Biodiversity Indicators for Wales

A report to the Welsh Assembly Government

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Executive summary

Policy context

Wales has adopted a target of halting and reversing the decline in biodiversity by 2026. In order to evaluate progress towards this target, **Wales needs to develop a small number of headline indicators that measure the state and rate of change of biodiversity in Wales**. This report details the work we have carried out to develop a set of biodiversity indicators for Wales, with specific focus on species-level biodiversity, together with our recommendations.

Biodiversity indicators

Biodiversity indicators summarise the state of biodiversity over time, so that progress towards a target can be monitored. They should have several properties: they should be a **close proxy** for the true state of biodiversity, and robust to attempts to target actions at the indicator rather than biodiversity itself. They should convey **uncertainty** and be readily interpretable by scientists and laymen alike. They should not be too numerous, and finally they should be cost-effective to produce.

Review of indicators developed elsewhere

Many different biodiversity indicators have been developed. The driving force behind the creation of most indicators has been the availability of datasets, rather than a consideration of what is important and should be measured. This has resulted in **long, ad hoc lists of indicators**, which are neither aggregated nor weighted. Only a small proportion of these indicators report the state of biodiversity, and these tend to be **highly selective in their taxonomic coverage**, and focus on abundance rather than diversity. In reviewing established practice we identify three facets of species-level biodiversity: diversity, abundance and distribution. Endangered and priority species are often the focus of separate indicators, but **we recommend that priority species they be represented using as a subset of a headline abundance indicator**, since alternative approaches lack transparency and comparability. Indicators of invasive species are best treated as indicators of pressure, alongside other indicators of ecosystem integrity such as habitat fragmentation and the marine trophic index. This report focuses on indicators of state.

Statistical explorations of potential indicators

Using two Welsh datasets (terrestrial breeding birds and bottom trawled fish) we quantify two important sources of variability in biodiversity indicators: between sites and between species, and demonstrate that these are large relative to the trends observed in the data. We also demonstrate that the choice of index (relative vs absolute changes in abundance, species richness or evenness) has a marked effect on the trend observed. In consequence, **we advocate the weighting of species in the indicators by some or all of the following: trophic level, phylogenetic distinctiveness and the international importance of their Welsh population**. The choice of measures of central tendency (geometric or arithmetic means or medians) used to aggregate data within and between sites and species also has a very large influence on the trends reported and may obscure real variability. **We recommend the presentation of percentile or probability distributions without measures of central tendency.**

Data for the indicators

We carried out a comprehensive review of biodiversity datasets covering Wales. This review identified many datasets that could be readily included in the indicators from launch (i.e. 2010, 16 years before the deadline) or which had the potential to be included given modest improvements (e.g. by 2016, ten years before the deadline). **We recommend that these indicators be launched in 2010 (the International Year of Biodiversity), with additional data incorporated as it becomes available**, and **we recommend that WAG consider a modest investment of resources in order to facilitate the improvement of existing datasets**. We also note that some significant effort will need to be expended by the agency compiling the indicators, in order to gain access to all of the datasets.

Recommended indicators

We recommend two headline indicators, measuring **diversity** and **abundance**. These **indicators should aggregate across all taxonomic groups** for which data is available, and **all habitats.** Indicators should be presented using **percentile** or **probability distributions** with no measures of central tendency, which are deeply problematic for indicators. **These indicators are demonstrated in Figure 1 and Figure 2, below.**

Each indicator would be accompanied by a summary statistic detailing what proportion of biodiversity had increased or decreased over baseline, to aid interpretation.

The diversity measure should incorporate **regional and national diversity** as well as **local diversity,** either in a single indicator, or as supplementary indicators. The abundance indicator should be accompanied by supplementary indicators of **endangered/priority species** and of **geographical range.** The status of endangered species should be represented by recalculation of the abundance indicator for this subset of species, to allow direct comparability.

Some issues require further exploration. These include: which measure of diversity (pure richness or richness and evenness) is most appropriate for the diversity indicator; the possibility of aggregating diversity measures over several scales; the appropriate method for weighting species in indicators; and the degree to which bias and precision in indicators are affected by taxonomic selectivity.

