fishing effort than environmental factors. As such, recent increases in fish stocks from a low base provide a misleading trend, and one that differs from the assessment of marine species across a wide range of ecosystem components provided in Scotland's Marine Assessment 2020 (SMA2020). Data from the SMA2020 was not suited to the NPF process due to the fact that its assessments do not report on an annual cycle. The Scottish Government has decided that for this indicator the NPF website should show trends in seabird species' abundance, terrestrial species abundance and terrestrial species' occupancy separately.

Indicator performance will be assessed as follows:

- **if one or more measures of the three measures show deterioration then indicator performance is assessed as "Performance worsening";**
- **if one or more measures show improvement and any remaining measures show no clear change then indicator performance is assessed as "Performance improving";**
- **otherwise indicator performance is assessed as "Performance maintaining".**

Showing the three measures will be more meaningful than one merged metric, and trends will be easier to describe. The Scottish Government wished to make readers of the report aware of this positive decision, but the report itself remains as presented to the Scottish Government. Some of the sections of the report where the concerns referred to above are raised by the researchers are now, therefore, less relevant than they were, since they have been addressed. The detail in the report about how data on different species can be gathered and amalgamated to reflect their abundance and distribution remains entirely relevant and will be adopted.

This report describes the work conducted by the RSPB, Centre for Ecology & Hydrology, James Hutton Institute, and University of Sheffield, under contract to the Scottish Government (reference SPB/001/18), in order to identify the most appropriate high-level indicator to measure and report trends in both terrestrial and marine biodiversity in Scotland. This indicator will enable trends in biodiversity to be considered as one of the 81 National Indicators in the National Performance Framework (one of eight used to measure progress towards the National Outcome for the Environment).

The combined biodiversity indicator proposed by this report will be an important measure of progress towards national commitments towards biodiversity. These include the commitments in the Scottish Biodiversity Strategy, and to the national outcome to 'value, enjoy, protect and enhance our environment'. Further than this, it can be regarded as a measure of progress towards targets in the European Union Biodiversity Strategy (such as target 1, to protect species and habitats), to the global Aichi targets used to assess progress towards commitments under the Convention on Biological Diversity and the UN Sustainable Development Goals.

The project entailed a number of components: i) a review of published literature relevant to the aims of this project; ii) a review of data on biodiversity in Scotland that might be used in a high-level indicator; iii) extensive consultation with a range of stakeholders to select the most suitable data and indicator format; iv) the collation of datasets required for indicator construction; and v) the creation of a draft indicator as presented in this report.

Most nations either publish or are developing biological indicators that assess the condition of specific aspects of the natural environment. The approaches adopted are diverse, but most fall into one of three definitions: the average trend in a measure of species' status (e.g. abundance); species status assessments often based around the International Union for Conservation of Nature (IUCN) Red List process; extent and condition of protected sites, habitat and ecosystems. The use of indicators showing the average trend in a measure of species' status is widespread, understood and accepted within the UK including within the indicators intended to measure progress against the Scottish Biodiversity Strategy. These existing indicators cover a range of measures encompassing some of Scotland's most valued biodiversity, and collectively give a valuable overview of trends in nature. The State of Nature reports at a UK (Hayhow *et al*. 2019) and Scotland scale (Walton *et al.* 2019) published government-endorsed high-level metrics of the status of biodiversity that are reasonably robust and credible measures of change. However, these reports did not publish a single headline indicator; the format of the NPF indicators require a single annually updated line. We also review other approaches to creating indicators using data on biodiversity, and proxies for biodiversity, but conclude that there is no compelling case for the use of these approaches given the availability of robust species' trend data for Scotland.

Our review of biodiversity data for Scotland found a considerable volume of species' data suitable for inclusion in a combined terrestrial and marine indicator. Robust abundance trends are available for 380 species of bird, mammal, butterflies and moths, and trends in occupancy (distribution) are available for an additional 1,578 species across a much broader taxonomic range including bryophytes, lichens and invertebrates. Constraints on the availability of these data are discussed: there are many gaps in data availability; for example, at present vascular plants are not included. Further still, we have far less data for marine species, and much of that which has been collected is not readily available for analysis.

An extensive consultation process was undertaken with Scottish Government and a wide range of other stakeholders in biodiversity policy, research and conservation. We report on this, describing how using stakeholder input helped us make key decisions on data to be used in a combined indicator, the treatment of this data, and the construction of the indicator itself.

We recommend an indicator based on the average of trends in species' status, measured at the scale of Scotland or Scottish marine waters. These trends should be measured in either abundance or occupancy, across as many species as possible to provide taxonomic breadth and thus represent the scope of Scottish biodiversity as best as possible. In total, trends for 2,073 species have been combined in the draft indicator presented here. We recommend that as new species trends become available, they are adopted within the indicator.

The recommended indicator begins in 1994 and runs to the most recent year for which data are available. The start year has been identified as the best balance between providing as long a time-series as possible, but keeping the taxonomic groups contributing to the index broadly consistent throughout. Based on current data (January 2020), we would recommend the initial, final year should be 2016. The indicator has annual index values, and is capable of annual updates, with nearly all of the constituent species' trends being updated annually. The recommended indicator is based on trends in abundance from a range of established monitoring schemes and trends in occupancy from analyses of biological records held by the Biological Records Centre. Set rules, either imposed by those organisations that operate these monitoring schemes, or created for the purposes of this indicator, filter species trends for suitability for inclusion, ensuring individual species trends are robust. With the exception of marine fish trends, these species' trends are created by existing work programmes, meaning that future updates of the proposed indicator will be efficient and low-cost. All single species trends are derived using well-established and published methods.

Whilst the combination of abundance and occupancy trends in the same metric, as proposed, is not currently used for other government biodiversity indicators in the UK, it is not without precedent. However, we should caution that this approach does combine trends measured in two different ‘currencies’, of abundance and occupancy (distribution), which may vary in different ways and at different rates within the same species. There is evidence that changes in occupancy may differ in scale to those in abundance, or even show trends in a different direction and so combining the two currencies in a single metric is far from ideal. Our recommendation to do so is on the basis that we feel the much greater taxonomic representation this gives the indicator warrants this approach given the requirement of the NPF indicators to be single trend lines. Without this constraint we would not recommend the combining of the two currencies. Note the 2019 State of Nature report (Hayhow *et al.* 2019, Walton *et al.* 2019) did not combine abundance and occupancy data in a single measure but was able to present measures of change in each separately. Note that using the two currencies together means that the indicator can only be described in abstract terms; a change cannot be described in terms of either abundance or distribution.

There are considerable biases in the availability of species trends for incorporation in the indicator. For example, the draft indicator contains trends for many more terrestrial and freshwater species than marine species, and vertebrates are over-represented in comparison to invertebrates and plants. However, we have failed to identify an objective approach to weighting the indicator to address these biases, so propose the indicator should be the unweighted average of all available species’ trends. Most notably this means that taxonomic groups measured using trends in distribution have a greater impact on the indicator than those for which we have abundance trends, and terrestrial and freshwater species have a far greater influence than marine species.

We recommend the indicator be created using a new hierarchical modelling method for calculating multi-species indicators within a state-space formulation developed by CEH (Freeman *et al*. 2020) which offers some advantages over the more traditional geometric mean method; it is robust, precise, adaptable to different data types and can cope with the issues often presented by biological monitoring data, such as varying start dates of datasets and missing values.

The project team, and stakeholders involved in consultations as part of this project, hold substantial reservations about the value of the proposed indicator for assessing change in Scottish biodiversity. A number of the decisions made, particularly regarding whether to combine trends in abundance and occupancy, and whether to weight to address biases in data availability, had no obvious “correct” answer and other choices to those made may have been equally valid. We retain substantial reservations about the value of an indicator summarising biodiversity trends at such a high level, particularly across terrestrial, freshwater and marine realms combined. Even if we were able to do this perfectly, the utility of such a high-level measure is doubtful as it will hide considerable, and important, differences in biodiversity trends between taxa, realms and ecosystems.

Differences between the now widely circulated and used metrics in the State of Nature Scotland 2019 report, and the draft composite indicator do have the potential to cause confusion unless carefully communicated. However, a similar broad pattern of biodiversity loss is shown by both measures.

The single line in the proposed headline indicator, incorporating trends in an extremely wide range of species across disparate taxa, collectively found in most if not all of Scotland's habitats and regions, and responding both positively and negatively to a disparate range of drivers, is intended to reflect the most broadscale changes in the country's biodiversity. However, amalgamating such a wide range of data means that the single line can mask massive variation in trends between species, and such variation may reflect wider patterns of change. As such, the headline indicator alone may be a misleading measure of biodiversity health; we strongly recommend the publication of disaggregated indicators to aid interpretation (and avoid misinterpretation) of the headline indicator and potential ways of disaggregating the headline indicator are demonstrated in this report.

As stated previously, the draft indicator is derived from existing data sources that are updated annually by funded monitoring programmes. To a large extent these programmes also run analyses to produce updated indices on an annual basis, or routinely make data available for those analyses to be conducted (biological records submitted to the Biological Records Centre are used by CEH to generate occupancy trends annually, under a Joint Nature Conservancy Council-funded work programme). A relatively small amount of work would be required on an annual basis to update the combined indicator.

The indicator proposed is, we feel, the best option currently available to represent change in terrestrial and marine biodiversity in Scotland although, as emphasised above, is very imperfect. We have in this report identified a range of steps that might be taken to improve upon this indicator. Some are far-reaching changes to the structure of biodiversity recording, such as those recommended by the Scottish Biodiversity Information Forum (SBIF) review (Wilson *et al.* 2018) to lead to a much improved system for biodiversity data collection, collation, curation and use in Scotland: if implemented this would lead to many improvements in data availability.

Finally, we make a number of recommendations; regarding (i) the communication of the changes shown by the indicator, particularly as regards the use of disaggregated indicators to enable better understanding of the underlying causes of change in the headline metric, (ii) further analytical developments, and (iii) priorities for the collation and analysis of existing biodiversity data to enable future improvements of the indicator.

1. Background

1. Simple, easy to understand indicators are essential to enable the assessment of public policies in meeting their stated objectives and communicating success (or otherwise) to a wide variety of audiences. For instance, there is a crucial need for robust and appropriate biodiversity indicators to measure progress towards goals for the conservation of biodiversity (such as reducing the current rate of loss, and then establishing progress in recovering lost biodiversity e.g. Mace *et al.* 2018) whether set at global, regional or national scales (see below for a review of relevant policy targets for Scotland). In addition, biodiversity indicators can be relevant for measuring the impact of a broad range of human activities upon the natural environment, and for assessing the success of measures intended to mitigate against such impacts.

2. This report describes the work conducted by the RSPB, Centre for Ecology & Hydrology, James Hutton Institute and University of Sheffield, under contract to the Scottish Government (reference SPB/001/18), in order to identify the most appropriate high-level indicator to measure and report trends in both terrestrial and marine biodiversity in Scotland. This indicator will enable trends in biodiversity to be considered as one of the 81 National Indicators in the National Performance Framework (one of eight used to measure progress towards the National Outcome for the Environment). The indicator on terrestrial birds, as used in the previous National Performance Framework, whilst based on robust and annually updated data and likely to be broadly representative of changes in Scottish terrestrial and freshwater biodiversity, had a number of shortcomings (most notably, but not restricted, to the absence of marine data) which a new indicator should seek to address.

3. This report describes the work conducted in order to identify the most suitable indicator, which was conducted as a number of components: i) a review of published literature relevant to the aims of this project; ii) a review of data on biodiversity in Scotland that might be used in a high-level indicator; iii) extensive consultation with a range of stakeholders to select the most suitable data and indicator format; iv) the collation of datasets required for indicator construction; and v) the creation of a draft indicator as presented in this report.

2. Biodiversity indicators – a brief introduction

4. Many authors have attempted to define the essential and desirable qualities required from indicators (generally) and biodiversity indicators (specifically). For instance, Dale & Beyeler (2001) stated that ecological indicators should meet the following criteria: be easily measured; be sensitive to stresses on the system; respond to stress in a predictable manner; be anticipatory; predict changes that can be averted by management actions; be integrative; have a known response to disturbances, anthropogenic stresses, and changes over time; and have low variability in response (e.g. not show large fluctuations due to random effects). To this one might add other qualities such as simplifying, easily understood, representative and policy relevant (e.g. Gregory *et al*. 2005). Other authors have focused on desirable statistical qualities e.g. van Strien *et al*. (2012). It is very important that indicators be unbiased (or at least that sources of bias are known, understood, and factored into interpretations of indicator change), and ideally indicators should be precise and accompanied by estimates of precision (confidence intervals) and be amenable to quantitative reporting of changes (Sutherland 2006).

5. Whilst the characteristics of a successful indicator are well known, the ideal indicator is rarely possible, if ever, and it is recognised that indicators should be selected depending on the specific questions being asked and, perhaps more pertinently, the data available (Feest *et al.* 2010). In the case of biodiversity indicators, considerable challenges are posed by constraints in data availability; even with the UK's long-established biological recording and monitoring community, we have robust measures of change for only a minority of species. At the same time as developing an indicator that draws from existing data sources, can be updated regularly (preferably annually), is responsive to change, can be assessed with formal statistical assessments, but remains simple to understand and communicate, it also needs to account for the fact that the available data represents a biased sample of trends in Scottish biodiversity. Careful consideration will be required to overcome this issue.

6. In addition, careful thought has to be afforded to the relevance of an indicator to policy objectives, and the actions taken to achieve those objectives. If designed to measure progress towards narrowly defined objectives indicators can perform admirably, but their value will be limited to this function only, and they can easily become obsolete as objectives change or evolve. Conversely indicators designed to measure response to broader suites of objectives and actions can be less sensitive to change and harder to interpret in light of policy.

7. Heink & Kowarik (2010) identified a useful list of criteria that could be used to assess the suitability of biodiversity indicators, based on a review of 56 papers discussing indicator selection. They grouped these criteria into five groups:

- Feasibility (knowledge about species, portability, suitability for statistical analyses, existence of reference values);
- Efficiency (feasibility of data collection, universality, parsimony);
- Relationship between indicator and indicandum (precision of correlation between indicator and indicandum, construct validity, aggregation of substantial amount of ecological information);
- Information to be provided by the indicator (relevance, sensitivity to change, functional importance, distinction between natural and man-made change, rarity and threat);
- Perception of indicators (acceptance, comprehensibility and simplification of information, economic importance).

8. Whilst not all of these criteria are necessarily relevant to all biodiversity indicators, depending on the circumstances for which indicators are required, they do provide a useful suite of considerations against which to test candidate indicators. As Heink & Kowarik (2010) intended, these criteria, or a subset of them, could be used to enable the transparent selection of a biodiversity indicator, although they identified that different applications for indicators will require different ‘patterns’ of selection (i.e. the relative importance of criteria may vary).

3. Government objectives for biodiversity conservation, and official indicators used to measure progress against these, in the UK and its constituent countries

9. The UK as a whole has overarching international responsibilities for biodiversity, but biodiversity policy is a devolved responsibility of its constituent countries. England, Scotland, Wales and Northern Ireland have all developed or are in the process of developing their own environmental strategies, policies and underpinning legislation. Ways of measuring progress against these policies, such as biodiversity indicators, are therefore required by each of the devolved governments as well as at the UK level.

10. Here we review biodiversity reporting at the UK and Scottish level, as these are directly relevant to our work on a new Scottish biodiversity indicator. We also present current practice in the UK's other three countries as this may be of use in guiding thinking on developing an indicator for Scotland.

11. The combined biodiversity indicator proposed by this report will be an important measure of progress towards national commitments towards biodiversity. These include the commitments in the Scottish Biodiversity Strategy, and to the national outcome to 'value, enjoy, protect and enhance our environment'. Further than this, it can be regarded as a measure of progress towards targets in the European Union Biodiversity Strategy (such as target 1, to protect species and habitats), and to the global Aichi targets used to assess progress towards commitments under the Convention on Biological Diversity.

3.1 United Kingdom

12. The UK is a signatory to international biodiversity commitments such as the Convention on Biological Diversity (CBD), the UN's Sustainable Development Goals, the New York Declaration on Forests, the OSPAR convention, and the EU's Biodiversity Strategy and Marine Strategy Framework Directive. All these contain policies and targets which require measures of biodiversity change over time.

13. The Joint Nature Conservation Committee (JNCC) currently publishes 24 official UK biodiversity indicators, which contain 49 individual measures, and another five are 'in development'. Last reviewed in 2011 and 2012, they are published annually and were mainly developed for reporting progress against international responsibilities and commitments, e.g. the CBD's Aichi targets (Defra 2018a).

Within this suite of indicators there is no overarching single indicator of biodiversity change; however, 27 include a measure of change (defined using either abundance, occupancy, extent, status or quality) in various aspects of biodiversity, including habitat types. These can be divided into three main areas:

- Those that document trends in the abundance and/or occupancy (a measure of geographic range size) of species of different wildlife groups (e.g. priority species, bats, butterflies, pollinators, invasive species, fish stocks, habitat or taxonomic groups of bird species).
- Those that measure changes in site, habitat or ecosystem extent and condition, such as protected areas on land and sea, SSSI's, priority habitats, agricultural and forest area under environmental management schemes.
- A single experimental indicator which attempts to measure habitat connectivity based on the size and distribution of patches of habitat and the relative ease with which typical species, in this case UK butterflies, can move through the landscape.

14. Similarly, in the marine context, a suite of indicators has been developed to assess progress towards Good Environmental Status (GES) under the EU Marine Strategy Framework Directive (2008/56/EC) (MSFD). These also can be grouped by those which document trends in distribution and/or abundance of key species or functional groups (especially fish, marine mammals, and seabirds), and those which quantify changes in habitat extent or condition (particularly of benthic habitats), although there are additional indicators of ecosystem structure and community composition, particularly for pelagic habitats (e.g. plankton community composition) and fish (e.g. size-based indicators of community condition, such as the Large Fish Indicator), as well as multiple indicators of diverse human pressures (e.g. non-native species, contaminants, eutrophication, marine litter) (Defra 2014).

15. As there is no headline indicator for biodiversity change it is hard to obtain a clear overall impression of the state of biodiversity in the UK, and progress towards national/international ambitions. Whilst changes in each of the 49 measures are categorised (improving; little or no change; deteriorating; insufficient or no comparable data) over the long-term (from when data are first available) and short-term (the most recent five years for which data are available), there is no obvious approach that could be used to provide an synoptic overview of these assessments as a whole, particularly as the number of measures for each of the indicators varies widely, and thus a simple summary across the 49 measures would provide a biased impression. Likewise, although there are 11 high-level descriptors of GES under the MSFD, each with clear reporting requirements, there

is no single synoptic measure of the status of marine biodiversity available from these.

16. Many of the biodiversity indicators used to measure progress at the UK level, are or have the potential to be used by devolved governments by adopting geographical restrictions to the data.

17. The State of Nature 2019 report (Hayhow *et al.* 2019) was published in October 2019, giving a high-level overview of trends in the UK's biodiversity, the pressures acting upon biodiversity, and the conservation responses being made to address these pressures. This was the third such report produced by an extensive partnership of conservation, monitoring and research organisations (following Burns *et al.* 2013, and Hayhow *et al.* 2016). Notably this partnership expanded in 2019 to include the UK and country Statutory Nature Conservation Agencies, so the report might now be considered as a government-endorsed assessment of the UK's biodiversity. In addition to the UK report, which included short summary accounts for nature in each of the UK's four countries, a separate The State of Nature Scotland 2019 report was also published (Walton *et al.* 2019) (see paragraph 28 below).

18. The State of Nature reports use a series of high-level metrics derived from species trend data, which have developed iteratively since 2013. As far as possible, the metrics reported at the UK-scale are repeated at the country scale, but issues of data availability and quality limit the ability to do this. The principal metrics published in the 2019 report were as follows:
    - Average change in species abundance since 1970, based on trends in 697 terrestrial and freshwater species. This was accompanied by additional measures reporting the percentage of species in each of five classes of change (strong increase, moderate increase, little change, moderate decrease, strong decrease) since 1970 and over the most recent 10 years.
    - Average change in species' distribution since 1970, based on trends in occupancy of 6,654 terrestrial and freshwater species. As above, this was accompanied by a breakdown of species' trends into five categories.
    - The percentage of species considered threatened with extinction from Great Britain, based upon formal IUCN threat assessments for 8,431 species.
    - A range of measures were published to illustrate change in marine biodiversity, but no single headline metric was created.

19. These metrics were accompanied by numerous others, including disaggregations of the principal abundance, distribution and red list metrics by taxonomic group,

and many existing measures such as the UK biodiversity indicators referred to above. As well as measures of the state of biodiversity such as these, the report contained many indicators relevant to the pressures acting upon biodiversity (e.g. pollution, farming intensity, invasive non-native species) and the response to help biodiversity (e.g. investment in conservation, volunteer hours donated).

3.2 Scotland

20. The Scottish Government has made strong, high-level commitments to the protection of the nation's rich natural heritage. These commitments are presented by the Scottish Biodiversity Strategy, as defined by "Scotland's Biodiversity: It's in Your Hands" (Scottish Biodiversity Forum 2004), and more recently, by "2020 Challenge for Scotland's Biodiversity" (Scottish Government 2013). The latter made the commitment to "protect and restore biodiversity on land and in our seas, and to support healthier ecosystems". These policies are driven both by the intrinsic value that Scottish people place in the country's natural heritage, but also a growing awareness of the value of maintaining healthy ecosystems for the wellbeing of society. This latter consideration, of the ecosystem services that biodiversity provides, is also recognised in the Scottish Government Economic Strategy. This recognition provides a strong impetus for Scottish Government to consider the needs of biodiversity, and to encourage the embedding of similar thinking within local government, agencies and other public bodies, as well as within business, civil society and individuals. However, the challenges and barriers to the protection and restoration of biodiversity remain considerable.

21. The Scottish Government's National Performance Framework (https://nationalperformance.gov.scot/) aims to create a more successful country through giving opportunities to all people, increasing wellbeing, creating sustainable and inclusive growth, reducing inequalities and giving equal importance to economic, environmental and social progress. To help achieve its aims this framework has identified 11 core 'national outcome' areas: children and young people, communities, culture, economy, education, environment, fair work & business, health, human rights, international and poverty. In order to measure progress against each of these, the Scottish Government has adopted 81 state indicators.

22. The 'biodiversity' indicator has been identified for revision, and this project aims to identify the most appropriate high-level indicator to measure and report trends in both terrestrial and marine biodiversity in Scotland. Any new metric will need to fit

in with the current suite of indicators used to assess progress in other outcome areas. Of the 62 state indicators that currently exist (19 are still in development):

- All are presented as a single index plotted on a line graph.
- 94% are updated annually: four (6%) are updated biennially.
- 71% either represent 'percentage' or 'proportion' change in a defined variable.
- As of the 21st March 2019, most indicators used data up to and including 2017 (73%), followed by 2016 (16%), 2018 (6%) and 2015 (5%).
- 85% have starting points (first data point) which are since 2005 (52% post 2010). Only four pre-date 2000, with the oldest being the previous biodiversity indicator (the index of abundance of terrestrial breeding birds) which starts in 1994.

23. Apart from 'biodiversity', there are currently seven other indicators identified against the 'environment' national outcome to 'we value, enjoy, protect and enhance our environment':

- Visits to the outdoors: Proportion of adults making one or more visits to the outdoors per week.
- State of historic sites: Percentage of pre-1919 dwellings (sites) classified as having disrepair to critical elements.
- Condition of protected nature sites: Percentage of natural features on protected nature sites found to be in favourable condition.
- Energy from renewable sources: Percentage of energy consumption which is renewable energy.
- Waste generated: Household waste (million tonnes).
- Sustainability of fish stocks: Percentage of fish stocks fished sustainably.
- Clean Seas: Percentage of biogeographic regions with acceptably low levels of contaminants.

24. It is also worth noting the Natural Capital Asset Index (NCAI), which is an indicator identified against the 'economy' national outcome but also has relevance with regards to biodiversity. This is reported as a high-level overall indicator, and as separate lines for three constituent classes of ecosystem services (provisioning; regulation & maintenance; cultural). Levels of ecosystem service provision in these categories are assessed through the quality of habitats providing the services, with the quality of habitats assessed by using a suite of 38 indicators. These cover a wide range of measures, some directly related to habitat quality, others only indirectly e.g. pressures that act upon habitat quality. Measures of biodiversity, such as the woodland bird indicator, are included in this suite.

25. A suite of indicators has been developed by the Scottish Government in order to measure progress against the aims of the Scottish Biodiversity Strategy. These were updated in 2013/14 following the publication of the 2020 Challenge for Scotland's Biodiversity, and fall within two groups; those that measure changes in biodiversity (species, habitats and ecosystems) and those that monitor public' engagement with the natural environment. The former comprises 17 separate indicators (SNH 2019). For each, the last year of data used to create the metric is shown in parenthesis. Some are no longer updated.
   - S01 Status of UK Biodiversity Action Plan (UK BAP) priority species – archived (2008)
   - S02 Status of UK Biodiversity Action Plan (UK BAP) priority habitats – archived (2008)
   - S03 Abundance of terrestrial breeding birds (2018)
   - S04 Abundance of wintering waterbirds (2015/16)
   - S05 The numbers and breeding success of seabirds (2016)
   - S06 Vascular plant diversity (2007)
   - S07 Woodland diversity – archived (1999)
   - S08 Terrestrial insect abundance: Butterflies (2018)
   - S09 Terrestrial insect abundance: Moths (2004)
   - S10 Condition of notified species (2016)
   - S11 Condition of notified habitats (2016)
   - S12 Status of otters in freshwater habitats (2004)
   - S13 Freshwater macroinvertebrate diversity – archived (2009)
   - S14 Marine plankton – archived (2010)
   - S15 Estuarine fish – archived (2005)
   - S16 Proportion of commercially exploited fish stocks which are at full reproductive capacity – archived (2007)
   - S17 Non-native species: Terrestrial freshwater and marine environments – archived (2001).

26. The Scottish Government has made international commitments to safeguarding biodiversity and publishes annual reports on progress to the Convention of Biological Diversity (CBD) (e.g. SNH 2017); it was the first government in the world to do so. A combined terrestrial and marine biodiversity indicator would allow progress towards the 'Aichi' targets of the CBD and the UN's Sustainable Development Goals (SDG) to be measured. Specifically, a robust biodiversity measure could help assess progress towards Aichi targets 7 (on the sustainable management of areas under agriculture, aquaculture and forestry) and 12 (on the conservation status of threatened species), and disaggregated metrics may also be relevant to targets 6 (sustainable fisheries) and 8 (levels of pollution). It would

also be relevant to measuring the success in meeting the Sustainable Development Goals 15 (life below water) and 16 (life on land).

27. Whilst at present we do not know what targets the CBD will adopt post-2020 (dependent on decisions made at the 15th meeting of the Conference of Parties in October 2020), it seems highly likely that they will require high level measures of trends in biodiversity, as measured using species data, and that a new Scottish biodiversity indicator will be relevant for this purpose.

28. The State of Nature 2019 report (Hayhow *et al.* 2019) was accompanied by a separate State of Nature Scotland 2019 report (Walton *et al.* 2019), as well as containing Scottish-specific indicators within the UK-scale report. The Scottish report attempted to replicate the UK-level headline metrics as described above, but with adjustments to accommodate restrictions in data availability. The headline indicators were:
    - Average change in species abundance since 1994, based on trends in 352 terrestrial and freshwater species. This was accompanied by additional measures reporting the percentage of species in each of five classes of change (strong increase, moderate increase, little change, moderate decrease, strong decrease) since 1970 and over the most recent 10 years. Note the start date for this indicator (1994) is later than that reported for the UK (1970), due to the lack of robust bird trend data prior to 1994. The indicator was based on trends in moths (175 species), birds (143), butterflies (25) and mammals (9).
    - Average change in species' distribution since 1970, based on trends in occupancy of 2,970 terrestrial and freshwater species. As above, this was accompanied by a breakdown of species' trends into five categories. It was based on a broad suite of taxonomic groups including vascular plants, bryophytes and many invertebrate groups.
    - The percentage of species that occur in Scotland that are considered threatened with extinction from Great Britain, based upon formal IUCN threat assessments for 6,413 species. Note that these are not Scotland-specific assessments, as most taxonomic groups assessed have only been done so at the British-scale. Therefore, for some species the assessed risk of extinction may be due largely to factors outside of Scotland.
    - A range of measures were included in the report to illustrate change in marine biodiversity, but no single headline metric was created. Measures of change in demersal fish abundance (separated into the Greater North Sea and Celtic Seas) and an index of breeding seabird numbers in Scotland were shown.

3.3 England

29. The Department for Environment, Food & Rural Affairs published their 25-year Environment Plan for England in 2018 (Defra, 2018b). This sets out the Government's ambitions 'to help the natural world regain and retain good health' in England, through delivering 'cleaner air and water in our cities and rural landscapes, protect threatened species and provide richer wildlife habitats'. One of the goals of the plan is 'thriving plants and wildlife', achieved through a growing and resilient network of land, water and sea that are richer in plants and wildlife. Defra have recently consulted on proposed metrics to measure progress against the Environment Plan goals (Defra 2018c). An indicator framework was published in Spring 2019, including many relevant to biodiversity:
    - B7: Health of freshwaters assessed through fish stocks
    - C2: Percent of seabed subject to high pressure from human activity, based around measures of intensity of human activity.
    - C3: Diverse seas: Mammals, birds, fish, based around abundance and occupancy.
    - C4: Diverse seas: condition of seafloor habitats.
    - C5: Diverse seas: condition of pelagic habitats.
    - C6: Diverse seas: threatened and declining features conserved, derived from the status of the individual features.
    - C9: Healthy seas: sea-floor habitats functioning, derived from combining indicators of individual habitats and selected vulnerable habitats.
    - D1: Quality, quantity and connectivity of (terrestrial) habitats
    - D2: Condition of protected sites - land, water and sea, based around criteria on extent and condition
    - D3: Area of woodland
    - D4: Abundance and/or distribution of widespread species (birds, butterflies, bats, plants) of farms, woods, wetlands and coasts.
    - H18: Healthy Seas: fish & shellfish populations and marine food web functioning. Indicator still in development, type unclear.
    - D5: Status of our native species, based around changes in IUCN regional Red List assessments.
    - D6: Abundance and distribution of priority species, as specified based around abundance and occupancy.
    - D7: Species supporting ecosystem functions. Indicator still in development, type unclear.

30. Unlike for Scotland, there was not a separate State of Nature report published for England in 2019, but a section within the UK report (Hayhow *et al.* 2019) gave England-specific versions of the UK headline metrics. These were:

- Average change in species abundance since 1970, based on trends in 241 terrestrial and freshwater species. This was accompanied by additional measures reporting the percentage of species in each of five classes of change (strong increase, moderate increase, little change, moderate decrease, strong decrease) since 1970 and over the most recent 10 years.
- Average change in species' distribution since 1970, based on trends in occupancy of 5,942 terrestrial and freshwater species. As above, this was accompanied by a breakdown of species' trends into five categories. It was based on a broad suite of taxonomic groups including vascular plants, bryophytes and many invertebrate groups.
- The percentage of species that occur in England that are considered threatened with extinction from Great Britain, based upon formal IUCN threat assessments for 7,615 species.

3.4 Wales

31. The environmental commitments made by the Welsh Government are outlined within the Environment (Wales) Act 2016, the State of Natural Resources Report (NRW 2016), the Wellbeing of Future Generations (Wales) Act 2015 and the Nature Recovery Plan for Wales (Welsh Government 2015). The latter sets out how Wales intended to address Convention on Biological Diversity commitments for 2020 and beyond, by tackling the underlying causes of biodiversity loss through putting nature at the heart of decision-making, increasing the resilience of the natural environment and taking action for habitats and species. It aims to 'reverse the decline in biodiversity, for its intrinsic value, and to ensure lasting benefits to society'.

32. Under section (10)(1) of the Well-being of Future Generations (Wales) Act 2015, the Welsh Ministers must publish national indicators (46 in total) to measure progress towards their Well-being goals. These Welsh national indicators must be 'expressed as a value or characteristic that can be measured quantitatively or qualitatively against a particular outcome'. Two relate to the health and status of biodiversity:

- National Indicator 43 assesses the Area of healthy ecosystems in Wales. This is an extent/area-based measure and is defined as the extent of semi-natural habitat in Wales (NRW 2018).

- National Indicator 44 aims to assess the 'status of biological diversity in Wales'. It is currently unknown what this indicator will represent as work has been commissioned by the Welsh government, through the Environmental and Rural Affairs Monitoring and Modelling Programme, to explore the potential of the available biodiversity data, primarily terrestrial, to develop an appropriate national indicator. This remains in development (NRW 2016).

33. Unlike for Scotland, there was not a separate State of Nature report published for Wales in 2019, but a section within the UK report (Hayhow *et al.* 2019) gave Wales-specific versions of the UK headline metrics. These were:
    - Average change in species abundance since 1970, presented separately for breeding birds, wintering waterbirds, butterflies and mammals. As the availability of species trends was strongly biased towards birds, it was felt a single metric across the 160 species for which trends were available would be misleading, so a headline metric was not created.
    - Average change in species' distribution since 1970, based on trends in occupancy of 2,977 terrestrial and freshwater species. As with other State of Nature headline indicators, this was accompanied by a breakdown of species' trends into five categories. It was based on a broad suite of taxonomic groups including vascular plants, bryophytes and many invertebrate groups.
    - The percentage of species that occur in Wales that are considered threatened with extinction from Great Britain, based upon formal IUCN threat assessments for 6,500 species.

3.5 Northern Ireland

34. Valuing Nature: A Biodiversity Strategy for Northern Ireland to 2020 outlines Northern Ireland's ambitions to halt biodiversity loss, through identifying a number of high-level challenges which will require particular attention (DOENI 2015). The Department of Agriculture, Environment and Rural Affairs publish a range of official statistics covering agriculture, environment, rural communities, food, animal health, fisheries and forestry in Northern Ireland. Six of these relate to biodiversity (DOENI 2018):
    - Area of nature conservation designations, based around extent
    - Condition of features within Areas of Special Scientific Interest (ASSIs), percentage based on a six-year rolling programme of condition assessments
    - Land under favourable management, percentage based around "favourable conservation status"
    - Marine under favourable management, percentage but definition of favourable is currently unclear.

- Wild birds – abundance-based measure
- Wetland birds - abundance-based measure

35. Unlike for Scotland, there was not a separate State of Nature report published for Northern Ireland in 2019. A section within the UK report (Hayhow *et al.* 2019) gave Northern Ireland-specific measures, although the constraints of data availability in Northern Ireland (largely due to the smaller size of the country) presented difficulties. The measures presented were:
    - Average change in species abundance since 1988, presented separately for breeding birds, wintering waterbirds, butterflies and mammals. As in Wales, the availability of species trends was strongly biased towards birds, hence it was felt a single metric across the 91 species for which trends were available would be misleading and a headline metric was not created.
    - There was insufficient data to produce an indicator of average change in species' distribution as published for the UK's other countries.
    - The percentage of species that occur in Northern Ireland that are considered threatened with extinction from the whole of Ireland, based upon formal IUCN threat assessments for 2,450 species.

3.6 Outside the UK

36. Whilst we do not intend to provide a comprehensive review of how biodiversity indicators are used to meet reporting requirements at multiple scales outwith the UK, here we reflect on approaches used at the spatial scales (regional, global) in which Scotland and the UK are nested. The EU's Biodiversity Strategy sets out targets to halt the loss of biodiversity and ecosystem services in the EU and help stop global biodiversity loss by 2020 (European Commission 2012). A range of Streamlined European Biodiversity Indicators (SEBI) have been developed to measure certain keys aspects of the natural world relevant to the Biodiversity Strategy targets (European Union 2019):
    - SEBI 01 Abundance and distribution of selected species: Common farmland birds and grassland butterflies.
    - SEBI 03 Conservation status of species of European interest by documenting changes in favourable or improving conservation status.
    - SEBI 04 Ecosystem coverage. coverage of ecosystem classes under the EU 'Mapping and Assessment of Ecosystems and their Services' (MAES) framework
    - SEBI 05 Conservation status of habitats of European interest, by documenting changes in favourable or improving conservation status.
    - SEBI 07 Nationally designated protected areas- changes in total area

- SEBI 13 Fragmentation of natural and semi-natural areas- changes in artificial and agricultural surfaces and forest connectivity.

37. The Convention on Biological Diversity mandates governments to report on the state of biodiversity on a national scale, and the JNCC indicators previously described have primarily been developed in the UK for this purpose. Other countries have developed similar suites of indicators although the approaches employed vary.

38. The Biodiversity Indicators Partnership is a global initiative to promote and coordinate the development and delivery of biodiversity indicators for use by biodiversity-related conventions, including CBD (www.bipindicators.net). For Aichi targets 5 (Habitat loss, degradation and fragmentation), 6 (sustainable fisheries), 7 (on the sustainable management of areas under agriculture, aquaculture and forestry) and 12 (on the conservation status of threatened species) they promote many of the same primary indicators previously mentioned in relation to the UK and its constituent countries, e.g. those based on species status assessments, abundance and distributional indices, extent and condition of habitats and protected sites. However, it does highlight other approaches such as Biodiversity Habitat Index, Biodiversity Intactness Index, Wildlife Picture Index, Marine Trophic Index, proportion of fish stocks within biologically sustainable levels, MSC certified catch, and area of forest under sustainable management: total forestry managed under certification by Forestry Stewardship Council and Programme for the Endorsement of Forest Certification. Many of these are discussed in more detail below.

39. A variety of indicators are used by individual countries to report on progress towards Aichi targets. Table 1 indicates the range of indicators used by a selection of six countries to report on Aichi targets 5, 6, 7 and 12.

40. As well as the indicator types similar to those used for reporting within the UK's four countries (as described above), there are a few different approaches. In the Netherlands, a Living Planet type index has been developed (although not adopted by government), which describes changes in the status of 361 animal species from 1990-2014 (van Strien *et al.* 2016). This indicator is a composite metric spanning trends in both abundance and species' occupancy - see below for further discussion on such approaches (e.g. paragraph 94). In Norway a 'Nature Index' is used (e.g. Certain *et al.* 2011, Aslaksen *et al.* 2015), which incorporates assessments of biodiversity status derived from both quantitative measurement and from expert assessments in order to create a series of indicators for different ecosystems. Each indicator measures distance from a reference state (whereby a

value of 1 indicates an undisturbed or perfectly sustainably managed state, and a value of 0 indicates complete degradation), and these indicators are then combined to produce the overall Nature Index.

Table 1: Biodiversity indicators used to measure progress against Aichi target 5 (Habitat loss, degradation and fragmentation), 6 (sustainable fisheries), 7 (on the sustainable management of areas under agriculture, aquaculture and forestry) and 12 (on the conservation status of threatened species) for six example countries (*https://www.cbd.int/reports/*).

Indicator type	Nether-lands	Canada	South Africa	Norway	Sweden	China
Species abundance index	5, 6, 7, 12	12				
Species status assessments	12	6, 12	6	5, 6, 12	5, 12	
Red List index			6, 12			6, 12
Defined habitat status and condition		5, 7		5, 6, 12	5, 12	5, 7
Nature index				7		
Living planet index						12
Protected area extent or status		6, 7	5		5, 7	
Defragmentation of nature	5					
Sustainable forestry	7	5, 7			5, 7	
Forest regeneration		5, 7				
Timber stocks		5, 7				5
Net primary productivity of forest ecosystems						5
Proportion of organic farming area	7					7
Total fresh grass output from natural grasslands						7

Table 1 continued

Indicator type	Nether-lands	Canada	South Africa	Norway	Sweden	China
Livestock overload rate of natural grasslands						7
Wildlife habitat capacity on farmland		5, 7				
Area of agri-environment schemes	7					
Environmental farm planning on agricultural land		5, 7				
Sustainable fisheries		7				
Barriers to fish migration	5					
Marine trophic index						6
Marine biodiversity index						6
Area covered by fishery no-take zones						6
Water management				7		
The number of plant species with ex situ collections active in restoration programmes			5			
Environmental bottlenecks	12					
Expert opinion			6, 7		5, 6, 7, 12	

41. At a global level, the Living Planet Index (LPI) has been adopted by CBD as an indicator to measure progress against the 2020 target to 'take effective and urgent action to halt the loss of biodiversity' (www.livingplanetindex.org). This is a collation of population (e.g. abundance) time series covering over 22,000 populations of 4000 terrestrial, freshwater and marine species. This is however, restricted to vertebrates and excludes all other taxonomic classes (Collen *et al.* 2009, WWF 2018).

3.7 Summary

42. This chapter reviews the use of biodiversity indicators for governmental assessments of progress towards biodiversity objectives in Scotland, elsewhere in the UK, and internationally. Most nations either publish or are developing biological indicators that assess the condition of specific aspects of the natural environment. The approaches adopted are diverse, but most fall into one of three definitions: the average trend in a measure of species' status (e.g. abundance); species status assessments often based around the IUCN Red List process; extent and condition of protected sites, habitat and ecosystems. The use of indicators showing the average trend in a measure of species' status is widespread, understood and accepted within the UK including within the indicators intended to measure progress against the Scottish Biodiversity Strategy. These existing indicators cover a range of measures encompassing some of Scotland's most valued biodiversity, and collectively give a valuable overview of trends in nature.

43. The State of Nature reports at a UK (Hayhow *et al*. 2019) and Scotland scale (Walton *et al*. 2019) published government-endorsed high-level metrics of the status of biodiversity that are reasonably robust and credible measures of change. However, these reports did not publish a single headline indicator.

44. This approach is consistent with that used by the UK and national governments in the UK, which is based on suites of complementary indicators rather than a single synoptic headline indicator, with a range of indicators being used to reflect various aspects of change, and progress towards various goals dictated by national or international policies. To our knowledge, no other country uses a single high-level metric to report on the status of biodiversity as is proposed for Scotland.

4. Overview of main biodiversity indicator types

4.1 Abundance and occupancy-based indicators

45. The main and most frequently-used biodiversity indicator types are those based on changes in either abundance or occupancy (a measure of geographic range size) usually accompanied by a measure of precision. These indicators can be used at a single population or species level but are often combined to form multi-species/taxa composite indicators. It is, however, worth noting that creating composite indicators using measures of change in both abundance and occupancy does create problems, as these measurement 'currencies' are not directly comparable and vary in a number of ways. This is discussed in more detail in section 5.1.

46. Both indicator types are often presented as a line on a graph and tend to rely on data from established long-term monitoring and recording schemes. Examples of abundance-based indicators include the:
    - Indicators for terrestrial birds, seabirds and wintering waterbirds in Scotland,
    - Living Planet Index,
    - UK Indicator C4a. Status of UK priority species- relative abundance,
    - UK Indicator C6: Insects of the wider countryside (butterflies),
    - UK Indicator C8: Mammals of the wider countryside (bats),
    - European Wild Bird Indicator (derived from the Pan-European Common Bird Monitoring Scheme, PECBMS).

47. Occupancy-based models form the basis of UK indicators on Priority Species (C4b) and Pollinating Insects (D1c), as well as nearly one third of species on the Living Planet Index of the Netherlands (van Strien *et al*. 2016). In the marine environment, trends in abundance or occupancy of certain marine species have been adopted as indicators in their own right, including abundance of grey and harbour seals, and of certain cetacean species, seabirds, and sensitive fish species (OSPAR 2017a, b, c, d).

48. Most published abundance-based metrics are composite multiple species trends. The creation of these involves two analytical steps; firstly, the production of annual population indices for each individual species (or, in some cases, a more categorical index, e.g. 'recovered / not recovered') and then combination of these indices into the grouping required to form a composite indicator.