All of our recommendations, together with issues needing further work, are summarised at the end of the report. We also make some suggestions concerning the **overall structure of the Welsh biodiversity indicators**, and note those aspects of biodiversity which are not yet well represented by indicators, including **higher levels of biodiversity** (communities, habitats and landscapes) and indicators of ecosystem integrity (pressure).

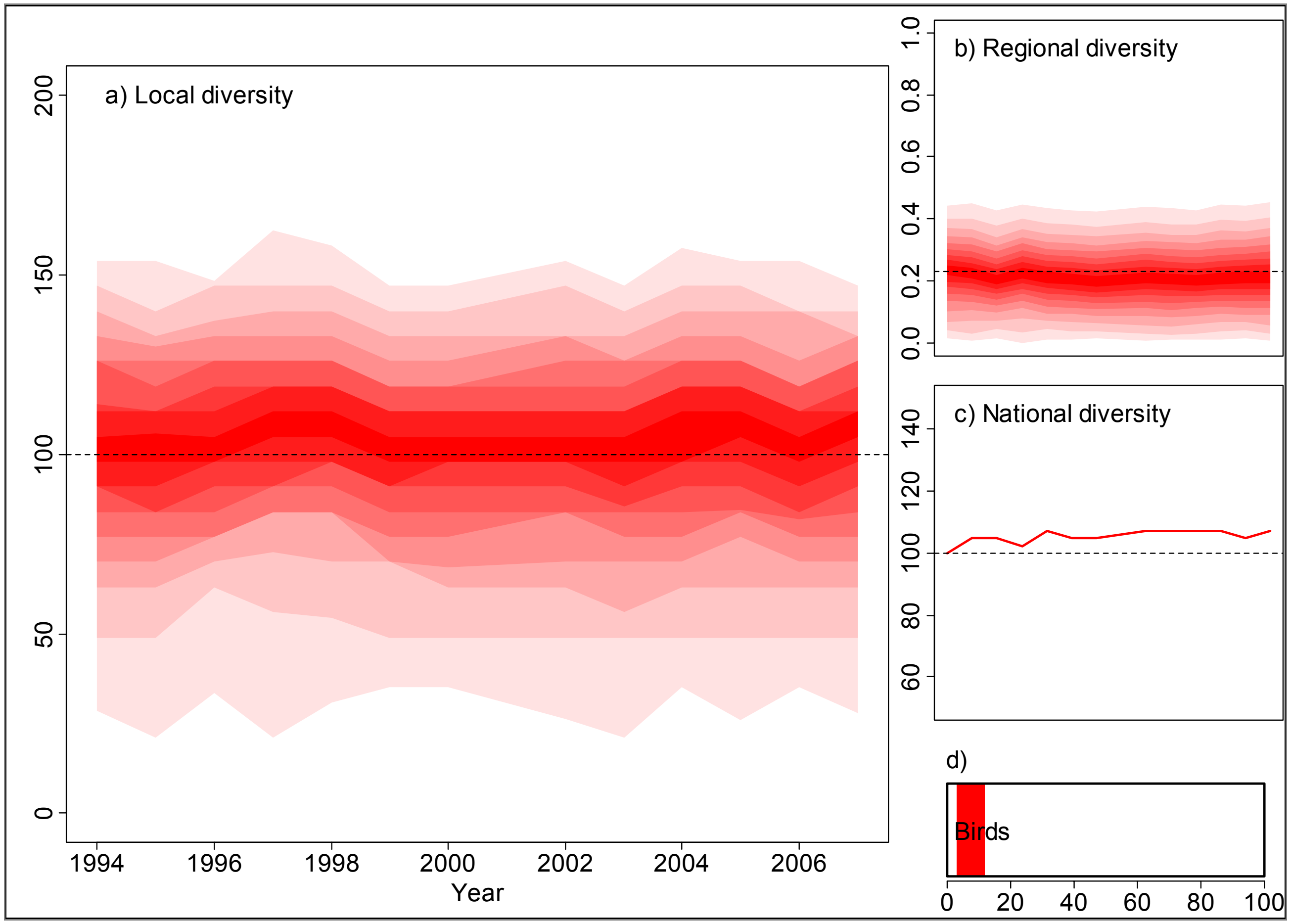

Figure 1. Suggested diversity indicator. (Figure prepared using the BTO breeding bird survey, actual indicator would incorporate data from all taxa). a) headline Indicator species richness at individual sites, b) between-site diversity where 1 is completely different species composition and 0 is the same species composition, c) total number of species at all Welsh sites, d) species coverage of all Welsh species. Shading indicates the percentage of sites for each diversity measure in 10% intervals, Inner darkest bands are the middle 10% of sites, 90% of sites lie within the outer lightest shading.