4.1.1 Single species indices

49. There are several different analytical approaches to the creation of single-species indices. Many of the annual indices produced in the UK use the following statistical modelling technique (Eaton & Noble 2018, Boughey & Langton 2017) - Generalised linear models (GLMs), with full site and year effects, a log-link function, and Poisson error term to deal with the distribution of count data. At an international level, the species trends incorporated in the WWF Living Planet Index (LPI) are created using a different statistical framework. Generalised additive models (GAMs) are used to identify underlying trends in different population time-series, and these are in turn used to calculate average rates of change at a species level (WWF 2018).

50. The single-species indices resulting from such analyses are frequently smoothed before use in composite indicators. This process brings benefits, by removing short-term 'noise' that may be caused by sampling error or minor fluctuations due to, for example, weather effects; smoothing can provide a clearer measure of the underlying trend. The smoothing procedure can thus influence the assessments of change over particular periods as well as the confidence in these estimates.

51. A number of smoothing methods are available. For the UK bird and bat indicators a post-hoc smoothing spline equivalent to the application of statistical models (GAMs) is used (Eaton & Noble 2018, Boughey & Langton 2017). GAMs are a non-parametric technique in which the population trend can be set for any degree of smoothing by altering the degrees of freedom (d.f.) used in the calculation of the model. If the d.f.'s are set to one, a model in which abundance follows a linear function of time is produced (i.e. a straight line), whilst if the d.f.'s are set to equal the number of years in the time series, a model is created in which the estimates for consecutive years are simply joined (equivalent to no smoothing) (Eaton & Noble 2018).

52. Abundance indices can then be generated for each species, indexed to a value of 100 (1 is sometimes used - both options are appropriate for ease of comprehension) in a baseline year. These indices report relative changes in abundance: a rise from 100 to 200 reflects a doubling in numbers, a decline to 50 a halving, relative to numbers in the baseline year (Eaton & Noble 2018). Species indices are often presented in both smoothed and unsmoothed forms; however, assessments of change over set periods are usually based on the smoothed version. Smoothing does, however, mean that the estimates for the final year of a trend must be treated with caution as they lack the smoothing effect of data in

subsequent years. The nature of smoothed trends, in that data from any given year has an impact on trend values for earlier (and later) years means that existing species indices (and hence indicator) values will be different in subsequent annual revisions (Eaton & Noble 2018). Unsmoothed indices are often used to measure change over the final year of a trend sequence.

53. Confidence limits around species trends are usually generated by bootstrapping; i.e. repeated resampling (with replacement) to generate a sample of estimated trend values, with the 2.5% and 97.5% percentiles giving the 95% confidence limits around the trend value for each year (Efron 1982). Some data sources do not allow the calculation of error in the trend estimate due to the structure of the data collected (e.g. from non-randomly survey sites, and sites of differing size); for instance, Wetland Bird Survey (WeBS) and Seabird Monitoring Programme.

54. Depending on the purpose of individual indices, alternatives to these continuous trend approaches may be used. For instance, in demersal fish species, an aim under the MSFD has been to determine whether species are recovering, or are not undergoing further decline, as a response to management efforts. To this end, the whole time series of a survey has been used as the reference period, and a species is classified for an assessment year based on whether its abundance falls in the top 25th percentile of all recorded abundances (recovery), or above the bottom 25th percentile (no further decline) (Greenstreet *et al.* 2012). This shows that similar data have been processed in contrasting ways depending on specific policy and management objectives.

55. Recently, species indices have been created from presence-only biological records. Species trends from such data are robust if analysed appropriately, for example using Bayesian occupancy-detection models (Isaac *et al*. 2014). The application of this approach in the UK has used data from national recording schemes held by the Biological Records Centre (BRC); these records are verified by species experts. Datasets are compiled into species assemblages, such as all species of bee, and records from the same date and 1-km^2 square (records at a coarser spatial scale are excluded from analysis) are considered to constitute ‘site visits’ and the number of species for each site visit calculated as ‘list length’ – a measure of effort. A Bayesian occupancy-detection model is then fitted for each species, using two hierarchically coupled sub-models: one models occupancy (i.e. presence versus absence of each site-year combination), and the other models detection (i.e. recorded versus not-recorded on each visit). Since true occupancy is unknown, this form of occupancy-detection model is of a class of statistical models known as ‘hidden process’ or ‘state space’ models. The ‘list length’,

defined above, is used as an estimate of sampling effort. The ‘season’ (also known as the closure period) in these models is the year (i.e. occupancy for each year, using all the recording visits that took place during that year, is estimated). Recent implementations of occupancy-detection models have enabled the approach to be used for species with sparser datasets than previously, meaning that occupancy trends can be produced for more species in more taxonomic groups, and reduces problems of under-representation of rarer species in the data. This development uses prior distributions in a Bayesian framework, which allow the probability of occurrence at a site in a given year to inform the probability of occurrence at that site in subsequent years, in a biologically plausible manner and can produce trends even where available data are sparse (Outhwaite *et al*. 2018).

4.1.2 Multi-species composite indicators

56. Once single species indices are created, multi-species indicators can then be calculated. The approach used for UK birds, bats and butterflies is outlined in Gregory *et al.* (1999) and use the geometric mean of the constituent species indices. Using the geometric mean means that a doubling in the population index of one species is balanced by a halving of another (Buckland *et al*. 2005). Methods for the creation of such indicators are discussed in more detail in section 5.1.

57. As with the species indices, some existing biodiversity indicators exist in both smoothed and unsmoothed forms. Where the species data are already smoothed (e.g. using a GAM), the gains from additional smoothing procedure may be limited. An alternative is to smooth the headline indicator, rather than the constituent species indices. The Multi-Species Indicator (MSI) tool developed by Statistics Netherlands (Soldaat *et al*. 2017) does this: it is used to create supranational indicators such as those produced by the Pan-European Common Bird Monitoring Scheme (e.g. Klvanova *et al.* 2009). A similar method has recently been developed at the Centre for Ecology & Hydrology (Freeman *et al.* 2020; see paragraph 139 for further detail), with the specific purpose of creating smoothed headline indicators from diverse datasets containing missing values. Both the MSI and the Freeman method are implemented in a Bayesian framework and make it possible to account for uncertainty in the species index values.

58. Marine indicators have again developed in a related but somewhat different way, reflecting the trends-based targets set by the MSFD and other drivers. For instance, in the demersal fish index individual species have been classified by their recovery status, and then this is summarised across species as simply the number (or proportion) of species meeting the relevant target (Greenstreet *et al.* 2012).

59. Composite indicators tend to give equal weighting across the species included. However, the use of weighting can bring benefits, such as addressing any biases within the availability of species trends relevant to the indicator. For example, we know that despite great strides in the availability of biodiversity data within Scotland, the trends available for indicator construction will not be representative of terrestrial and marine biodiversity as a whole. Potential sources of bias that might be addressed through the use of weighting include:

- Taxonomic bias – for instance, trend data will be available for more vertebrates than invertebrates, and within invertebrates there are biases towards groups such as Lepidoptera (butterflies and moths). Burns *et al*. (2018) investigated the impact of weighting upon indicator outputs and found the impact of controlling for taxonomic bias through weighting was sensitive to the taxonomic level (i.e. phylum or kingdom) at which weighting was deployed.
- Habitat – due to issues such as ease of access, there are disparities between the volumes of data available for species within different habitats. This presents two issues, in that trends for individual species may be biased towards certain habitats (although this can be addressed within trend analyses), and the species composition within indicators may be biased towards those using widespread and accessible habitats (e.g. montane species may be underrepresented). This could be particularly relevant to combining terrestrial and marine elements of a combined indicator, with robust trend data likely to be available for a substantially higher proportion of terrestrial species than marine.
- Ecological function – biases might favour higher trophic levels (due to the wider interest and hence the availability of data on vertebrates), and disfavour other functional groups such as detritivores for which data are scarce or absent. Such biases can be difficult to control due to the lack of systematic data on such traits.
- Conservation status – there may be a bias in trend availability towards species of higher conservation concern such as those on the Scottish Biodiversity List (both because species are only likely to be designated as being of concern if sufficient monitoring data are available, and because designation may subsequent increase the likelihood of monitoring). Whilst species of concern may be faring more poorly than those not, designation as a conservation priority means a species is more likely to become the recipient of targeted conservation action.
- Commercial importance - in marine systems, species that are commercially exploited in fisheries are often surveyed more systematically than unfished species.

- Abundance – sample sizes, which influence the ability to produce trends, may be larger for widespread and abundant species leading to a bias.

60. Even apparently simple issues, such as addressing taxonomic biases in data availability, can present difficult decisions. Weighting can be used to correct biases in the availability of species trends for example to upweight the contribution of under-sampled taxonomic groups, although it cannot correct for biases in instances where no data is available at all. The impact of such an approach will vary, however, depending at what taxonomic level (e.g. family, order) weighting is conducted (Burns *et al*. 2018). Such an approach will also perpetuate imbalances caused by some taxonomic groups being more biodiverse than others. If, for example, we had data for all of Scotland's naturally occurring species, the impact of changes in vertebrate population upon a composite indicator would be minute, unless a weighting approach was employed to control for the greater diversity within some taxonomic groups. Conversely, we may need to address how to incorporate data reported at an amalgamated level – for instance, trends from long-term monitoring of zooplankton, an important measure of marine ecosystem health, are not available at the species level.

61. The best available data sources for some species do not allow indices to be produced for the complete time period required for a composite indicator; in such cases, provision must be made to allow species to drop into and out of the indicator according to data availability. If the indicator is set to a baseline year before the entry date of such species (e.g. if it is baselined to its start year) then they can be entered into the composite indicator at the mean value of the indicator for the year in which they enter. This ensures that the addition of new species does not have an artificial impact upon the composite indicator (Noble *et al.* 2004). Similarly, protocols are available to deal with species indices that do not run to the final year of an indicator (Eaton & Noble 2018).

62. Composite indicators, an aggregation of individual species indices showing average trends, can hide a large disparity in the fortunes of the constituent species. Increases and decreases in individual species can balance each other out, leading to a relatively stable index over time. However, additional supporting information, such as categorical change and ratio values outlined by Eaton & Noble (2018), can be produced to inform on this in addition to the publication of the disaggregated data.

63. Indicators based on Bayesian occupancy-detection models follow similar procedures. The headline statistic measures changes in the geometric mean occupancy across species. Uncertainty around the headline value is

straightforward to calculate in a Bayesian context, since the species indices are presented as a distribution of estimates, rather than a point. Moreover, the relationship between data and model permits an intuitive interpretation of the uncertainty. For example, if 95% of the credible estimates are in one direction (e.g. a decline) then we can be 95% confident that species in the indicator have declined, on average.

64. In the creation of any indicator based upon multiple species trends, proper consideration must be given to ensuring constituent trends are of sufficient quality as to ensure the robustness of the resulting indicator. The UK's existing biodiversity indicators rely mainly upon data that originates from well-established long-term monitoring schemes (e.g. the UK Breeding Bird Survey www.bto.org/volunteer-surveys/bbs and the UK Butterfly Monitoring Scheme www.ukbms.org/). Such schemes employ rigorous stratified random sampling design, strict standardised protocols around survey methods and use quality assurance procedures relating to data collection, data collation, verification, storage, trend analyses and composite indicator construction. This allow statistical corrections to be applied to counter spatial and other biases. Even where schemes incorporate a non-random sampling approach (e.g. due to the aggregated nature of the species being monitored such as in the Wetland Bird Survey https://bto.org/our-science/projects/wetland-bird-survey and the Seabird Monitoring Programme https://jncc.gov.uk/our-work/seabird-monitoring-programme/) temporal changes in population abundance can still be estimated by repeat coverage of the same sites (Eaton & Noble 2018). Even so, the trends derived from such data sources need to be screened for suitability, although approaches used to do so differ between indicators, variously using factors such as timescale, frequency of update, sample size, precision and concerns over bias to screen species data.

65. Information on species abundance, such as that collected by many of our long-established biodiversity monitoring schemes, represents the highest quality data for the creation of biodiversity indicators; however, in practice, they cover a relatively small proportion of the total number of species found in the UK. Many taxonomic groups, particularly invertebrates, are poorly represented. Opportunistic biological records, collected in relatively unstructured ways, are increasing being used to explore trends in a greater range of species (e.g. Hayhow *et al*. 2016, 2019). Statistical methods to account for biases caused by sampling effort, spatial coverage and detectability, are being developed to provide robust estimates of occupancy over time (Isaac *et al.* 2014, Outhwaite *et al.* 2018). Thus, the quality of the data on species indices is a function of both the availability of raw data and the statistical techniques used to analyse them.

4.2 Red List Indices

66. The IUCN Red List (www.iucnredlist.org) is widely accepted as a robust system for assessing the conservation status of species, specifically with regards to their risk of extinction. A standardised set of criteria, using quantitative thresholds based on population size, population trends and area of distribution, enable species to be assigned to a category based on relative risk of extinction. These categories range from Least Concern, through Near Threatened and then three categories of threat (Vulnerable, Endangered, Critically Endangered) as well as Extinct, Extinct in the Wild and Data Deficient (IUCN 2012a).

67. Whilst other systems of assessing conservation status (e.g. *Birds of Conservation Concern* for birds in the UK, Eaton *et al*. 2015a) exist, none have the universal applicability of the IUCN Red List. Whilst there are challenges in ensuring the uniform applicability of the IUCN assessment process to different taxonomic groups, differing levels of data availability, and different spatial scales, the system is designed to enable application in all circumstances. While originally developed for use at a global scale, the development and subsequent refinement (IUCN 2012b) of guidelines for the application of the Red Listing process at a regional scale has resulted in a proliferation of Red Lists at continental (e.g. for birds in Europe, BirdLife International 2015) and national (e.g. Stanbury *et al*. 2017a) scales; this regional process is designed to be used at any spatial scale although concerns have been raised about the validity of the process at smaller spatial scales (e.g. Charra & Sarasa 2018). The regional assessment process is two-stage, with the first stage applying the global assessment process, followed by a second stage considering the impact of populations of the same taxon found outside the region of interest, e.g. whether such populations offer the possibility of a ‘rescue effect’ and so reduce the extinction likelihood within the region itself. Within the UK, regional IUCN assessments are generally applied for Great Britain, and/or all-Ireland, as these are more appropriate biogeographic units than the political area of the UK. At present approximately eight thousand species (http://jncc.defra.gov.uk/page-3352) have IUCN Red List assessments for Great Britain, although as yet none of these have been assessed more than once using the modern regional Red List process. No assessments have been conducted at a Scotland-only scale, although for a small number of species that only occur in Scotland within Britain, British-scale assessments are de facto Scottish assessments.

68. The Red List Index (RLI) uses available IUCN Red List assessments to measure overall trends in extinction risk for given sets of species and geographical areas, based on the number of species in the different categories of extinction risk

(Butchart *et al*. 2007). Initially developed for use at the global scale, the RLI can also be calculated for any spatial scale that assessments are available, and for any given taxonomic group or combination thereof.

69. The RLI is calculated by multiplying the number of species in each Red List category by a category weight, summing the products of this across all categories, and then expressing this as the proportion of the maximum possible product, whereby a RLI value of 1.0 equates to all species being of Least Concern. The lower a RLI value falls below 1.0, the greater the level of extinction risk across the species included in the index. In order to be of value as a measure of change in extinction risk through time, the RLI requires species to be reassessed for extinction risk at intervals – it can be calculated for any group of species that have been assessed at least once. It is important that the RLI reflects genuine change, either in the form of improvement or deterioration in extinction risk; however, changes in assessed risk are frequently due to revised knowledge, and these need to be excluded from the calculation.

70. At present global RLIs are published for birds, mammals, amphibians, reef-forming corals, and cycads. Given the uneven taxonomic spread no attempt has been made to combine these into an overarching indicator. An initiative to broaden the taxonomic spread of repeated assessments by sampling species from a wide range of taxonomic groups, such as dragonflies, fish, dung beetles and monocotyledonous plants (grasses, lilies, orchids etc.) is intended to enable the production of a more representative Sampled Red List Index (SRLI), although the relative scarcity of Red List assessments of marine species (Webb & Mindel 2015) may limit use of the SRLI as a fully integrated biodiversity indicator.

71. The RLI approach has been widely accepted as suitable for measuring and reporting changes in biodiversity status at a high level, and is particularly suited for assessing progress towards target 12 of the Aichi 2020 targets, which states “By 2020, the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained”. Global RLI are used for reporting progress towards this target (Secretariat of the Convention on Biological Diversity 2014) as well as progress at a national level, aided by specific guidance (Bubb *et al*. 2009). The use of Red List criteria which are designed to be used even in the absence of robust species data (e.g. abundance trends) means the RLI can be calculated for geographical areas and taxonomic groups for which such data are scarce, given sufficient time for repeat assessments to be made. There are, however, shortcomings, with RLI being relatively insensitive to change (given the coarse level of resolution –

species can undergo very considerable status change without changing Red List category), and having low temporal resolution, given the often long periods between species being assessed.

4.3 Diversity metrics

72. The role of anthropogenic pressures in perturbing the dynamics between different species within communities has long been recognised, and so 'diversity' metrics are well-established to measure changes in the relative abundance of species. Indices such as Shannon, modified Shannon and Simpson's are used to measure changes in community structure, often on local sites (e.g. for specific communities).

73. Simpson's index (Simpson 1949) is a diversity metric which accounts for both the number of species and their abundance. If d_{ij} is the number of individuals in the system (abundance) in year j that belong to species i and $p_{ij} = d_{ij} / \Sigma_i d_{ij}$ the proportion of them from all species. Simpson's index is then $Dj = \Sigma_i p^2_{ij}$. The transformed index $- log_e D_j$ is used as a diversity metric, with low values indicating dominance of a few species, high values meaning higher evenness of population sizes. The Shannon index (Shannon 1948) is a similar diversity metric, again with low values when a few species dominate and high values when none do. It is defined as $H_j = - \Sigma_i p_{ij} \, log_e(p_{ij})$. If, however, all species increase and decrease with a similar rate (and thus any unevenness remains the same), both Simpson's and Shannon's indices would remain unchanged – not ideal if they are intended for use as indicators of changes in biodiversity. Buckland *et al.* (2005) proposed a modified Shannon index to address this, whereby abundances of species in all years are divided by the summed abundances of all species in year one.

74. Such measures are typically used to make spatial comparisons, rather than measure trends through time, but diversity indicators could be of considerable use in measuring the impact of drivers of biodiversity change such as landscape-scale degradation, which can result in generalist species increasing whilst specialists (often in habitat use, although niche breadth can be defined in other ways) decrease. Buckland *et al.* (2017) reviewed approaches to measure diversity change over time and proposed that measures that consider turnover between species (e.g. Yuan *et al*. 2016), rather than simply diversity, might be most appropriate for measuring changes arising from the impact of anthropogenic drivers.

75. Various measures of diversity and community composition have been adopted as indicators in marine systems. For instance, Rombouts *et al.* (2019) present a test of measures of phytoplankton community change, incorporating both changes in alpha diversity as well as temporal change in community composition. In marine fish communities, size structure is often considered a useful indicator of community composition, with indices such as the Large Fish Indicator (proportion of individual fish that are over some nominal size, e.g. 30 cm) being widely employed as a simple measure of how fish community structure and diversity changes through time (e.g. Greenstreet *et al.* 2010, Mindel *et al.* 2018).

4.4 Biodiversity Intactness Index

76. The Biodiversity Intactness Index (BII) was first proposed in 2005 (Scholes & Biggs 2005) as an attempt to quantify loss of biodiversity compared to 'intact' pre-modern abundance levels, by measuring change at the site rather than species level. This is done by combining estimates of local abundance with data on land use and other anthropogenic pressures in order to model likely abundance levels, and compare these to predicted intact abundance, using fine-scale (1-km) remote-sensed datasets of these pressures. Subsequent development and massive data collation have enabled the production of global indicators of BII (Newbold *et al*. 2016), with further refinements of methods (Purvis *et al*. 2018). The method is scalable, meaning that indicators can be produced at any spatial scale given sufficient data; for example, estimates for BII in the UK's four countries were presented in Hayhow *et al*. (2016). At the global scale the BII has been adopted at a high level, including by the Intergovernmental Platform on Biodiversity and Ecosystem Services as an indicator of progress towards CBD Aichi targets 12 and 14. However, there is considerable debate about the robustness of the BII, with concerns about its precision at smaller spatial scales, and evidence that it substantially underestimates loss compared to intact levels (Martin *et al*. 2019).

4.5 Essential Biodiversity Variables

77. Essential Biodiversity Variables (EBVs) are a recent concept (Pereira *et al.* 2013), modelled on the existing Essential Climate Variables, and are intended to serve as the minimum set of parameters required to be measured for the robust monitoring of biodiversity status at a national scale, and by amalgamation at a global scale. If such a suite of measures could be identified and agreed upon at a global scale they would serve as the basic units with which to study, report and manage biodiversity change, and thus would inform the development of global indicators and enable a harmonised monitoring system to be developed.

78. At present, six classes of EBV have been identified – genetic composition, species populations, species traits, community composition, ecosystem function and ecosystem structure. Between two and six potential EBVs have been suggested for each of these classes. For example, the species populations class includes the suggested EBVs of species distribution, species abundance, and population structure by age/size class.

79. An ideal EBV should be: able to capture critical scales and dimensions of biodiversity; biological; a state variable; sensitive to change; ecosystem agnostic; technically feasible; economically viable; and sustainable in time (GEO BON 2017).

80. EBV's are themselves not indicators, but could be regarded as the building blocks of indicators, and a common currency on which to base biodiversity indicators. Whilst an interesting concept for structuring the requirements for the monitoring and reporting of biodiversity change, further development is required before EBV's offer a practical approach to reporting at an overarching level.

4.6 Non-species metrics

81. It could be argued that there is no place for non-species-based metrics in the development of a combined biodiversity indicator, as an indicator measuring change in biodiversity should be based on the status (e.g. population trends) of species.

82. Measurements of biodiversity can be made at more than one level, with genes, species, and ecosystems being the most typically employed scales. The indicator approaches reviewed so far are those that consider species' status as the basis for measuring change in biodiversity, and this is the commonest approach in usage, and likely to be most appropriate for the purpose of a biodiversity indicator for Scotland. However, biodiversity varies below species level, in the genomes and genotypes of individuals and populations, and can be considered at the broader scale of ecosystems; communities of individuals of multiple species that coexist and interact within a given area.

83. Indicators at genetic and ecosystem scales are not as well developed as those for species, and have not been adopted as high-level measures of biodiversity status. Many questions remain: for example, there is no consensus over how best to measure genetic diversity e.g. whether to measure diversity in genotypes, or in

genomes. At present most developments have focussed on indicators of commercially-valuable genetic variation in livestock or crop plants, such as indicator C9a of the UK Biodiversity Indicators, which describes trends in rare and native breeds of farm animals.

84. Despite the greater suitability of species-based metrics, there are circumstances where such non-species information could be useful. Non-species metrics may:

- act as proxy measures for biodiversity, if these are appropriately backed by studies that relate biodiversity impacts to the measured metric. For instance, measures of habitat areas subject to nitrogen deposition above their critical loads provides information regarding both the impacts of pollution on species and on ecosystem processes. There is, however, less information available concerning lag times for recovery, so current deposition levels may not be reflective of current biodiversity trends. Habitat area in itself can be a useful metric, though there is an inherent problem in relating area to habitat quality and hence biodiversity.
- partially counter the taxonomic bias of some aggregate metrics if backed by suitable studies showing the impact of what has been measured across taxonomic groups; for example, measures of the status of water bodies is relevant for all species within the system. However, an integrative measure cannot account for individual drivers having impacts on specific species or species groups.
- provide information concerning the balance between target/protected species and species that are out of place or invasive. For instance, habitat condition assessments generally provide information regarding both desirable and undesirable species. However, they are focussed at common species as rare species appear rarely in the habitat level sampling carried out.

85. Potential non-species metrics fall into a range of categories:

- **Area of habitat**- Potential metrics include the extent of well-defined habitats, area under agri-environment management, certified forest, grass cut for hay, fallow/set-aside, High Nature Value Farming, (inverse of) soil sealing and the area of statutory designated sites. All show correlation with biodiversity value, as areas under these types of management should have higher levels of biodiversity than similar areas managed more intensively. Correlations may, however, be weak; for example, areas cut for hay may have previously lost their characteristic hay meadow vegetation and invertebrates, or the evidence for this correlation may be lacking - Scottish data on the success of agri-environment is lacking other than for a few species (e.g. Corn Bunting, Perkins *et al*. 2011). Habitat area is the main driver of population size for many species (Fahrig *et al*.

2019) but connection/fragmentation is also important (Horváth *et al*. 2019), so a measure of habitat fragmentation would be a useful indicator of the ability of species to move through landscapes. However, all area metrics are dependent on high quality, repeatable data sources available at appropriate habitat resolution; products based on data such as the land cover map of Great Britain could be developed but are not currently available. In marine benthic systems, habitat-focused indicators have formed the basis of most assessments and are integral to both OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) and MSFD, with targets related to the distribution, extent, and condition of various key sediment, rocky, and biogenic habitats (OSPAR 2017, Defra 2014).

- **Site condition monitoring** has been a feature of designated sites (Sites of Special Scientific Interest) for many years. Initially sites were visited on a six-year cycle but recently visits have been based on a risk assessment of likely changes: for example, geological sites designated for solid geology were generally deemed low risk and visited less frequently. Site condition provides an overall assessment of the quality of the habitat assessed against a template of what a good example of that habitat should look like. However, the method has rarely been assessed in terms of how well it captures the biodiversity value of a site (MacDonald 2003) and it suffers from repeatability problems (MacDonald 2010). The proportion of natural features of designated sites in favourable condition (a combination of the three categories 'favourable', 'unfavourable – recovering' and 'unfavourable – recovering due to management change') is reported annually by SNH in an official statistics publication.
- **Water quality**- A range of water quality indicators are routinely collected from many marine and freshwater bodies, including measures of nutrients, such as phosphate and nitrate; elevated levels of which have been correlated with reduced biodiversity (e.g. Lambert & Davy 2011). Similarly, high levels of water abstraction can also have substantial impacts on biodiversity (e.g. Flavio *et al*. 2017) as can poor coastal bathing water quality. More integrative is SEPA's condition assessment of water bodies (Scotland's environment 2019), which uses data on water quality problems arising from discharges of pollution and diffuse pollution running into rivers from agricultural land and urban areas, modified river flows and river channels, barriers to fish passage and the presence of aquatic invasive non-native species.
- **Agricultural intensification** is known to have negative impacts on biodiversity (Tscharntke *et al*. 2005). Fertiliser and pesticide use are negatively correlated with biodiversity, including a strong relationship between eutrophication and plant species richness (e.g. Firbank et al. 2007) and pesticide use and bumblebee colony productivity (Goulson *et al.* 2015). However, national or

regional figures may not provide useful data for an indicator because, for example, an increase at a large spatial scale may either indicate low-level, widespread increases or substantial, localised increases.

- **Air pollution** is an important driver of biodiversity, with demonstrable effects on biodiversity in a range of habitats (e.g. Bobbink *et al*. 1998). Experimental and survey research has developed a range of critical loads; the amounts of pollution deposition above which impacts are detectable. Combining habitat and deposition maps provide an assessment of the area of habitat experiencing pollution above the level which impacts plant communities. However, as levels of pollution are currently declining, there is less knowledge of how quickly habitats recover and what potential lag times might occur before recovery is seen.
- **Invasive species** are established as a driver of biodiversity loss (e.g. Hooper *et al*. 2012), but there is little data on the impacts of most invasive species on biodiversity, except for species such rodents (Stanbury *et al.* 2017b), mink (Moore *et al.* 2003), rhododendron (Hulme *et al.* 2015) and American signal crayfish (Holdich *et al.* 2014), and, in the marine environment, species such as the Australian tubeworm and the bay barnacle (Katsanevakis *et al.* 2014) Additionally, invasive species include novel diseases such as ash dieback (Mitchell *et al.* 2014), as well as vectors of disease (e.g. the invasive crab *Rhithropanopeus harrisii* which has spread white spot syndrome to commercially harvested shrimp; Katsanevakis *et al*. 2014) where impacts may take years to develop after the first evidence of the disease. The inclusion of species, such as invasive species, as a negative contributor to a biodiversity index is attractive as it moves beyond treating all species as equivalent. Note that non-native species are excluded from most species-based indicators including existing wild bird indicators in Scotland and the UK, as trends in these species are felt inappropriate for an assessment of the status of biodiversity and, by inference, the wider environment.

86. Non-species metrics may have a role to play in the development of a biodiversity indicator, but their use in such an indicator is hindered by a number of characteristics. For example, substantially different data units are used across the various measures and changing methodologies over time may make it difficult to use some metrics, including those describing habitat condition. There may be overlap with other indicators used in the National Performance Framework, such as the Natural Capital Asset Index, so useful indicators such as those relating to water and air pollution may already be represented within the NPF suite.

87. Moreover, such indicators are as best regarded as proxies for what changes might be happening in biodiversity. Changes in such non-species metrics might reflect

changes in biodiversity as both are subject to the same drivers and might respond in the same way (for example, if the condition of protected sites deteriorates, we might expect biodiversity to also decline), or the non-species metric might be the driver of change itself (e.g. air pollution). But the relationship is rarely close: species may have a large proportion of their populations outside of designated sites, for example, or be influenced by many factors in addition to air pollution. There are exceptions, for example tropical deforestation can be taken as a good measure of biodiversity loss given the scale of the impact it has, and in the absence of robust data on biodiversity trends, such proxies would be better than nothing in informing what might be happening. In Scotland, however, there are robust measures of changes in species dating back over a number of decades which mean that resorting to the use of non-species proxies should not be necessary.

4.7 Summary

88. We have described the main types of biodiversity indicators in use currently, in the UK and more widely. Most of these are derived directly from data on species, measuring change in either abundance or occupancy (distribution).

89. There are a number of ways this species' trend data can be used to develop biodiversity indicators. Although single species' trends can be used to report on change in nature more widely, the commonest approach is to combine species' trends into multi-species indicators. We have discussed the methods used to do this, and technical issues that arise, for example weighting to address biases in data availability.

90. Species' data can be manipulated in other ways to produce biodiversity indicators. These include: Red List Indices, based on average threat of extinction; diversity indices which measure changes in relative abundance between species which can reflect changes in community composition; and Biodiversity Intactness Index, which measures loss from a hypothetical intact state.

91. We also consider a range of measures based on data other than on biodiversity itself, which might inform about pressures acting on biodiversity, or act a proxy for changes in biodiversity should direct biodiversity data be missing. There are a wide range of such measures, such as habitat extent and condition, pollution, and populations of non-native species. There is not, however, a compelling case for their use given the availability of robust species' trend data for Scotland.

5. Further detail on producing a headline metric

5.1 Combining species data from disparate sources

92. As already discussed, most terrestrial biodiversity indicators measure trends in the status of species using abundance data. The standard approach is to calculate the geometric mean abundance each year (Buckland et al. 2005), and to scale to some baseline value in the reference year (e.g. set to 100 in the year 1970). Indicators constructed in this way are effectively tracking changes in the abundance of some notional average species. Thus, it is relatively straightforward to combine data from separate sources, so long as they can be converted into a common currency. For example, the Priority Species Indicator of species abundance (Eaton et al. 2015b) is made up of a mix of count data and modelled outputs, but all are easily converted into a metric of species' abundance.

93. Combining data into a headline metric could be regarded as more problematic when the data represent different currencies. The headline metrics in the 2016 State of Nature report (Hayhow *et al.* 2016) and the Dutch Living Planet Index (van Strien *et al.* 2016) both contain a mixture of data on species abundance and distribution (occupancy). Combining them is technically straightforward if one assumes that a given change (e.g. 10%) is comparable in both occupancy and abundance. However, there are reasons to believe that occupancy and abundance are not directly comparable, and it's likely that changes in species' occupancy underestimate changes in abundance (Bart and Klosiewski 1989; Buckley and Freckleton 2010). A recent study of moths in Scotland (Dennis *et al.* 2019) showed no clear correlation between abundance and occupancy trends; indeed, species with negative population trends showed varied occupancy responses. It is therefore harder to interpret changes in an indicator that combines occupancy and abundance data. For these reasons, a decision has been made to retain two separate indicators for Priority Species with the UK Biodiversity Indicators, one based on distribution data and the other based on abundance data, rather than combining them as a single indicator. Furthermore, the most recent State of Nature report (Hayhow *et al.* 2019, and Walton *et al.* 2019 for Scotland) reverted to reporting trends in abundance and distribution in separate metrics.

94. The creation of composite indicators is further complicated when the currencies are more heterogeneous, for example an abundance trend and a red list index. More extreme would be to combine an index based on abundance with an index in which the data represent something other than individual species, such as the marine trophic index. However, there are indicator approaches which enable the combination of such disparate sources, providing they can be presented as

quantitative measures. The Natural Capital Asset Index for Scotland, one of the National indicators used to measure progress towards the National Performance Framework 'Economy' outcome, combines measures of natural capital across a broad range of services and habitats, using weightings to address variation in the importance of these to human wellbeing, and thus combines a total of 38 separate indicators (SNH 2019).

5.2 Disaggregation of headline indicators

95. In addition to the headline aggregated metric, many indicators are presented in a form disaggregated by taxonomic group, geography or habitat. These disaggregated indicators are often treated as supplementary information but are usually essential to inform an understanding of the reasons behind underlying trends in any high-level metric – this is particularly true when that metric summarises data across a broad suite of species that show a wide variation in trends, and if there is any systematic pattern to this variation, in other words if some subsets of species have a different trend to others. This can be seen, for example, in the UK Wild Bird Indicator (C5), in which farmland birds (C5a) show a very markedly greater decline than other species, and within the farmland birds a subset of species defined as farmland specialists show a greater average decline than those defined as farmland generalists. There is currently considerable variation in how the various disaggregations are presented. The UK Wintering Waterbirds indicator (C5e) presents separate lines for wildfowl and waders on the headline indicator plot, while for the UK priority species indicators (C4a, C4b) and pollinating insects (D1c) taxonomic disaggregations are only presented in technical annexes. By contrast, the Living Planet Indicator (WWF 2018) has many disaggregations, including into five biogeographic realms and ecosystem (marine vs terrestrial vs freshwater). In some cases, 'sub-indicators' might be necessary steps to enable the creation of the headline metric (e.g. metrics for the state of nature, or natural capital, for individual habitats/ecosystems as used in the creation of the Norwegian 'nature index', or the Scottish NCAI); in other instances they are backwards disaggregations of the headline measure.

5.3 Uncertainty and assessment

96. There are a variety of techniques for assessing change in biodiversity indicators. A common theme is to use some kind of statistical procedure to calculate the uncertainty around this headline value (e.g. the 95% confidence intervals). The magnitude of this uncertainty is then used to determine whether change in the headline indicator has been statistically significant.

97. Uncertainty in biodiversity indicators tends to be measured relative to the index value in some baseline year, which is nearly always the first year in the series. The index value in the baseline year is typically shown without error, so the uncertainty in subsequent years measures change relative to the baseline. Treating the data in this way is potentially misleading and has a number of undesirable consequences. First, the confidence intervals are constrained to become progressively wider over time, making it harder to detect statistically significant change, not easier. Second, the presentation shows only whether long-term change has been significant: it's not possible to determine the statistical significance of changes over recent years (e.g. the last decade). Third, treating the baseline as if it were known without error is counter-intuitive, because the early years of the time series are typically based on far fewer data than later years (e.g. the UK Butterfly Monitoring Scheme consisted of approximately 30 sites in the mid-1970s, but now has over 1000).

98. A variety of alternative statistical treatments exist, each of which has different implications for how uncertainty in the headline indicator can be presented and interpreted. Two (non-exclusive) options are 1) to allow the baseline to be expressed with uncertainty, and 2) to use a year other than the first year as the baseline. This could be, for example, a year with particular relevance with regards to drivers of change in biodiversity, such as when new governmental policies are initiated.

99. As noted above, there are many techniques currently employed for calculating uncertainty in the headline indicator. These approaches differ fundamentally in what the uncertainty represents, making it impossible to compare across methods. Bootstrapping across the raw data propagates uncertainty from the raw observations into the headline indicator, but it is time-consuming and not appropriate for all datasets. An alternative approach is to separate the production of species indices from assembling them into a composite indicator. Until recently, such two-stage approaches tended to ignore uncertainty in the species' indices, but new methods are now available for this purpose (Soldaat *et al*. 2017; Freeman *et al*. 2020).

5.4 Presentation of indicators

100. The most common format for presentation is as a line showing how the indicator has changed over time, with a ribbon to delimit the confidence intervals. This is a standard presentation format that is straightforward to produce when input data permit a single interpretable metric to be calculated on an annual basis (notwithstanding the issues raised in section 5.3).

101. More complex forms of presentation are necessary when the data depart from this format. For example, if the indicator were to contain a mixture of species metrics (section 4.1) and non-species data (section 4.5) then it may be impractical to combine them into a single headline metric that could be interpretable. In this instance, some kind of vote-counting approach would be required, whereby the number or proportion of separate indicators showing positive or negative trends, or no change, could be summarised.

102. In addition to the line graph, the UK species indicators, for example C5ai: Breeding farmland birds in the UK, also display stacked bars that display how species are distributed into five categories of change (2 increasing categories, 2 declining categories and one ‘no change’ category). These bar charts are based on the same data as the headline indicator but display a different type of information: the bar charts are primarily qualitative in that they display the balance of species into categories, whereas the line graph is quantitative in that it represents the average trend across all species. We do not propose the use of such bar charts for the new Scottish indicator, because it is unclear whether the threshold rates of change are equally appropriate across the diverse range of taxa and data types available (for example, is a 10% decrease in abundance for a fish equivalent to a 10% decline in occupancy for an insect?).

5.5 Summary

103. In this chapter we have focused in more detail on the creation of a biodiversity indicator through combining species’ trend data. This includes how data from disparate sources can be combined in a single indicator, although there are good reasons for holding reservations about the combination of trends in the different currencies of abundance and occupancy (distribution).

104. We stress the value of presenting disaggregated indicators showing trends underlying headline indicators, which may hide important detail, and so aid understanding of patterns of biodiversity change.

6. Review of suitable biodiversity data for Scotland

105. A list of data sources that may be available to be used to create a biodiversity indicator for Scotland can be found in the accompanying spreadsheet "Biodiversity_indicator_data_review.xlsx". This spreadsheet summarises details including dataset name, taxonomic group covered, number of species covered, start year, current end year, type of metric, whether it is an ongoing project and if data are freely available. The datasets have been split into two types; those that are species-based and measure trends in either abundance or occupancy, and other relevant non-species metrics.

106. Datasets documenting trends in either abundance or occupancy within Scotland's terrestrial, freshwater and marine environment are currently available for approximately 2400 species***;*** however, most of these trends (>80%) measure change in occupancy rather than abundance. These datasets can be split into the following main groups:

- Abundance-based data generated by well-established national monitoring schemes. These could be considered as the highest quality data, as they are already published, usually annually, at the spatial resolution required, and would therefore require minimum additional effort to incorporate into any biodiversity indicator. Examples include the BTO/JNCC/RSPB Breeding Bird Survey, BC/CEH/UK/BTO/JNCC Butterfly Monitoring Scheme and the Bat Conservation Trust's National Bat Monitoring Programme. At a Scotland resolution, these cover approximately 380 species of bird, mammal, butterflies and moths.
- Occupancy-based metrics using more ad hoc presence-only biological records. Following several years of development and refinement of methods to produce such trends at the UK scale (e.g. Outhwaite *et al*. 2018), draft trends for the UK's four constituent countries have been produced by the UK Centre for Ecology and Hydrology (UKCEH; previously the CEH) (Outhwaite *et al*. 2019). Whilst the production of such trends at a smaller (national-level) spatial scale means a reduction in sample size and a consequent reduction in the number of species for which sufficiently robust trends can be derived, this work presents a step change in the ability to report upon Scotland's biodiversity. UK occupancy trends are available for a wider range of taxonomic groups, potentially encompassing over 4000 species of invertebrates, 1200 vascular plants and 1600 bryophytes and lichens. For Scotland 1,761 species have sufficient data to be included in an indicator (although 1,578 have been used in the draft indicator presented by this report, as abundance-based trends have been selected for

moth species in preference to occupancy trends for species for which both existed).

- Datasets that are regularly published but for which further manipulation would be required for use in a Scotland biodiversity indicator, for example, due to the data not being available at the correct spatial resolution. This is the case with data from the Rare Breeding Bird Panel (approximately 50 species), which is currently only published at a UK-level. Similarly, very little of the marine data is currently published at other spatial resolutions; for example, OSPAR region or individual seas.
- The application of Bayesian occupancy modelling to vascular plant datasets (provided by the Botanical Society of the British Isles (BSBI) and held by the BRC) has not generated suitable annual trends: consultation with BSBI identified issues with temporal bias in recording effort that modelling has been unable to account for satisfactorily. For the State of Nature 2019 report (Hayhow *et al.* 2019) an alternative approach using the Frescalo method (Hill 2011) was used to create trends at the UK and country scales. However, this relied on pooling records into just five time periods between 1930 and 2018 of which only two lie within the period from 1994 onwards proposed for this combined indicator. This in effect provides a straight line trend between two estimates for all vascular plant species, without annual updates, which we feel is not appropriate for the main purposes of the indicator. The National Plant Monitoring Scheme (NPMS), initiated in 2015 by the Botanical Society of the British Isles, CEH, JNCC and Plantlife, will produce annual trends in abundance for a suite of widespread vascular plant species at a UK and, where possible, country scale. These trends could be integrated into future iterations of the combined indicator.
- Datasets based on intermittent, non-annual, often species-specific, surveys (approximately 20 species). Generally, these cover bird and mammal species not included in national monitoring schemes, often due to their small population or range size; for example, the approximately 17 bird species covered by the Statutory Conservation Agency and RSPB Annual Breeding Bird Scheme (SCARABBS), otter (SNH 2015) and seal surveys (SMRU 2015). Several weaknesses apply to these datasets, including that some surveys haven't been repeated for many years (e.g. the last national merlin survey was in 2008 (Ewing *et al*. 2011)), and technical issues must be surmounted when combining these intermittent data into an annual abundance-based indicator.

107. The situation within the marine environment is different. Indicators are very widely used in assessment of the state of marine ecosystems (e.g. under MSFD), but these indicators tend to be different from terrestrial-focused assessments, in that

most are not based on species data, and when they are they tend to be based on data on species composites rather than individual species. While some continuous species data are available that could be incorporated into an overarching abundance/occupancy-based Scottish indicator (for example, from the International Bottom Trawl Survey (IBTS)) the amount available is limited. Further manipulation and analysis of datasets, such as Marine Biodiversity and Climate Change Project (MarClim), Seasearch and Ocean Biogeographic Information System (OBIS), would be required to derive species-level trends in occurrence and/or abundance from these additional sources.

108. Single-species indices from many of the potential datasets, particularly the national monitoring schemes, are freely available either through online downloads or data requests, although prior engagement with data stakeholders will assist with the provision of data; the engagement process (see Section 7) conducted as part of this project has secured the relevant permissions for the inclusion of data within the draft indicator and although further permission will be required for use in a published NPF indicator, we firmly anticipate this will be the case. A data collation process would need to be established before the indicator is updated, and this will be more complex for data sources away the established data channels.