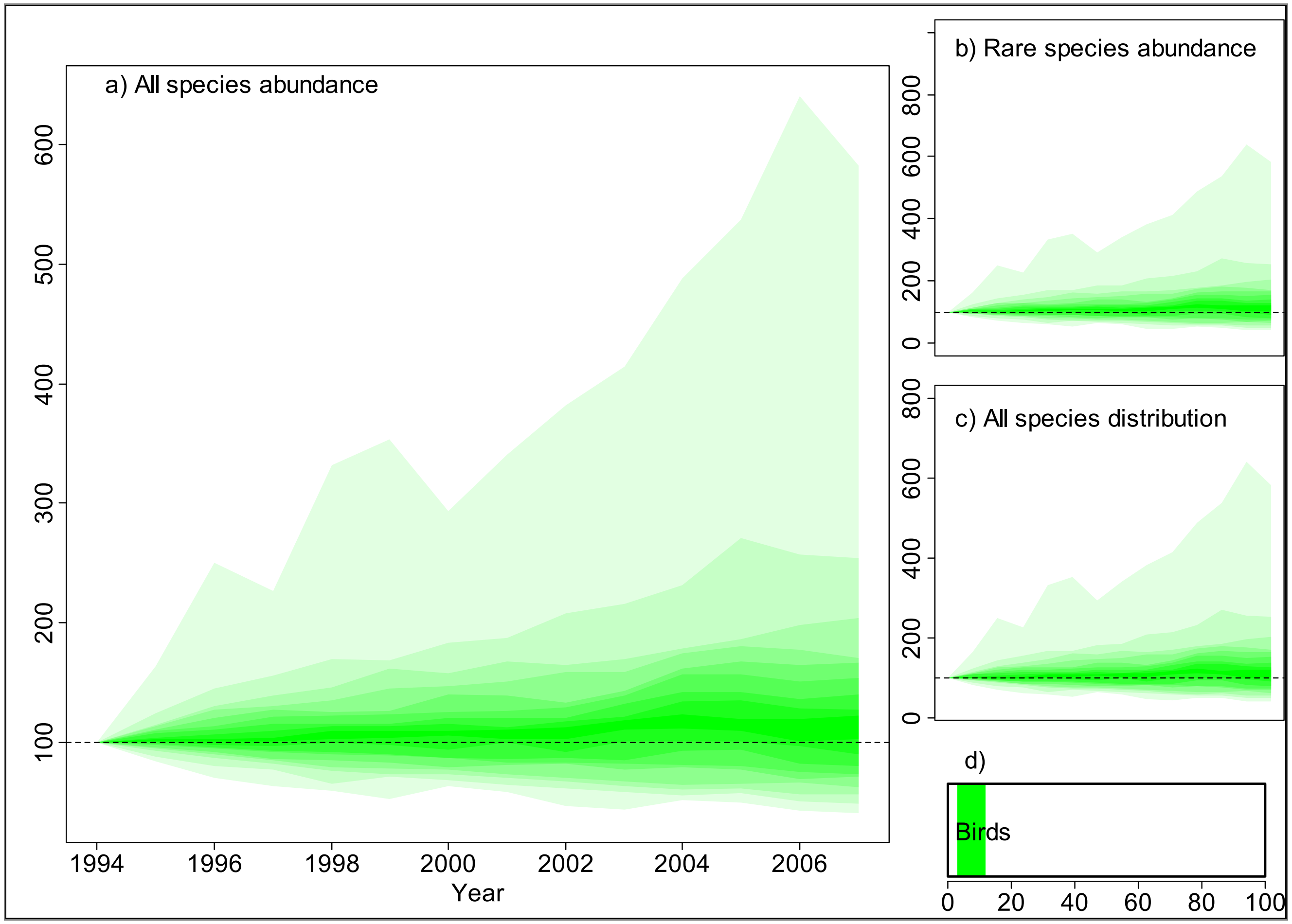

Figure 2. Recommended abundance indicator. (Figure prepared using the BTO breeding bird survey, actual indicator would incorporate data from all taxa). a) change in abundance for all species (1994=100), b) change in abundance for rare species, c) change in range for all species, d) species coverage of all Welsh species. Note that b) and c) are for illustration only and are the same data as a). Shading as previous figure.

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Abbreviations

BSBI- Botanical Society for the British Isles
BTO- British Trust for Ornithology
CCW- Countryside Council for Wales
CEBC- Centre for Evidence Based Conservation
CEFAS- Centre for Environment, Fisheries and Aquaculture Science
CEH- Centre for Ecology and Hydrology
CNS- College of Natural Sciences
DEFRA- Department for Environment, Food and Rural Affairs
JNCC- Joint Nature Conservation Committee
MBA- Marine Biological Association
RSPB- Royal Society for the Protection of Birds
SENR- School of the Environment and Natural Resources
WAG- Welsh Assembly Government

Contents

Policy context and project objectives

Biodiversity has clear economic and social importance, as recognised by Welsh and UK governments (WAG 2006, Defra 2009) and the international community (CBD 2006), but has deteriorated considerably over the past century. As a consequence, Welsh biodiversity is the subject of targets at the global, European, UK and Welsh levels. The international community, including the UK, has agreed to slow the rate of biodiversity loss by 2010 (CBD 2006), while the European Union has opted for a stricter target: halting the loss of biodiversity, also by 2010. Indicators measuring progress towards each of these targets have been identified, and are under development, but neither target is expected to be met by 2010 (Countdown 2010, 2009). Indeed, it seems likely that the indicators will not even be fully developed by that date (see review below).

Perhaps wisely, given the experiences at supra-national levels, Wales has opted for a more ambitious target, to be achieved over a longer time frame (by 2026):