109. Another factor to consider is how many years it takes from data collection to publication (the data lag), which is inherent within products derived from biological data, particularly as a large proportion of field data collection is by volunteers working within citizen science projects. As many of our national monitoring schemes are already used for national indicators the data lag is often minimal (<2 years). Issues arise when trying to incorporate additional data sources away from these schemes and how and when they are integrated into any indicator. For example, data from the Rare Breeding Birds Panel and the Seabird Monitoring Programme tend to be slightly older, with currently (September 2019) published trends terminating in 2016 and 2015 respectively, while the trends derived from occupancy modelling end in 2014, 2015 or 2016, but in a few cases in 2011, depending on taxonomic group. As noted above, incorporating species-specific surveys can be problematic as some are relatively out of date and repeated irregularly.

110. Twenty-eight relevant non-species metrics were identified. These come from a variety of sources including Scottish Natural Heritage, JNCC, Scottish Environment Protection Agency, CEH, Forestry Commission, Defra and Scottish Water, and cover many of the topics discussed in section 4.5, such as protected sites/habitat extent and condition, pollution, and invasive species. Much of the data

are freely available; however, six of the metrics have been discontinued. Like the species data, they have various data lags associated with them, with end dates varying from 2013 to 2018.

6.1 Summary

111. Our review of biodiversity data for Scotland found a considerable volume of species' data suitable for inclusion in a combined terrestrial and marine indicator. Robust abundance trends are available for 380 species of birds, mammals, butterflies and moths, and trends in occupancy (distribution) are available for an additional 1,578 species across a much broader taxonomic range including bryophytes, lichens and invertebrates. Issues around the availability of these data are discussed.

112. There are many gaps in data availability; for example, at present vascular plants are not included. Furthermore, we have far less data for marine species, and much of that which has been collected has not yet been analysed and the resources required to do so were beyond the capacity of this current project.

7. Stakeholder consultation and decisions made

113. This chapter describes the process of decision-making by the project team, the Scottish Government Research Advisory Group, and through consultation with a range of stakeholders. We **highlight** the key issues raised and decisions made through this process.

114. Consultation with a broad stakeholder community was conducted through three workshops and accompanying email correspondence (e.g. with experts unable to attend), through three meetings with a Scottish government-convened Research Advisory Group, and with the Scottish Biodiversity Strategy Science Support Group through attendance at one meeting and the circulation of a short document for consultation (Appendix 2).

7.1 Stakeholder workshops

115. Workshop 1, 23rd April 2019, City of Edinburgh Methodist Church: engagement with stakeholders in terrestrial and freshwater biodiversity data, with a focus on conservation professionals involved in biodiversity monitoring and the use of biodiversity data for conservation decision-making. A list of attendees is given in Appendix 2.

116. Main topics discussed: an introduction to the project and its aims; existing biodiversity indicators; reviewing biodiversity data and its suitability; data flows and how producing an indicator might work; issues and identifying priorities for improving data availability.

117. Conclusions:
- A general support for the project, and Scottish Government's intention of producing a new NPF indicator. Partners willing to provide data for inclusion.
- A number of datasets not identified in our original review were suggested for consideration (e.g. SEPA dataset on freshwater invertebrates, biting midge monitoring, Rivers Trust fish data, tipulid flies, estuarine fish) (although none were included in the proposed indicator following subsequent investigation).
- **Agreement with the project team's focus on an indicator based on the average trend in species' status.**
- Consensus that the recommended indicator should not be regarded as static, but as a starting point with the aim of improvement in subsequent iterations (e.g. through the inclusion of more trends to make the indicator more representative).

- A clear call for actions that will support the biodiversity monitoring in Scotland (and in turn support the future improvement of the indicator). A wide range of points were raised in this regard, including the following: supporting and developing the biological recording community in Scotland, particularly by developing new recorders and prioritising effort at particular gaps; securing long-term funding for monitoring and recording schemes; develop new systematic monitoring schemes for key taxonomic groups; strong support for the implementation of the recommendations of the Scottish Biodiversity Information Forum (SBIF) review (Wilson *et al*. 2018);
- **Concern that the indicator will not function in a 'useful' way – that the requirement to have a single headline metric will mean it will not be responsive, and indicative of changes in biodiversity in a way that will stimulate responses.** It was felt that as well as the best possible indicator design, strong communication of how the indicator was created, and how changes (or lack of changes) in the indicator should be interpreted were essential.
- As a consequence of the point above, **there was a clear and strong support for the publication of disaggregated indices at a level that would enable better understanding of changes in Scottish biodiversity than the headline indicator alone**. A number of options for this disaggregation – e.g. by taxa, habitat, region – were discussed, as well as possibilities for the publication of such indicators.

118. **Workshop 2**, 24th April 2019, RSPB Scotland Headquarters, Edinburgh, engagement with stakeholders in marine biodiversity data. A list of attendees is given in Appendix 2. The main topics discussed included: an introduction to the project and its aims; suitable marine biodiversity data sources for use in an indicator; spatial and temporal extent; relationship with existing marine indicators; indicator construction.

119. Conclusions:
    - Agreed that the marine element of the indicator should be regarding as reporting on biodiversity within the Exclusive Economic Zone (EEZ), so a range of up to 200 nautical miles.
    - A range of potential data sources were discussed, the principal amongst them being Seasearch; MarClim (covering a range of intertidal taxa), data on seabirds and cetaceans collected at sea and collated through the MERP project; OBIS (offshore benthos), Continuous Plankton Recorder and Marine Scotland plankton sampling, and fisheries data.

- However, it was recognised that **most of these have not yet produced robust species trends suitable for use in an indicator, and the work required to do so was beyond the resources of this project.**
- The issue of trends being influenced by factors outside of Scottish waters was discussed, but it was acknowledged that little could be done about this, and it was true for all biodiversity to an extent.
- As with terrestrial biodiversity, felt important to use the longest timeline possible to illustrate past biodiversity change.
- Concerns expressed whether trends derived from fish abundance would reflect ecological change, or could perform perversely, for example as overfishing results in an abundance of small individuals.
- Content to use trends in both abundance and occupancy (if and when the latter become available).
- The issue of weighting elements of the indicator to address biases in data availability was discussed, but nothing concluded.
- As with the terrestrial discussion, **there was a clear interest in disaggregation of a headline metric** for example by habitat (substrate), functional group or region.

120. **Workshop 3**, 17th July 2019, City of Edinburgh Methodist Church: engagement with Scottish Government stakeholders, with additional input from conservation, monitoring and research stakeholders. A list of attendees is given in Appendix 2. The main topics discussed included: available biodiversity data; options for producing an indicator, including draft versions; understanding and communicating the indicator; requirements to enable future revisions, and potential for improvements; conclusions and next steps.

121. Conclusions
    - Valuable input was received on issues regarding data proposed for use in the indicator, covering a wide range of points: need to understand risks around data supply and hence potential issues with future updates; potential future evolution of the indicator as new data becomes available.
    - Datasets for future inclusion were discussed. These include a large number of freshwater biodiversity records available from SEPA. As yet these data have not been added to the BRC database, so are not currently available for the Bayesian occupancy analyses contributing species' trends to the draft combined indicator, but the intention it that this will happen so future analyses will benefit from these records, leading to more robust trends for species included already, and very likely to trends being derived for a larger suite of freshwater species.

- As with marine workshop, there was discussion over whether using fish abundance was appropriate as a measure of marine health.
- There was considerable discussion on start date of the indicator, **with general support for it starting as early as possible. 1994 was identified as potentially the most suitable date.**
- **On balance, attendees agreed with the intent of combining both abundance and occupancy, although not all agreed.**
- **The use of weighting to address biases in data availability was discussed; although there appeared to be some support for this as a concept, there was no clear advice or opinion on how this should be done in practice.**
- Concerns were expressed by a number of attendees over the **requirement of producing a single line indicator, with some frank opinions of the limited value of this, and potential problems it might cause for policy use, funding efforts, communication – in effect being an impediment to successful nature conservation in Scotland.**
- As in all other consultation conducted as part of this project, there was considerable discussion on and **strong support for the need for simultaneous and linked publication of disaggregated indicators (possibly by SNH) to improve the value of the headline indicator.** There was discussion over the various forms of this disaggregation – taxon, trend currency, realm, habitat, functional group, geography, drivers of change – whilst acknowledgement that not all of these would be possible.

7.2 Research Advisory Group

122. Meetings of a Scottish Government-convened Research Advisory Group (RAG) were held on 14th Jan and 15th May 2019. RAG members were updated on project progress and provided guidance on project requirements and particular issues. Key input was received on set of questions raised in advance of the meeting on 15th May, via a short note circulated to the RAG electronically. This is given in Appendix 2, along with notes on the decisions made by the RAG. We summarise these here:
    - **The indicator should conform to NPF indicator template, being a single index presented without any estimate of error. There was, however, strong support for the separate publication of a suitable range of disaggregated indices to provide contextual supporting material.**
    - **The balance of opinion was in favour of a broad composite indicator created from species' trend data. It was felt preferable that this be capable of being updated annually, with a time lag in reporting of no more than three years. A long timeline (i.e. as early a start date as possible) was supported.**

- The RAG agreed that the indicator might be subject to future development to address shortcomings (e.g. poor representativity of some taxa or ecosystems) which might result in retrospective changes to the indicator.
- There was considerable discussion on the use of trends of species' abundance, and trends of species' distribution; the relative merits of each, whether one should be preferred over the other, or whether the two should be combined in a single metric.
- Other discussions centred on issues around marine data.

7.3 Scottish Biodiversity Strategy Science Support Group (SBS SSG)

123. One of the project team (ME) attended a meeting of the SBS SSG in early 2019 to outline the project requirements and the plan for the work to be conducted. Due to the lack of a suitably-timed meeting, it was not possible to discuss the final recommendations arising from the project at a further SSG meeting, so a short note outlining the proposed indicator was circulated in mid-September. This included decisions made through the process of consultation outlined above, but also those final decisions made by the project team and outlined in section 7.4 below.

124. Responses were received from five members of the SSG. **All were broadly supportive of the recommendations of the project team, including the key decisions highlighted within the note. The common denominator in the feedback received was strong support for recommendations that disaggregated indicators should be produced to support interpretation and understanding of patterns of change shown by the headline indicator.**

7.4 Further decisions made by the project team

125. The consultation described above guided the project team through many most of the decisions required to identify a suitable indicator. However, there were a number of remaining decisions to be made.

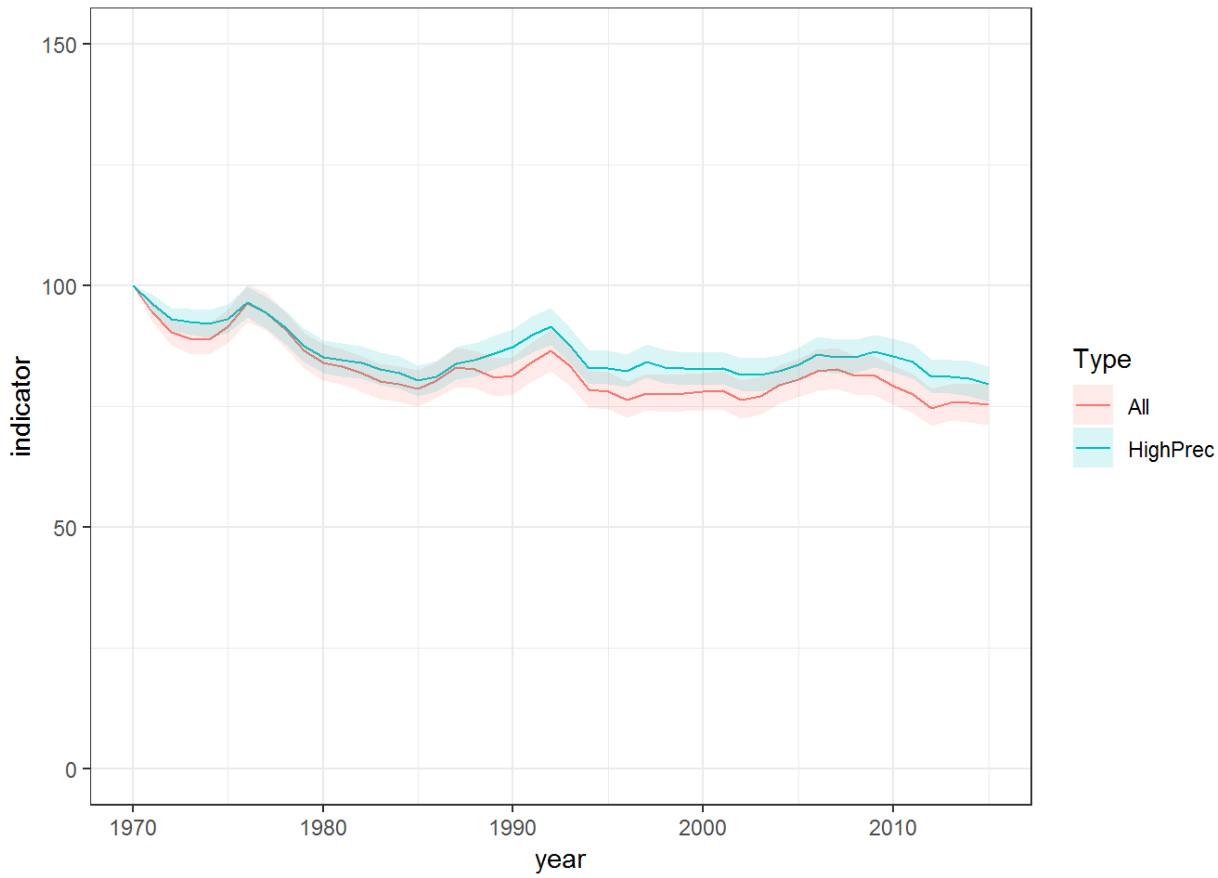
7.4.1 Data

Rules for the inclusion of species' trends

126. Trends for individual species have only been considered for inclusion in the indicator if considered to be sufficiently robust. For abundance trends, we have relied on assessments provided by those responsible for overseeing schemes. For example, we have only incorporated trends for breeding birds from the BTO/JNCC/RSPB UK Breeding Bird Survey if considered sufficiently robust for publication (i.e. species that have been recorded from a minimum annual average of 30 survey squares within Scotland over 1994-2018 course of the survey). Similar assessments have been applied to other bird data sources and those for mammals, moths, butterflies, marine mammals and fish.

127. For the broad sweep of species for which we derived trends in occupancy from biological records through the application of Bayesian modelling techniques, a similar threshold approach was applied. We first explored a threshold based on the number of records (i.e. the sample size per species). Lower sample size thresholds may result in individual species' trends that were less robust being incorporated within the indicator. Higher thresholds will exclude such species, as a consequence reducing the number of species' trends which can be incorporated within the indicator. We found that below threshold of 50 records the models did not produce sufficiently robust results. It is not apparent that a higher threshold can be justified *a priori*, so we looked instead at the precision of the trend estimates that emerged from the occupancy models. Whilst species with larger sample sizes tended to have more precise trend estimates, there are many species that buck this trend: on the one hand rare species with few records and precise trends, and widespread species with many records and imprecise trends. However, the distribution of precision across species is clearly bimodal (Pocock *et al*., draft report to JNCC), implying a clear separation between "precise" and "imprecise" trends. One option would be to take the midpoint between these modes as a precision threshold, but in practice it makes a negligible difference to the resulting indicator line, particularly the trend since 1994 (Figure 1). In other words, the "imprecise" trends merely add noise, not bias. In the absence of an objective threshold, we therefore suggest using the full set of 1763 occupancy model outputs.

Figure 1: Indicator of Scottish biodiversity from distribution data only, using occupancy models. The red line is derived from all 1763 species with at least 50 records in Scotland, the blue line is the subset of 1317 species whose trend estimates exceeded the precision threshold.



128. For a few species of birds and moths, trends were available from more than one source. In such cases we have identified a hierarchy for identifying the most suitable trend for incorporation. We have given precedence to assessments of change in abundance, as this is thought to be the most sensitive measure. In the case of multiple abundance trends being available for a species, we selected the trend from the dataset believed to be the most robust, based on the survey method subject to the fewest known biases, and maximising the sample size and time period covered. For example, for bird species for which trends in both breeding and wintering abundance were available, we gave precedence to the breeding population trend.

Marine Groundfish (demersal fish) data

129. For the marine data, there exist different versions of the ICES bottom trawl datasets. ICES serve these data directly via their DATRAS data portal (https://www.ices.dk/data/data-portals/Pages/DATRAS.aspx) in close to real time, and they provide web services allowing programmatic access. We developed a workflow in the statistical computing environment R to access and process the data directly, adding specific functionality (e.g. subsetting to Scottish waters, deriving species-level abundance trends) on top of open source tools developed within ICES (https://github.com/ices-tools-prod/icesDatras). The key advantage is that this entire workflow can be replicated to access updates to the DATRAS database, so that the resulting index can be updated to incorporate new data from these ongoing surveys.

130. However, there are persistent concerns about the level of quality control conducted on ICES data, particularly in earlier years. This led the Scottish Government to invest in a high degree of quality control of ICES trawl surveys in order to support the OSPAR interim assessment in 2017. These data products are provided by Marine Scotland, and described in full here: https://data.marine.gov.scot/dataset/manual-version-3-groundfish-survey-monitoring-and-assessment-data-product. Again, we developed a workflow in R to process these data, sub-setting to the Scottish EEZs and deriving abundance trends at the species level. These trends are likely to be more robust than those derived directly from the ICES data, however they do not run past 2017 and additional resource would need to be committed year on year to perform equivalent quality control to all new ICES trawl survey, and publish these as new data products, or as revisions to the existing products. In addition, although these data products are openly available to download (which was our approach), programmatic access in R is not yet possible and so even if the data were updated, additional revision of code would be required in order to update the abundance trends.

131. One common approach to this kind of problem is to use the period of overlap between time series to derive correlations which can then be used as a ‘correction factor’ for years in which only one data source is available. That is complicated in this case, however, because different units of abundance are used (the Marine Scotland data products use individuals per unit area, whereas ICES use individuals per unit time). It would be a substantial research exercise to work out how best to combine these two data sources, and is beyond the scope of our project. To better inform the choice between these two sources of trawl survey data, we did, however, compare both species-level abundance trends and the

overall aggregated trend derived from both sources. We ran this comparison from the year 2000 on the assumption that quality control issues would be a lesser issue in newer ICES data, as processes have become better standardised. Although trends are similar for many species (Figure 2), there are also some substantial divergences, and the overall trends diverge substantially around 2012 (Figure 3).

132. It is our considered view that the advantages inherent in accessing ICES data directly from DATRAS – namely, a straightforward, repeatable programmatic workflow which can be updated year on year with minimal additional resource – makes this the best choice for the current purposes. This is not to ignore the data quality issues addressed by the Marine Scotland products, but the general concordance in species-level trends between the two data sources (Figure 2) reassure us that the advantages of an easy-to-update index that does not require additional annual resource outweigh these concerns.

Figure 2. Species-level trends from 2000-2017 for four species of fish present in both the ICES (red) and Marine Scotland (blue) versions of the trawl survey data. Each panel represents a species, and all indices are scaled to equal 100 in the year 2000.

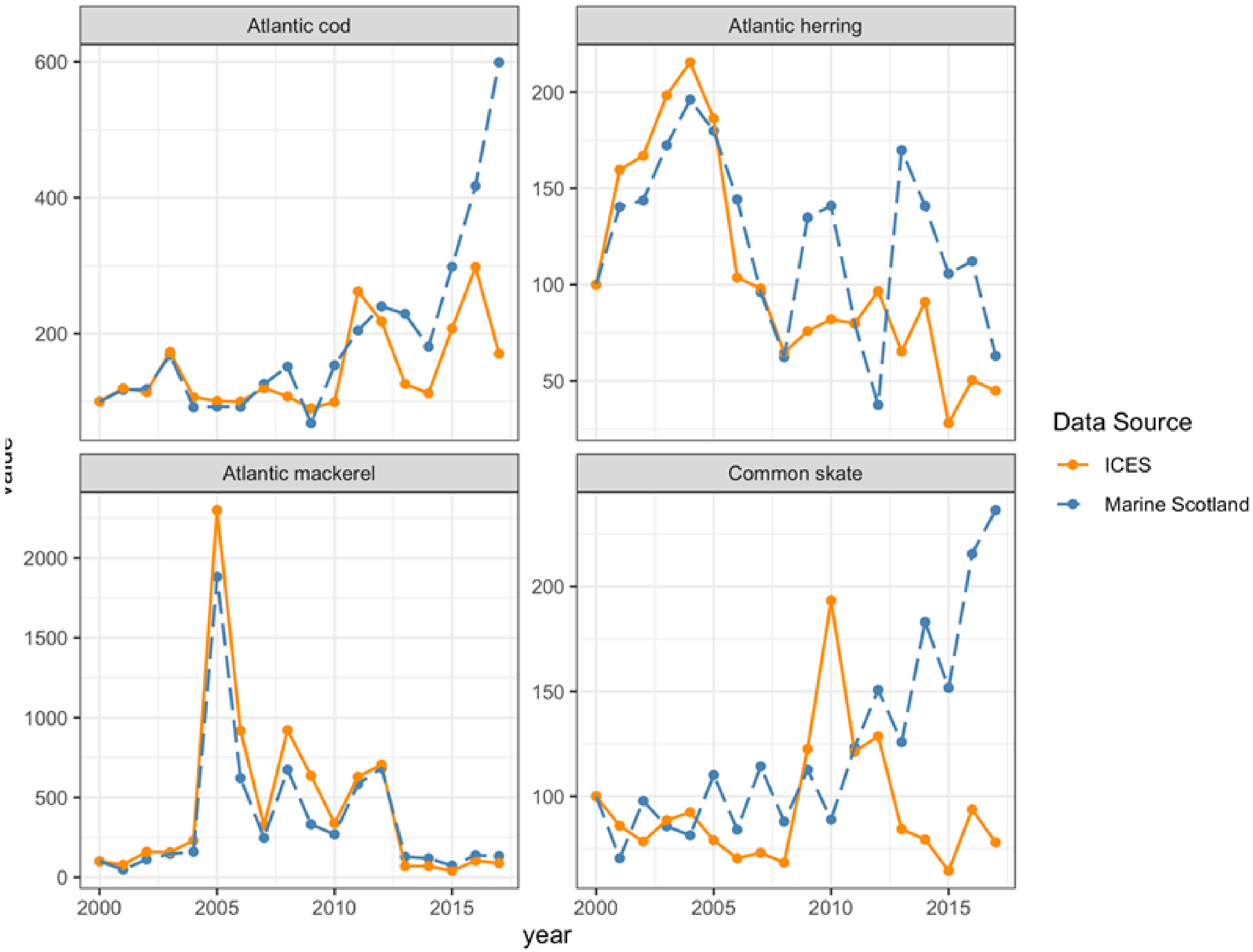
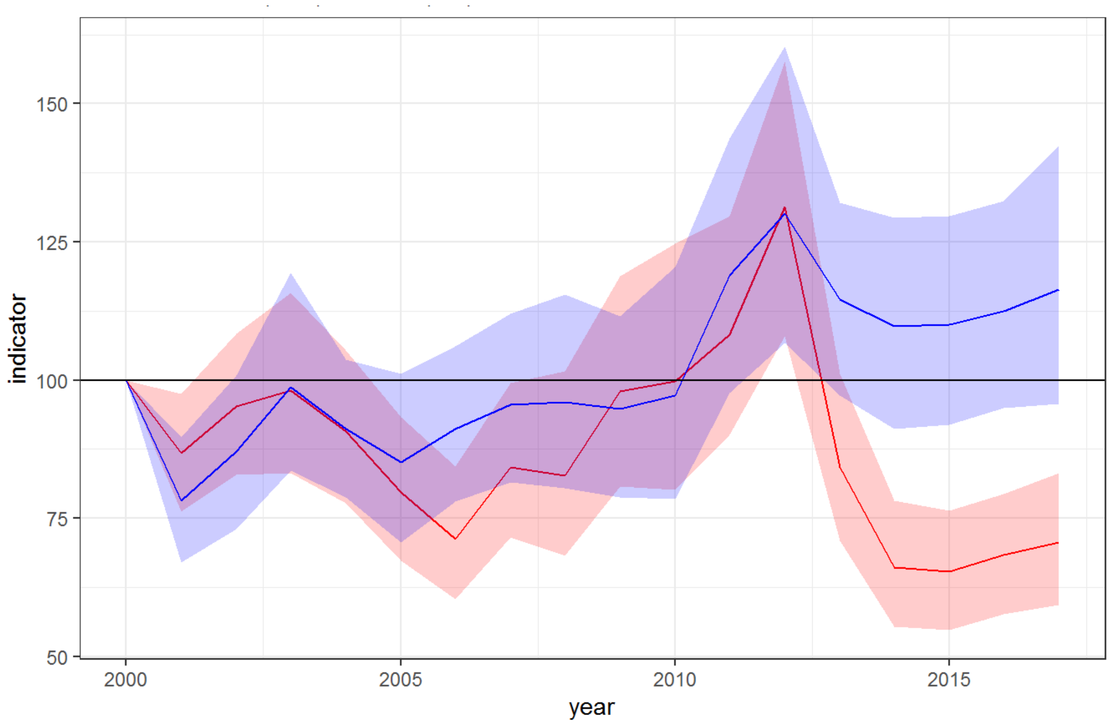


Figure 3. Multi-species indicators derived from marine fish abundance from the ICES (red) and Marine Scotland (blue) versions of the trawl survey data, between 2000-2017. Trends are scaled to equal 100 in the year 2000.



7.4.2 Indicator start and end date

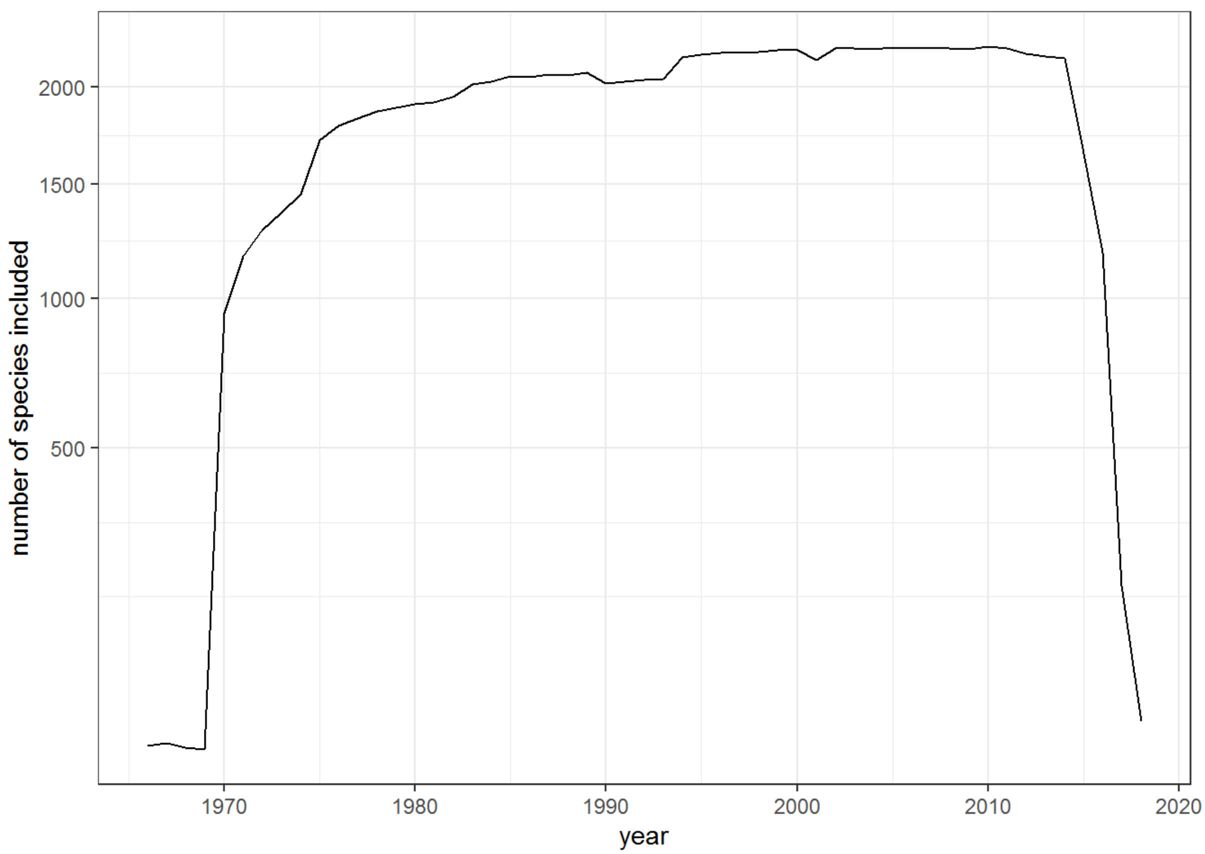
133. Many of the stakeholders who partook in the consultation exercises described above expressed a wish for the indicator to extend back in time as far as possible, in order to provide context to current day changes. This desire has to be balanced against changes in data availability through time, and variation in the robustness of the indicator, and consistency of what change the indicator is measuring. Figure 4 shows how, using the data for 2,073 species as described above, the number of species contributing to the indicator increases through time. Trends in wintering waterbirds are available from 1967 onwards, trends in occupancy for many species are available from 1970 onwards (hence the massive jump at this date). Smaller but significant increases in species sample size arise with the addition of taxon-specific monitoring schemes, for example the Rothamsted Insect Survey (moth trends) in 1975, the Seabird Monitoring Programme in 1986, and the UK Breeding Bird Survey in 1994.

134. ***We recommend 1994 as the start date for the indicator***. Although further species trends are incorporated in the indicator in subsequent years (e.g. five species of bats and four species of terrestrial mammals from 1998 onwards), such

additions have an extremely minor impact on the indicator and so do not justify delaying the start date. Whilst an earlier start date would be possible – after all, the majority of the trends used in the indicator are available from 1970 onwards, the lack of data on vertebrates during this period means the indicator line would not be representative of biodiversity as a whole.

135. Similarly, the choice of the current end year also requires careful consideration, because of the time-lag in making data widely available. Setting it too early would make the indicator out-of-date; setting it too late would be unrepresentative of all biodiversity. The number of species with data drops off markedly after 2014 (Figure 4) and is very low indeed for the most recent years (29 species in 2018, 191 species in 2017). ***We believe that 2016 represents a reasonable compromise based on current data:*** there are 1003 species with data for this year, and all major taxonomic groups are represented.

Figure 4. Number of species with index values for each year



7.4.3 Indicator creation

136. The consultation and decision-making outlined above left two significant decisions to be made, concerning how the species' trends identified for inclusion should be combined into an indicator. The first question concerned whether to use weighting (also referred to as 'stratification') to attempt to correct for biases in the availability on species' trends. The second is which technique should be employed to create the indicator, and how the uncertainty should be represented.

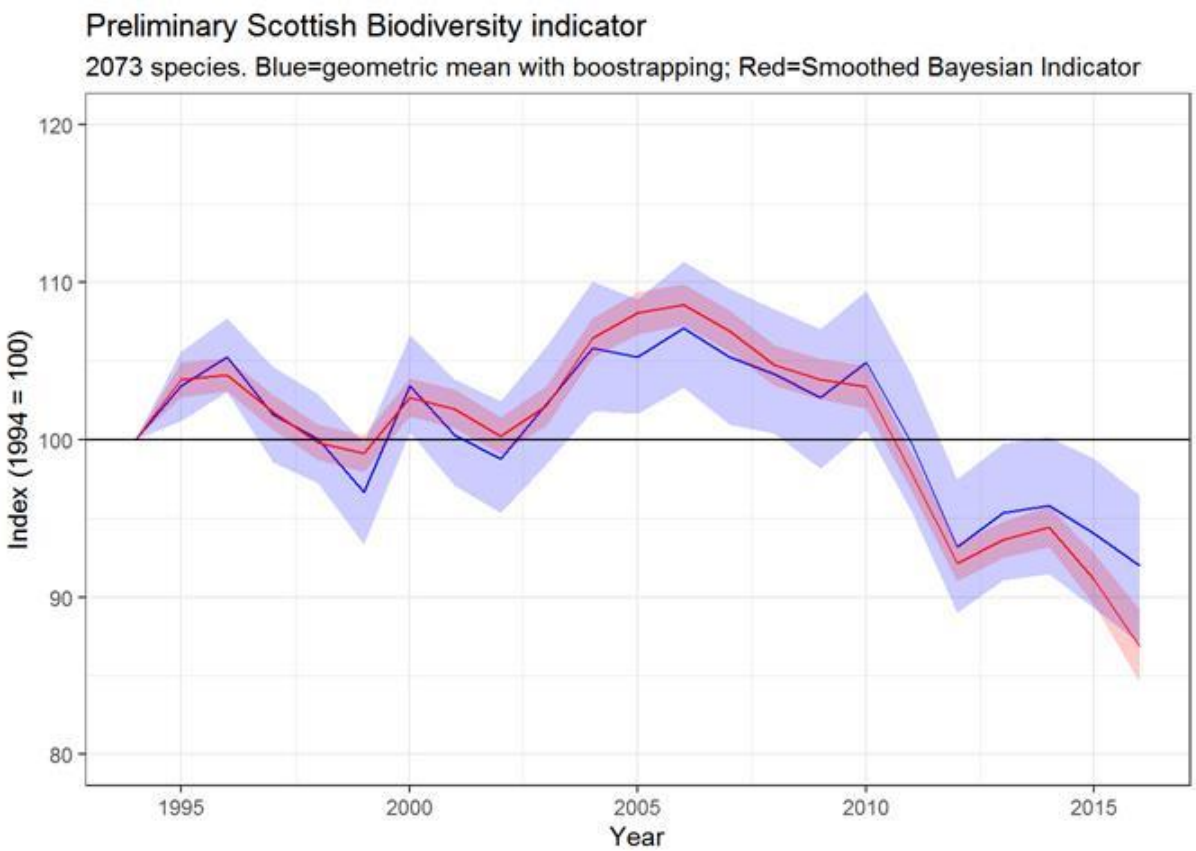
137. **We chose to weight all 2,073 species equally, regardless of taxonomic group and whether the data represent trends in occupancy or abundance.** This choice reflects the fact that any choice of weighting is necessarily subjective, and we lack a clear rationale for favouring any one of the available choices. One could weight species by the degree to which different taxonomic groups are represented (as in the WWF Living Planet Index), but this requires some choice about how to delimit the taxonomic groups. For example, should "birds" be considered a taxonomic group, or should birds, mammals and fish be grouped together as 'vertebrates'? If weighting is employed, there also remains a decision about whether the purpose is to introduce equality between groups (e.g. giving equal weighting to each taxonomic group), or to reflect the relative diversity of such groups (e.g. giving increased weighting to invertebrates to correct for the lower proportion of all invertebrate species included in the indicator). **Our choice of an unweighted indicator does not represent a strong preference for this approach, but rather a lack of preference for any alternative.** We suspect the difficulties in identifying the most appropriate use of weighting to address biases in data availability underpins the widespread and continued use of unweighted indicators e.g. in other countries.

138. We compared two methods for indicator creation, both of which seek to estimate the geometric mean of the species index values. The first approach is a simple geometric mean across species, adjusted to account for missing values (species:year combinations with no data). Confidence intervals are calculated from a bootstrapping procedure in which the indicator is recalculated 1000 times. In each of these 'bootstraps', species data are sampled with replacement to create a dataset equal in size to the original (2073 species) but differing in composition (some species absent, some replicated several times). This is the method used for the UK Priority Species indicator, and for the State of Nature reports (methods described in Burns *et al*. 2018). The resulting index has substantial confidence limits around it, and considerable year-to-year variation (blue line in Figure 5).

139. The second approach is a new hierarchical modelling method for calculating multi-species indicators within a state-space formulation developed by CEH (Freeman *et al*. 2020). Model-fitting is straightforward in either Bayesian or classical inference implementations, the latter following from efficient hidden Markov modelling. As the indicator presented in this report was calculated using the Bayesian approach, hereafter we refer to it as the 'Bayesian' indicator. The key features of this method are 1) species index values are assumed to be imperfect, and 2) the indicator is smoothed in-situ rather than post-hoc. The resulting line varies less from year-to-year (compared with the geometric mean) and is substantially more precise (narrower ribbon of uncertainty on Figure 5). A further difference with this approach from the 'conventional' geometric mean indicator is that the imputation of missing values is informed by between-year change in species for which data is available, which means that for the terminal year the indicator may be more appropriate than that obtained using the geometric mean method, which assumes no change in index values for missing species.

140. **We believe the second, new, approach to be most suitable for use for the new combined indicator;** it is robust, precise, adaptable to different data types and can cope with the issues often presented by biological monitoring data, such as varying start dates of datasets and missing values. This approach is likely to be adopted for the production of biodiversity indicators elsewhere including some of those produced for official indicator suites for the UK and England. As Figure 5 shows, the two methods provide similar results.

Figure 5. A comparison of methods for a preliminary Scottish biodiversity indicator. The blue line and ribbon show the geometric mean with 95% confidence intervals from bootstrapping across species; the red line and ribbon show the smoothed Bayesian method, with 95% credible intervals.



7.5 Summary

141. In this chapter we have outlined the consultation process undertaken as part of this project, with Scottish Government and a wide range of other stakeholders in biodiversity policy, research and conservation.

142. The consultation process clarified the requirements of Scottish Government for an indicator to be included within the NPF indicator suite, so consisting of a line showing variation in a single measure over time.

143. Using the input from stakeholders received through this consultation we were able to make the key decisions on data to be used in a combined indicator, the treatment of this data, and concerning issues around the construction of the indicator itself such as start and end dates, the combination of data measuring both trends in abundance and occupancy, whether to use weighting to address

biases in data availability, and the statistical method used to generate the indicator.

144. Our recommended approach for a combined biodiversity indicator for Scotland is given in Chapter 8.

8. A headline biodiversity indicator for Scotland: recommendations

145. **We recommend an indicator based on trends in species' status,** measured at the scale of Scotland or Scottish marine waters (defined by the EEZ). **These trends should be measured in either abundance or occupancy, across as many species as possible** to provide taxonomic breadth and thus represent the scope of Scottish biodiversity as best as possible.

146. **The indicator will begin in 1994 and run to the most recent year for which data are available**. The start year has been identified as the best balance between providing as long a time-series as possible, but keeping the taxonomic groups contributing to the index broadly consistent throughout (a substantial tranche of bird trends become available from 1994 onwards). **Based on current data, we would recommend the current final year should be 2016**. The indicator will have annual index values, and be capable of annual updates, with nearly all of the constituent species' trends being updated annually.

147. **The indicator will be based on trends in abundance from a range of established monitoring schemes and trends in occupancy from analyses of biological records held by the Biological Records Centre.** Set rules, either imposed by those organisations that operate these monitoring schemes, or created for the purposes of this indicator, will filter species trends for suitability for inclusion, ensuring individual species trends are robust. **With the exception of marine fish trends, which were produced specifically for this indicator, these species' trends are created by existing work programmes, meaning that future updates of the proposed indicator will be efficient and low-cost.** All single species trends are derived using well-established and published methods.

148. **Whilst the combination of abundance and occupancy trends in the same metric, as proposed, is not currently used for other government biodiversity indicators in the UK, it is not without precedent.** The same approach, also without the use of weighting to correct perceived biases, was used in the State of Nature 2016 report (Hayhow et al. 2016, Burns et al. 2018) and in a Dutch 'Living Planet Index' (Van Strein et al. 2016).

149. However, we should caution that **this approach does combine trends measured in two different 'currencies', of abundance and occupancy (distribution), which may vary in different ways and at different rates within the same species.** There is evidence that changes in occupancy may differ in scale to those in abundance (Van Strien et al. 2019), or even show trends in a different direction

(Dennis et al. 2019), and so combining the two currencies in a single metric is far from ideal. **Our recommendation to do so is on the basis that we feel the much greater taxonomic representation this gives the indicator warrants this approach; if the requirement of the NPF indicators was not for a single indicator line, we would not recommend the combining of the two currencies**. Note the 2019 State of Nature report (Hayhow et al. 2019, Walton et al. 2019) did not combine abundance and occupancy data in a single measure, but was able to present measures of change in each separately.

150. Note that using the two currencies together means that the indicator can only be described in abstract terms; a change cannot be described in terms of either abundance, or distribution.

151. The draft indicator is based upon species' trends from the following sources: UK Breeding Bird Survey, Wetland Bird Survey, Statutory Conservation Agency and RSPB Annual Breeding Bird Scheme, Rare Breeding Birds Panel, Seabird Monitoring Programme, UK Butterfly Monitoring Scheme, Rothamsted Insect Survey, National Bat Monitoring Programme, International Bottom Trawl Surveys, and a wide range of biological recording schemes collated within the Biological Records Centre. **In total, trends for 2,073 species have been combined in the draft indicator presented here.** A breakdown of species trends by source is given in Appendix 1. We recommend that as new species trends become available they are adopted within the indicator; this might include single or small numbers of species through the development of existing schemes (e.g. when increasing survey coverage on the Breeding Bird Survey increases to enable the production of Scotland-specific trends for additional species), or larger numbers in the event of new monitoring programmes maturing to the point at which species trends are available (e.g. the National Plant Monitoring Scheme, which started in 2015).

152. There are considerable biases in the availability of species trends for incorporation in the indicator. For example, the draft indicator contains trends for far more terrestrial and freshwater species than marine species, and vertebrates are over-represented in comparison to invertebrates and plants. **However, we have failed to identify an objective approach to weighting the indicator to address these biases, so propose the indicator should be the unweighted average or all available species' trends.** Most notably this means that **taxonomic groups measured using trends in distribution have a greater impact on the indicator than those for which we have abundance trends, and terrestrial and freshwater species have a far greater influence than marine species.**

153. We recommend that the indicator is created using a **new hierarchical modelling method for calculating multi-species indicators** within a state-space formulation developed by CEH (Freeman et al. 2020) which offers some advantages over the more traditional geometric mean method; it is robust, precise, adaptable to different data types and can cope with the issues often presented by biological monitoring data, such as varying start dates of datasets and missing values. As Figure 5 shows, the two methods provide similar results.

154. **The project team, and stakeholders involved in consultations as part of this project, hold substantial reservations about the value of the proposed indicator for assessing change in Scottish biodiversity.** A number of the decisions made, particularly regarding whether to combine trends in abundance and occupancy, and whether to weight to address biases in data availability, had no obvious "correct" answer and other choices to those made may have been equally valid. **We therefore retain substantial reservations about the value of an indicator summarising biodiversity trends at such a high level,** particularly across terrestrial, freshwater and marine realms combined. Even if we were able to do this perfectly, the value of such a high-level measure is doubtful as it will hide considerable, and important, changes in biodiversity.

155. The draft indicator presented here is derived from much the same data sources as used for metrics in the recent State of Nature Scotland 2019 report (Walton et al. 2019; see https://nbn.org.uk/wp-content/uploads/2019/09/State-of-nature-Report-2019-Scotland-full-report.pdf), but does not fully match the metrics presented in that SNH-endorsed report. Walton et al. did not seek to produce a single metric, as is required by the format of the NPF indicators; therefore abundance and occupancy trends were not combined, nor were data for terrestrial and marine biodiversity. The general pattern of the separate State of Nature indicators for abundance and occupancy can be seen in the draft composite indicator (Figure 6), but with some variance caused by differences in the use of data. Chiefly, the State of Nature occupancy indicator started in 1970 (not 1994) and underwent a pre-1994 decline omitted from the draft combined indicator; it incorporated vascular plant trends for this longer period (omitted from the joint indicator due to the lack of annual data; see paragraph 107); and the composite indicator includes many (largely increasing) trends for marine fish that were not included in the State of Nature metrics.