Outcome 19: "*The loss of biodiversity has been halted and we can see a definite recovery in the number, range and genetic diversity of wildlife, including those species that need very specific conditions to survive*"

Box 1: Biodiversity Indicators

Biodiversity indicators are simply statistics which are repeatedly calculated through time to provide information about how biodiversity is changing. They can also be calculated to show trends in the threats to biodiversity, and actions taken to protect it (see Box 2). Like all statistics they provide a simple summary of what is often very complex data. Although they can help to make overall trends clearer, there is also a risk that they can obscure important details. They are also only as good as the data from which they are calculated. If this data is highly selective (e.g. from only one taxonomic group) any indicator based on it is unlikely to be represent the true state of biodiversity.

This target is one of five targets relating to biodiversity in the "Distinctive Biodiversity, Landscapes & Seascapes" theme, which also includes: Outcome 20 (wider environment is favourable to biodiversity); 21 (designated sites are in favourable condition); 22 (seas are healthy); 23 (relating to the quality and diversity of land/seascapes). Although some indicators have already been developed for these targets, the set is very incomplete. Specifically for outcome 19, indicators of wild bird populations, and state of Biodiversity Action Plan (BAP) species have developed, but indicators are still required "to illustrate range and genetic diversity of Welsh wildlife" (19c). This is the final report of a project commissioned by the Welsh Assembly Government, to develop options for a set of indicators for outcome 19. In particular, the project brief asked us to consider options for the range and diversity of species, and to make specific reference to endangered/priority species and non-native species.

Introduction to biodiversity indicators: concepts and issues

A large number of biodiversity indicators are already in existence or have been proposed and we review them in the next section. Here we first outline some desirable properties and features of indicators, and some points to consider when developing them.