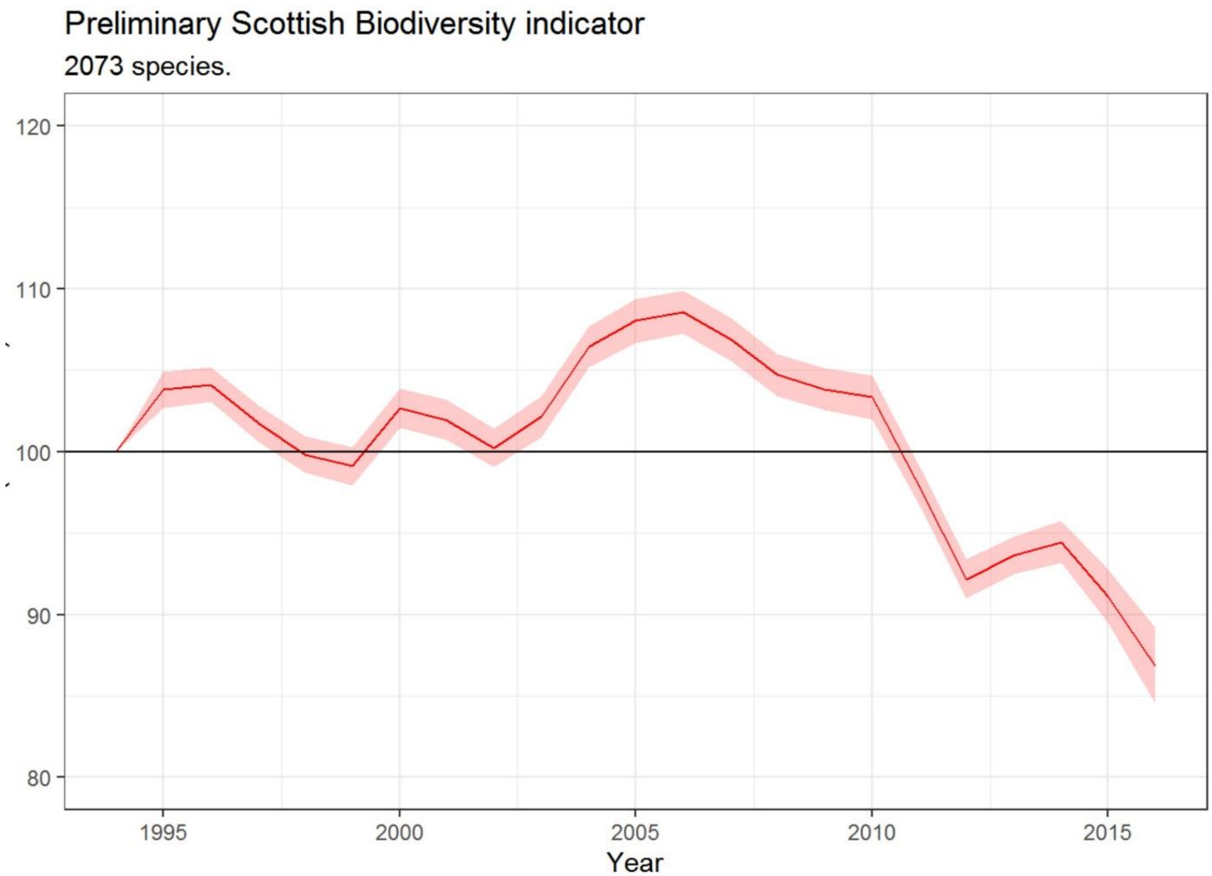
156. Differences being the now widely circulated and used metrics in the State of Nature Scotland 2019 report and the draft composite indicator do have the

potential to cause confusion unless carefully communicated. However, a similar broad pattern of biodiversity loss is shown by both measures

157. As stated previously, the draft indicator is derived from existing data sources that are updated annually by funded monitoring programmes. To a large extent these programmes also run analyses to produce updated indices on an annual basis, or routinely make data available for those analyses to be conducted (biological records submitted to the BRC are used by the CEH to generate occupancy trends annually, under a JNCC-funded work programme). **A relatively small amount of work would be required on an annual basis to update the combined indicator**: to collate species trends, derive trends for the small proportion of species for which these are not readily available (e.g. to analyses ICES data for demersal fish using the approach developed by this project) and to calculate the indicator using the code provided.

158. The indicator proposed is, we feel, the best option currently available to represent change in terrestrial and marine biodiversity in Scotland although, as emphasised above, is very imperfect. We have in this report identified a range of steps that might be taken to improve upon this indicator. Some are far-reaching changes to the structure of biodiversity recording, such as those recommended by the SBIF review (Wilson et al. 2018) to lead to a much improved system for biodiversity data collection, collation, curation and use in Scotland: if implemented this would lead to many improvements in data availability.

Figure 6. Proposed indicator for Scottish terrestrial and marine biodiversity, 1994-2016, produced from data on trends in abundance and occupancy in 2,073 species. The red line shows the indicator (derived using the Bayesian method) and the ribbon shows the 95% credible intervals.



159. This indicator increased by 9% from 1994 to 2006, but declined thereafter to a level 13% below the 1994 level in 2016.

9. Further recommendations

9.1 Disaggregation

160. The single line in the proposed headline indicator, incorporating trends in an extremely wide range of species across disparate taxa, collectively found in most if not all of Scotland's habitats and regions, and responding both positively and negatively to a disparate range of drivers, is intended to reflect the most broadscale changes in the country's biodiversity. However, amalgamating such a wide range of data means that the single line can mask massive variation in trends between species, and such variation may reflect wider patterns of change. A relatively stable headline indicator can, for example, hide very substantial declines in abundance and occupancy of particular species groups, or within particular habitats or regions, if other groups are showing increases. As such, the headline indicator alone may be a misleading measure of biodiversity health; **we strongly recommend the simultaneous and linked publication of disaggregated indicators to aid interpretation (and avoid misinterpretation) of the headline indicator.**

161. The most straightforward approach to presenting disaggregations of the headline biodiversity indicator is to identify relevant subsets of the species trends of which it is comprised. **Simple options include by realm (terrestrial, freshwater and marine), by taxon, and by the two currencies by which trends are measured, abundance and occupancy.** We present draft disaggregations of these in Figures 7-9. Note that these drafts are intended as examples of what is possible; they have been calculated using the geometric mean method, not the new hierarchical modelling approach we advocate for the published indicator. Additional divisions are possible - further taxonomic breakdowns, for example.

Figure 7: disaggregation of headline indicator by realm. The three lines show composite metrics of change for freshwater, marine and terrestrial species, respectively. In each case, the solid line shows the geometric mean across species and the ribbon delimits 95% confidence intervals derived from bootstrapping. The thin black line is the geometric mean of the three realm-specific geometric means.

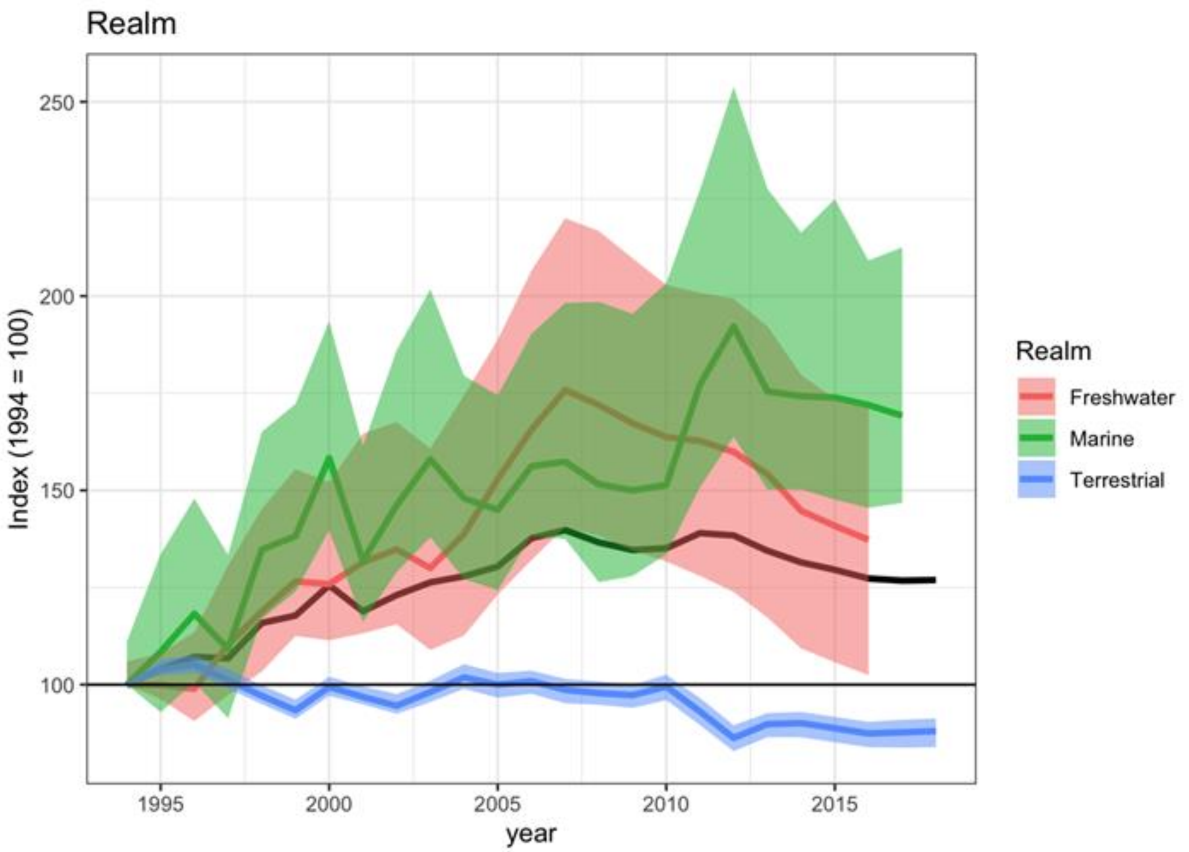


Figure 8: Disaggregation of headline indicator by higher taxonomic group

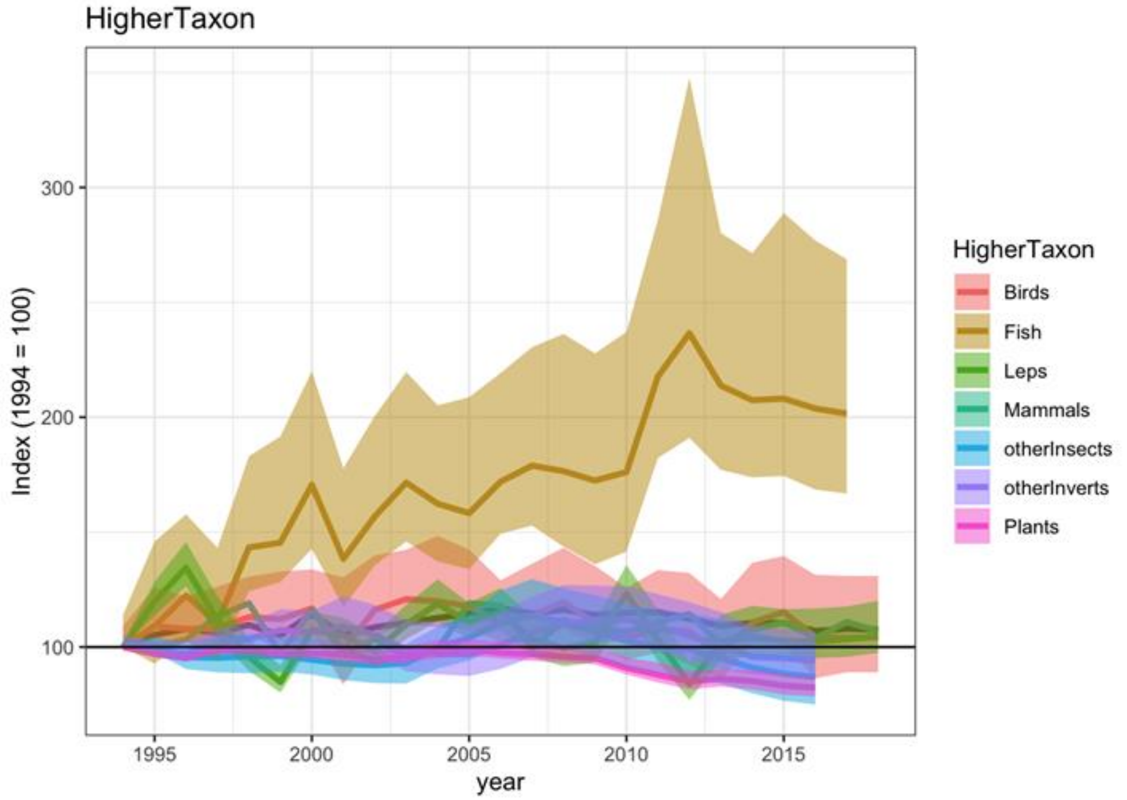
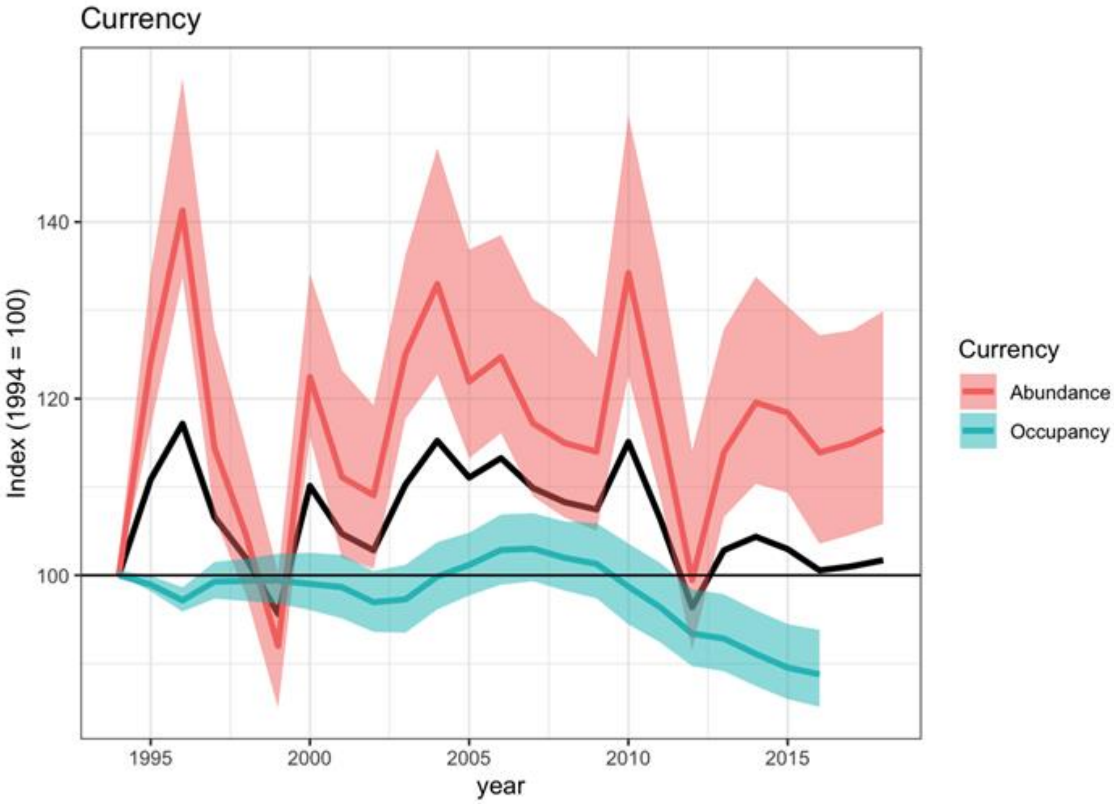


Figure 9: Disaggregation of headline indicator by trend 'currency'



162. These disaggregations aid interpretation; additional disaggregations may be equally or even more informative but may require more work to produce. In some cases, indicators might not be straightforward divisions of the trend dataset used to create the headline indicator, but involve additional analyses of the original data sources. **Two obvious disaggregations are by habitat, and spatially (e.g. Scottish regions).**

163. **Habitat.** Two broad approaches can be used to present trends in biodiversity by habitat. The first is to define species by habitat, then produce indicators by grouping species by these definitions and using their national trends. This approach is commonly used for wild bird indicators, such as those within the UK Biodiversity Indicators (indicator C5), in which bird species are defined as belonging to farmland, woodland, wetlands, or seabirds and indicators created for these groups. Typically species are assigned to just a single habitat, although there are instances in which they may be included in more than one habitat class. The habitat designations used are derived from published literature. A similar approach would be possible for biodiversity in Scotland, for those groups for which such habitat definitions are available; such definitions have been created for some taxonomic groups e.g. for vascular plants (Hill *et al*. 2004), although there is variation in the methods used. Approaches using a standardised approach to

allocate species to preferred habitats, such as that of Redhead *et al*. (2016) who analysed the distribution of biological records in relation to land cover data, may be worthy of further exploration.

164. The alternative approach to producing habitat-specific indicators is to generate trends using only data from specific habitats. This approach has been explored for wild birds and for butterflies in England, for which sufficiently large and robustly-sampled datasets exist to enable habitat-specific trends to be produced for individual species (Newson *et al*. 2008) which can thus be combined to produce indicators (Renwick *et al*. 2012). However, the capacity to do so is severely constrained by sample size, as well as the structure of species' datasets, and this approach is unlikely to be possible for a large proportion of species in Scotland.

165. **Regional.** There is obvious merit in being able to look at spatial patterns of biodiversity change by producing indicators for regions within Scotland and Scottish waters. Unfortunately, at present there is little possibility of doing so. None of the monitoring programmes generating species' trends incorporated in our draft indicator currently produce trends at a spatial scale smaller than all-Scotland. While this might be possible for those more abundant species, for which sample sizes might be sufficient to support the generation of trends at a smaller spatial scale (e.g. 'regional', however that might be defined), this will be a minority of species, and the species for which it is possible will vary between regions. Furthermore, this will introduce a substantial bias towards species with larger datasets (i.e. that receive more recording effort, and more detectable, or are more abundant) and so interpreting change in resultant regional indicators, in comparison with the headline indicator for Scotland, will be extremely difficult. It is conceivable that developments in citizen science-based biodiversity recording, such as those proposed by the recent SBIF review (Wilson *et al*. 2018), may eventually strengthen data flows to the point at which regional disaggregation becomes viable.

9.2 Reviews

166. **Whilst we believe the headline biodiversity indicator recommended in this report, if accompanied by a range of disaggregated indicators to aid interpretation of patterns of change, is the most suitable format possible currently, it is clear that it has a number of shortcomings.** Some of these concern the availability of sufficient data to avoid bias in the representation of taxonomic groups, realms and habitats.

167. **We recommend a programme of regular reviews of the indicator and the data contributing to it, in order to identify developments to address shortcomings**. In particular, such reviews could identify new sources of species' trends suitable for incorporation (for example, when the National Plant Monitoring Scheme has collected data for a sufficient length of time, and with a sufficient sample, to produce trends for vascular plants in Scotland), and identify datasets which could produce appropriate species' trends with suitable collation and analysis (see section 9.3 below).

9.3 Improving indicator coverage

168. Our review of suitable data for inclusion in a headline biodiversity indicator identified a number of data sources that might be of value but are not currently available in a format for inclusion in the indicator. Given the relatively low number of trends for marine species that we have been able to incorporate in our draft indicator, **we recommend that if possible further effort should be focussed on enabling the inclusion of more marine species' trends.** There are a number of existing datasets which seem to offer considerable potential:

169. The Marine Biological Association's MarClim project has an extensive time-series (from the 1950s onwards) of rocky shore species across a range of taxonomic groups, surveyed annually at over 100 recording locations.

170. The Ocean Biogeographic Information System (OBIS) is an open-data repository for marine biodiversity records, holding over 50 million records globally. Initial research by project team members (TW and NI) has identified the potential for deriving trends in species' occupancy from this data, in a similar way to those terrestrial trends already utilised within our draft indicator.

171. Seasearch, a Marine Conservation Society project, has encouraged the recording of biodiversity records by amateur divers since the 1980s. As with OBIS, occupancy-modelling methods might be applied to this dataset in order to derive species' trends.

172. Data on marine mammals are available from a number of sources, with differing spatial coverage. New analytical approaches, developed under the Marine Ecosystems Research Programme (MERP), may offer the best opportunity incorporate cetacean trends at a later revision, pending peer-review of the new methods.

173. As well as bottom trawl data for groundfish, ICES survey data for pelagic fish is available freely. The resources of this project did not allow us to develop dataflows and analyses for generating suitable abundance trends from this data, notably because the R interface to allow access to data requires further development.

174. Coverage of terrestrial and freshwater species is, in comparison with marine biodiversity, more robust. Incremental improvements in biological recording will mean future improvements in the availability of occupancy trends, but this may not be sufficient to address the significant gaps such as the lack of data on trends in fungi. At present, we do not have vascular plant trends for Scotland as concerns raised by data stakeholders over inconsistencies in recording efforts over time mean the trends derived to date are not regarded as suitable for use. It is possible that this can be resolved with further investigation; alternatively, the National Plant Monitoring Scheme will enable abundance trends to be included in the indicator from 2015 onwards. It is unlikely, however, that such trends will be available for range-restricted and rare species, whereas those from biological records may be.

9.4 Data flows

175. The continued publication of a biodiversity indicator dependent on species' trends derived from both structured monitoring programmes (e.g. the UK Breeding Bird Survey and UK Butterfly Monitoring Scheme) and the analysis of biological records is reliant on the continuation of the data flows that enable these trends to be produced.

176. **At present, we believe the programmes that produce the 2,073 species' trends used in the draft indicator to be relatively secure.** Most of the structured schemes that produce trends in abundance are funded through long-term partnerships between NGOs, such as the Bat Conservation Trust, British Trust for Ornithology, Butterfly Conservation and the RSPB, and UK Government (Joint Nature Conservation Committee). The work of the Biological Records Centre is supported by the Natural Environment Research Council, with the analysis of occupancy trends funded by the JNCC. International Bottom Trawl Surveys are supported by the International Council for the Exploration of the Seas (ICES).

177. **However, such programmes are reliant not only on the continuance of funding, but moreover the wider support of biological surveillance through citizen science: the great majority of data used in the creation of our draft indicator (as with the existing NPF biodiversity indicator) are collected by volunteer surveyors and recorders.** This volunteer effort is reliant upon support,

e.g. to retain existing volunteers, engage and train new volunteers, maintain and increase standards, encourage efforts to strategically fill gaps in knowledge.

178. As well as the need to nurture the recording and monitoring community, there is a clear case for the transformation of existing infrastructure for biological recording to improve data flows and thereby ensure data collected becomes available for use, and thus encourages increased recording. Our consultation with data stakeholders, who are essential for the successful continuation of the proposed indicator, identified the implementation of the findings of *A Review of the Biological Recording Infrastructure in Scotland* (Wilson *et al*. 2018) as the key step in securing a step change in data availability in Scotland. This would not only secure the data required for the indicator proposed in this report, but enable substantial improvements in future iterations.

10. Acknowledgements

179. We would like to thank the other members of the project team - Prof. David Elston, Prof. Jeremy Wilson, and Prof. Richard Gregory - for their input to this report and the development of this proposal more widely. John Landrock, Scottish Government Environment Statistics, provided clear guidance on the requirements of this contract, and support throughout our work programme. We received valuable input from the members of the Scottish Government's Research Advisory Group for this project, all the experts who attended the three workshops conducted, and the members of the Scottish Biodiversity Strategy Science Support Group who commented on our proposal.

180. Finally, we wish to thank all those helped with the provision of data that has been utilised within the draft indicator.

11. Glossary of technical terms used in this report

Aichi targets: 20 time-bound, measurable targets adopted in the Strategic Plan for Biodiversity 2011-2020 in order to assess progress towards Convention on Biological Diversity goals.

Bayesian modelling: a statistical approach in which probability is used to represent all uncertainty within the model, both the uncertainty regarding the output but also the uncertainty regarding the input (aka parameters) to the model.

Biological records: validated records of species at a given location and time. Collected through a wide range of sampling approaches often without overarching design, and with varying resolutions (e.g. spatial). They are collated in a variety of ways, most notably by the Biological Records Centre (BRC) but also by a network of regional centres (Local Environmental Records Centres).

Confidence limits: the maximum and minimum values within which a value is believed to lie at a given level of probability. Often 95% is used to e.g. give the values either side of an indicator line within which the true value of the indicator is 95% likely to lie.

Demersal fish: species which live and feed on or near the bottom of water bodies (e.g. seas). Also referred to as **groundfish**.

Disaggregation: the analytical disassembly of categories that have been previously been combined together.

Generalised Additive Models: a class of Generalised Linear Model (see below) in which the usual linear relationships between the response and predictor variables are replaced by non-linear smooth functions

Generalised Linear Models: a flexible generalization of ordinary linear regression that allows for response variables that have error distribution models other than a normal distribution.

Geometric mean: a measure of average, which indicates the central tendency or typical value of a set of numbers by using the product of their values (as opposed to the arithmetic mean which uses their sum). Often used to calculate averages for measures of proportional change.

Indicandum: the subject to be indicated – in this case biodiversity.

Invasive species: an organism that causes ecological or economic harm in a new environment where it is not native – most often defined as a country in which it does not naturally occur.

Living Planet Index: a measure of the state of the world's biological diversity based on population trends of vertebrate species from terrestrial, freshwater and marine habitats.

Natural Capital: the stock of elements of nature (including living things, soil, air, water and geology) which directly or indirectly provide benefits for humans (often referred to as ‘ecosystem services’).

Occupancy-detection modelling: used to account for imperfect detection of organisms in surveys and to determine the probability of the true presence or absence of a species at a site.

Pelagic: relating to open marine waters e.g. pelagic fish, excluding zones near the bottom of the sea, so not including fish defined as demersal (see above).

Red list: an inventory of the conservation status of species, usually defining risk of extinction using a formal process governed by the IUCN (International Union for the Conservation of Nature), although alternative red-listing approaches do exist.

Smoothing: use of functions to remove minor fluctuations (“noise”) in an ordered series to reveal underlying trends.

Weighting: the use of factors to increase or decrease the importance of given data points. Often used to address biases in sampling across different groups.

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Appendix 1: Sources of species' trend data selected for indicator

Taxon	Currency	No. species	Source
Ants	Occupancy	6	Bees, Wasps and Ants Recording Society
Aquatic Bugs	Occupancy	9	Aquatic Heteroptera Recording Scheme
Bats	Abundance	5	National Bat Monitoring Programme
Birds	Abundance	64	Breeding Bird Survey
Birds	Abundance	24	Rare Breeding Birds Panel
Birds	Abundance	13	Statutory Consveration Agency and RSPB Annual Breeding Bird Scheme
Birds	Abundance	14	Seabird Monitoring Programme
Birds	Abundance	31	Wetland Birds Survey
Bees	Occupancy	20	Bees, Wasps and Ants Recording Society
Bryophytes	Occupancy	328	British Bryological Society
Butterflies	Abundance	25	UK Butterfly Monitoring Scheme
Carabids	Occupancy	13	Ground Beetle Recording Scheme

Centipedes	Occupancy	7	British Myriapod and Isopod Group – Centipede and Millipede Recording Schemes
Craneflies	Occupancy	8	Cranefly Recording Scheme
Dragonflies	Occupancy	22	British Dragonfly Society – Dragonfly Recording Network
Empid & Dolichopodid flies	Occupancy	9	Empididae, Hybotidae & Dolichopodidae Recording Scheme
Ephemeroptera	Occupancy	18	Riverfly Recording Schemes: Ephemeroptera, Plecoptera and Trichoptera
Fungus Gnats	Occupancy	36	Fungus Gnat Recording Scheme
Gelechiid Moths	Occupancy	9	Gelechiid Recording Scheme
Ground Fish (marine)	Abundance	100	International Bottom Trawl Survey
Hoverflies	Occupancy	101	Bees, Wasps and Ants Recording Society
Ladybirds	Occupancy	6	UK Ladybird Survey
Leaf and Seed Beetles	Occupancy	1	Leaf and Seed Beetle Recording Scheme
Lichens	Occupancy	437	British Lichen Society

Millipedes	Occupancy	8	British Myriapod and Isopod Group – Centipede and Millipede Recording Schemes
Molluscs	Occupancy	56	Conchological Society of Great Britain and Ireland
Moths	Occupancy	239	National Moth Recording Scheme
Moths	Abundance	215	Rothamsted Insect Survey
Orthoptera	Occupancy	5	Grasshopper Recording Scheme
Plant Bugs	Occupancy	9	Chrysomelidae Recording Scheme
Plecoptera	Occupancy	13	Riverfly Recording Schemes: Ephemeroptera, Plecoptera and Trichoptera
Spiders	Occupancy	164	British Arachnological Society
Terrestrial Mammals	Abundance	4	Breeding Bird Survey
Trichoptera	Occupancy	45	Riverfly Recording Schemes: Ephemeroptera, Plecoptera and Trichoptera
Wasps	Occupancy	3	Bees, Wasps and Ants Recording Society
Weevils	Occupancy	6	Weevil and Bark Beetle Recording Scheme

Appendix 2: Consultation documentation

Appendix 2.1: Attendees at consultation workshops

Workshop 1, 23rd April 2019

- Botanical Society of the British Isles: Chris Miles
- British Ecological Society: Maggie Keegan
- British Trust for Ornithology: David Noble, Mark Wilson
- Buglife: Craig Macadam
- Highland Biological Records Centre: Ro Scott
- James Hutton Institute: Robin Pakeman
- Joint Nature Conservation Committee: Chris Cheffings
- Marine Scotland: David Stirling
- National Biodiversity Network: Jo Judge
- RSPB: Mark Eaton, Ellen Wilson, Jeremy Wilson
- Scottish Government: John Landrock
- Scottish Wildlife Trust: Gill Douse
- SNH: David O'Brien
- UK Centre for Ecology & Hydrology: Nick Isaac

Workshop 2, 24th April 2019

- Cefas: Murray Thompson
- Marine Biological Association: Dan Lear
- Marine Conservation Society: Calum Duncan
- Marine Scotland: Kirsty Bosley, Tom Reilly
- RSPB: Mark Eaton
- SNH (retired): John Baxter
- University of Sheffield: Tom Webb

Workshop 3, 17th July 2019

- British Ecological Society: Brendan Costelloe, Maggie Keegan
- British Trust for Ornithology: Ben Darvill
- Buglife: Craig Macadam
- Butterfly Conservation: Paul Kirkland
- Highland Biological Records Centre: Ro Scott
- James Hutton Institute: Robin Pakeman
- Joint Nature Conservation Committee: James Williams
- Marine Scotland: Kirsty Bosley
- National Biodiversity Network: Jo Judge
- NFU Scotland: Emma Bradbury
- RSPB: Mark Eaton, Jeremy Wilson

Scottish Government: John Landrock, Sarah McCutcheon
Scottish Wildlife Trust: Gill Douse
SEPA: Scot Mathieson
SNH: John Baxter, David O’Brien
UK Centre for Ecology & Hydrology: Nick Isaac

Appendix 2.2: Document circulated for consultation with RAG:

This interim report outlines the different approaches, and associated issues, that could be used to create a high-level Scotland biodiversity indicator, while the associated data review highlights potential sources of information. We believe that the approaches employed elsewhere, and the availability of biodiversity data for Scotland, point towards an approach based upon trends in species status measured in both abundance and occupancy, available for both terrestrial and marine habitats. The report authors' will be meeting the Scottish Government's Research Advisory Group (RAG) on the 15th May 2019 to discuss and narrow down the options for the next stage of the project, short-listing potential indicators. To help this process, a number of questions have been developed:

Indicator presentation

Given the issues raised above, can the RAG confirm that there is no option in final presentation other than a single index line presented without any estimate of error? **This was confirmed.**

Would the RAG prefer a single simple measure of a relevant biodiversity variable, or a composite from a narrow range of measures (e.g. bird trends), or would they be happier with a composite combining a wider spread of biodiversity data from disparate sources and potentially measured in differing currencies? **The balance of opinion was in favour of a broader composite indicator.**

Related to the question above, does the final indicator need to be easily understood/interpreted by the public (e.g. a measurable of change in abundance), or would a more complex measure – albeit one that still follows an 'up = good, down = bad' basis – be acceptable? **No clear recommendation; although the former approach is preferable, it was accepted that some indicators are more complex (e.g. Natural Capital Index)**

Does it need to be updated annually and what time lag in reporting (time since last year of data) will be acceptable? **Annual update was preferred but not essential. Time lag of no greater than three years, although shorter would be preferable.**

Data inclusion

We understand the focus on a current indicator, and that a start date in 2007 would be desirable, but how valuable would a longer time span be? There is potential for reporting of biodiversity trends for considerably longer which might enable an indicator to span a longer period and would provide valuable context to more recent changes. Options could include from as far back as 1970, from the change of government administration in 2007, or a more recent trajectory e.g. the last five years. **There was considerable support for an indicator with as long a timeline as possible**.

The composition of existing species-based indicators often changes through time as species data starts e.g. the existing UK species-based indicators start in 1970, but with new species entering the index at later dates as their monitoring began. Is the RAG happy with this for this indicator? **Yes.**

Depending on design, there is considerable potential for the indicator to become more robust in the future as new data becomes available e.g. to fill substantial gaps in the taxonomic representivity of the indicator, or as new methodological developments lead to improved analyses. Would the RAG be happy with the intention of future development, perhaps managed by periodic reviews? **Yes.**

In the event of such future revision, this may mean retrospective changes in the indicator – the addition of new data sources for previous years, or new analytical methods, may mean changes in index values for years already published. Would the RAG be comfortable with this? **Yes.**

We are disinclined to pursue indicator options based upon/incorporating proxy data e.g. on habitat extent or condition. Are RAG content with this? **Yes.**

Likewise, we are not convinced of the suitability of indicator options that are based upon species data in the form of diversity indices, measures of turnover, homogeneity, and Red List Indicators, with our preference being an average measure of species' status. Do the RAG have any thoughts on this, and any exceptions that they would like us to consider further? **RAG were happy for the focus to be on a metric of average species' status.**

Answers to the questions above notwithstanding, our current thinking is that the indicator will be a composite from species trend data. This will likely encompass the different currencies of abundance and occupancy data. Does the RAG have any opinion on the treatment of these metrics and whether they can be treated equally (e.g. combined straightforwardly into a single measure) or not (e.g. so may need to be treated separately to create sub-indicators that can then be merged, in an approach not dissimilar to the NCAI). **Although some concern expressed, on balance RAG were happy for abundance and occupancy trends to be merged.**

Alternatively, does the RAG have a preference for one of these metrics over another? **Abundance regarded as better measure of change in species status, but the benefits of the larger sample of occupancy trends recognised; in effect, very difficult to choose one as preferable to the other.**

For the consideration of marine biodiversity, the authors believe the indicator should consider the full reach of Scottish seas, therefore propose considering data from within the Exclusive Economic Zone (to 200 nautical miles) rather than territorial waters (12 nautical miles). Is the RAG happy with this suggestion? **Yes.**

Disaggregation

The RAG has previously expressed interest in indicator disaggregations, but we expect our ability to do this will be limited by data. Taxonomic disaggregations will be possible, and by data source/type, but others – habitat, spatial – will be either impossible currently or constrained by resources. How important is this to RAG, and will there be future interest in resourcing work to take this forward e.g. to identify disaggregations likely to respond to specific policy interventions? Our recent engagement with data stakeholders indicated a high level of interest in the provision of such contextual supporting information amongst this community (whose cooperation is essential for the creation of the headline indicator). **RAG members recognise the restrictions around the headline NPF indicator, but are very supportive of the publication of disaggregations through other routes.**

Should all the disaggregations be nested together, or would the RAG be happy with multiple types of disaggregation? For example, the Living Planet report presents disaggregations both by taxonomic group and by major habitat. **No clear opinion – but interest in a wide range of disaggregations, not all of which are likely to be possible, at least in the short term.**

Resourcing

What resources might be available beyond the scope of this current work in order to create/revise the final indicator in the future? For example, what is the scope of resources available each year to collate data outside the usual published data streams? Does this mean we should avoid the inclusion of data that may require annual processing outside the scope of other funded work streams, in order to minimise future resource requirements? **No certainty over future funding, but advised that whilst future developments could be recommended, Scottish Government would not be able to commit to development funding at this stage; we are recommended to identify a draft indicator that can be produced using current data streams, with a limited amount of collation and processing time required.**

The availability of terrestrial data, and the analyses required to produce species trends from this data, suggest that an indicator for terrestrial and freshwater biodiversity may be delivered within the scope of this project, albeit with recommendations for further improvements. However, the same can only be said for a proportion of the data required for a robust marine indicator (e.g. for demersal fish), with the time required to obtain and analyse other marine datasets being beyond the scope of current resources. We would wish for advice from the RAG as to how to approach this issue. **No clear solution other than to do our best to incorporate marine data.**

Appendix 2.3: Short note circulated to SBS SSG for input on indicator decision-making

Short note: progress on developing a Biodiversity Indicator for Scotland

Work to date

The following work has been conducted by the consortium working on the Scottish Government contract SPB/001/18, Development of a Combined Marine and Terrestrial Biodiversity Indicator for Scotland, by the project team from the RSPB, James Hutton Institute, Centre for Ecology & Hydrology and University of Sheffield.

- A review of the potential approaches for reporting on the state of biodiversity at a high level, drawing on practice in the UK, its constituent countries and further abroad.
- A review of the available terrestrial and marine biodiversity data. As well as species data, which often underpins biodiversity indicators, we considered a wider range of environmental data which might be used as a proxy for biodiversity.
- Collation of existing biodiversity to be used in the creation of draft indicators.
- Extensive consultation, with the Research Advisory Group and through three workshops with a wide range of consultees. Two workshops focused on data sources, for terrestrial and marine biodiversity separately; the third workshop focused on indicator creation.
- Inception and interim reports have been submitted to Scottish Government, describing the work listed above and the decisions made as a consequence.

We have, through the work described above, made decisions on the key elements of the biodiversity indicator which we will recommend to Scottish Government in a final report due to be submitted by the end of September 2019. This short note summarises this progress, and identifies in **bold text** the key issues which this work, including the consultation with relevant stakeholders, has made decisions on. Further to this we have ***highlighted*** the decisions on which we would most like to invite comment, to be considered in the final days of this project, although feedback on any other considerations would be welcomed.

Our conclusions

- The indicator will use the well-established approach, as used in the indicator on terrestrial birds which was part of the previous National Performance Framework, and in a number of the UK Biodiversity Indicators, **of calculating the average trend from a wide range of individual species trends.**

- **The indicator should use as many species' trends as possible,** to reduce various sources of bias e.g. taxonomic. In order to do so, the indicator could incorporate **both trends in species abundance,** as are available for species for which trends are derived from structured monitoring schemes, and **trends in occupancy**, a measure of distribution derived from Bayesian modelling of biological record datasets.
- A combination of robust standardised monitoring schemes, and recent CEH-led developments on the analyses of ad-hoc data, mean trends in either of species status are available for approximately 2,400 species native to Scotland and Scottish waters: an extremely impressive resource for the creation of biodiversity indicators.
- We will use established approaches, e.g. based upon sample size, to identify species' trends of sufficient robustness for inclusion in the indicator and filter out those of insufficient quality. For species which trends in both abundance and occupancy are available, the abundance trend would be used in preference to that in occupancy.
- Trends in abundance, and trends in occupancy are essentially different 'currencies' that are not directly comparable with each other. An indicator produced through combining these two will present some challenges in interpretation and communication. ***Nevertheless, we recommend that they should be treated as equivalent measures of changing species' status and combined*** in order to make best use of the available data, and produce an indicator as representative of Scottish biodiversity as possible.
- Data for marine biodiversity are considerably sparser, available for a much more restricted range of species than for the terrestrial realm. At present we have identified species' trends in abundance for groundfish (from bottom trawl surveys), marine mammals, and breeding seabirds for incorporation in the indicator. Trends for 88 species of marine groundfish are derived from bottom-trawl surveys from ICES, from the early 1980s onwards. Two versions of this dataset exist. Data are available from ICES, via the DATRAS portal in almost real-time, having received some filtering for data errors. Alternatively, Marine Scotland (MS) have created an improved dataset (Moriarty & Greenstreet 2017) with considerably more rigorous quality control, for use in OSPAR assessments. At a species level, species trends derived the two data sources vary in a non-consistent way i.e. they match for some species, and show marked discrepancies for others. When combined into multi-species indicators, the two versions show some consistency in overall pattern but differences in magnitude of change particularly in recent years. The MS data, with better quality control, is more robust, but to our knowledge there are no plans for its revision currently, and so is not available beyond 2017. **Unless future updates of this are likely to be available, we will recommend the use of the ICES dataset.**
- Species' trends suitable for inclusion in the indicator have start years from 1970 onwards, but the number and type of dataset increases through time as new

monitoring schemes originated. Whilst the priority is a robust indicator going forward in time, and measurement of change over recent years, it has been acknowledged that an indicator encompassing as much historical timeline as possible would be preferable. ***We recommend a baseline year in the mid-1990s, aligned with the introduction of a large number of abundance trends for birds and mammals.***

- We have identified a number of data sources which may prove to be valuable for inclusion in a future iteration of the indicator, thereby improving robustness. However, at present considerable further work (e.g. collation, analysis) is required to enable such datasets to be made available for use in an indicator, and such work is well beyond resources of this current project. We recommend, however, that further consideration is given to development work to enable future inclusion of such data. This is most pertinent for a number of marine datasets, e.g. data gathered on abundance of a range of intertidal species through the long-running MARCLIM project, as well as for terrestrial plants to address that gap in data availability.
- Existing workflows enable the production of annual trend updates from most of the data sources identified, enabling the indicator to be updated annually with relatively little effort. At present, we have permission from data-owners to use these trends for the purpose of this contract – to identify a suitable indicator – and not for a finalised, published indicator. However, we do not expect permission for a finished and published indicator to be withheld.
- There are a number of options for the creation of a final, single headline terrestrial and marine indicator using the species data as outlined above. Whilst each employs the same basic approach of calculating an average trend across all species trends, there are a number of options for stratification: employing weightings in an attempt to address biases in the availability of species' trends. Such biases include between terrestrial/freshwater and marine realms (we have far more trends for terrestrial/freshwater species than marine species); between taxonomic groups (there are considerable disparities in the representation of taxonomic groups e.g. species trends are available for a high proportion of birds, but a low relatively proportion of invertebrates); and in trend type (more species are represented by trends in occupancy than distribution). Note that we cannot address biases when data for desired underrepresented groups are not available at all e.g. fungi.
- We have, however, been unable to identify an objective manner in which to identify the appropriate approach to weighting e.g. by identifying which biases are most important to address, and how they should be addressed. Consultation to date has failed to identify a preferred option, and there is no published precedent to follow. In addition, further development work would be required in order to identify how to incorporate measurement of error within a weighted indicator. ***Therefore, our recommendation is that all available species trends***

should be incorporated in the indicator without weighting, each having an equal influence upon the indicator.

- Whilst fulfilling the requirements for a headline indicator for inclusion in the National Performance Framework indicators, the indicator recommended by this work will be difficult to interpret in terms of underlying biodiversity changes and the drivers of these changes. **We strongly recommend the publication (which could be as supporting material to the headline indicator, or entirely separate) of disaggregated indicators to show patterns of change in constituent groups of the headline indicator which will aid understanding of change in the headline metric.** Disaggregation could include by realm (terrestrial and freshwater, marine), by trend type (abundance and occupancy) and by taxonomic group. Further disaggregation, such as by region of Scotland or by habitat, might also be desirable but could require considerable additional work to achieve, or may not be possible given data constraints.

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