Categories of indicator: driving forces, pressure, state, impact, response

Biodiversity indicators are often instinctively seen as indicators of the *pressures* on biodiversity, rather than the *state* of biodiversity (Gregory & Failing 2003). Thus, taxa are often chosen on the grounds that they are particularly ‘sensitive’ to certain threats (e.g. climate change or water pollution)[1]. There are serious problems with this approach as such taxa are, by definition, not representative of biodiversity as a whole, and therefore may tell us little about the state of biodiversity. They may provide a measure of a given threat, but often this can be measured more simply and directly in other ways: climate change is already measured more accurately by meteorologists than it ever will be by biologists, and monitoring of indicator species may be at least as difficult as monitoring abiotic factors[2]. Arguments in favour of using certain species on the basis of their “sensitivity” may simply be post-hoc justification of using existing data sets in an indicator.

Box 2: categories of indicators (DPSIR)

Driving Forces e.g. human population or ecological footprint. Factors which might be expected to influence biodiversity

Pressures e.g, Invasive species, habitat loss. Direct, proximal causes of biodiversity change.

State e.g. Species richness. Indicators of biodiversity itself.

Impact e.g. Social value of nature-based recreation. The effect of biodiversity change on society

Response e.g. Area protected or money spent on biodiversity protection.

A given indicator may fall into more than one category. An indicator of invasive species provides information directly about state (invasive species are themselves biodiversity) and pressure (invasives may have negative impacts on the rest of biodiversity).

This is not to argue that measuring threats is unimportant, but rather that we should be very clear about what any given indicator is measuring. To this end, biodiversity-related indicators can be divided into five categories, on

[1] For example, Scotland’s biodiversity indicators of state include one tracking otter populations, on the grounds that “As otters rely upon good quality fresh water; their presence and/or absence in fresh water are good indicators of water quality.” SNH (2009). An argument could of course be made for the inclusion of otters on the grounds that they are a particularly *valued* component of Scotland’s biodiversity (perhaps because of their public appeal), but that is quite another matter.

[2] It might be argued that indicators are required to measure the *effect* of a given threat on biodioversity, but this will always be complicated, with many confounding factors, and may be better addressed by research rather than indicators.

the basis of the part of the system for which they act as a proxy: driving forces, pressures, state, impact, response (Box 2).

Ultimately, indicators of state (and also impact) are the most important, since these measure what we actually value. Other indicators complement these, and may aid decision-making and our understanding of the system, but the objects they measure (threat reduction, protected areas) represent means to an end, rather than being ends in themselves.

Indicators are subjective, arbitrary and imperfect proxies for biodiversity

It is impossible to completely describe the state of biodiversity at any one time. This is partly because of the well-recognised constraints on data collection (sampling and measurement error, taxonomic and spatial bias). More importantly, however, it is because biodiversity is a complex meta-concept, comprising multiple facets, e.g. diversity, including species richness (the number of species) and evenness (the relative number of individuals of each species); abundance (number of individuals of each species); and habitat and community diversity (Scholes & Biggs 2005). It is difficult to define precisely (Magurran 2004), no definitions specify the relative weight given to each component and there is no objective basis on which to treat them as commensurable (Failing & Gregory 2003). This means that any indicator or set of indicators can only be a partly subjective and probably somewhat arbitrary proxy for the real, somewhat indefinable thing which society considers important. While science plays an important part in developing biodiversity indicators, they are not 'scientific' in the sense of being objective or value-free (Weber et al 2004), while at the same time, they do not necessarily reflect the trends in the true value of biodiversity to society.

Selectivity and representativeness

It is clearly desirable that indicators be as close as possible a proxy for the component(s) of biodiversity we wish to measure. This requires the indicator to possess two characteristics. The first is something with which scientists are very familiar: ensuring that the samples on which the indicator is based are representative of the underlying population (stratified, unbiased samples), and also that they are numerous enough that changes in the underlying population are detected with reasonable precision. If these characteristics are achieved, the trends observed from the samples on which the indicator is based will be an accurate reflection of the true state of biodiversity.

The second is something less familiar to ecologists who are used to collecting data to inform science rather than policy: that the relationship between the indicator (a summary statistic based on samples) and the true underlying state of biodiversity should be robust to changes in policy specifically targeted at the indicator. This will not be the case if policy becomes targeted at the sample, rather than the underlying state of biodiversity. For example, a particular species (e.g. the otter) might be selected for inclusion in an indicator on the grounds that it is "representative" (i.e. correlated with) other components of biodiversity which remained unmeasured. Even if this was true before the indicator is launched, it may not remain so. For example, captive breeding and augmentation of otter populations (which may be legitimate conservation actions) would boost the indicator, but might make little difference to the other components of biodiversity which were not included in the indicator.

There are numerous examples of targets and indicators distorting policy, perhaps the most famous being waiting time targets in the National Health Service, where the imposition of a target and indicator based on *maximum* waiting times for hospital admissions has increased *median* waiting times and distorted clinical priorities for admission (NAO 2001). It is imperative that those involved in developing biodiversity indicators learn from these examples. It is simply not possible to argue that politicians and agencies should be judged on the basis of trends in indicators, and not expect that they will consider the effect of their actions on those same indicators. Indeed, to the extent that the indicators do reflect an important reality, it would be inexcusable if they did not.

Since data quality is not usually consistent across all taxonomic groups, there may be a tendency to restrict indicators to a select group, in order to increase the "accuracy" of the indicator. In fact, any increase in accuracy may be misleading, since restricting the taxonomic range of an indicator also reduces its ability to represent the underlying state of biodiversity and may increase bias. Taxonomical selectivity may simply make true uncertainty larger and less well measured. It will also increase the potential for policy to be distorted, weakening the link between the indicator and the true underlying state of biodiversity. A good indicator, therefore, should be a close proxy of reality and be difficult to separate from it. Of course, increasing sample size and taxonomic breadth require resources, and a balance must be struck. The point is that the focus should not simply be on increasing sample sizes and within-group precision.

The role of indicators

Indicators summarise information (Box 1) to provide a succinct evaluation of the state of a system. Failing & Gregory (2003) identify three purposes of indicators: i) tracking performance (results-based management), ii) discriminating among hypotheses (scientific exploration), iii) choosing between alternative policies (decision analysis). A given indicator may play more than one role, but the authors considered that most indicators were directed towards the first two. This means that the effect of a given policy on an indicator tends not to be estimated before deciding whether to implement the policy. This is likely to depend on how long the indicator has been in existence, and how well-known it is amongst agency staff. The better-known, the more it is likely to affect policy decisions. The biodiversity indicators we develop in this report are primarily designed to track performance, with aiding understanding as a secondary purpose. They are not intended to be useful in choosing between specific policy actions, indeed, the aim is to design indicators which are so general and broad based as to be difficult to target specific actions towards them.

A key part of the policy process is scrutiny of policy and results by many different stakeholders: scientists, lay enthusiasts, the media and the general public. Indicators influence this scrutiny by focussing greater attention on the trends they report. They may do this in part by making existing attention more efficient by summarising dispersed information about a complex system in a relatively focussed set of indicators. They may also draw attention away from other aspects of the system which are not represented in the indicators. It is therefore important to recognise that headline indicators do not substitute for research, though in stimulating data collection and collation they may facilitate it.

Desirable properties of biodiversity indicators

Failing and Gregory (2003) identify ten mistakes commonly made in developing and selecting biodiversity indicators and several other authors have provided guidelines on the properties that a set of biodiversity indicators should have (e.g. Rees et al 2008, Failing & Gregory 2003, Balmford et al 2005, Buckland et al 2003, Scholes & Biggs 2005). We summarise the properties which we consider most important below:

- Biodiversity indicators cannot be developed without a clear vision of what biodiversity is and what is being measured (in particular the division between indicators of state and other indicators should be clear).
- Indicators should be a close proxy to the true state of biodiversity, or those facets of biodiversity which are considered important.
- Indicators should be useful for evaluating performance, without distorting policy.
- Indicators should be sensitive to the effects of policy change, at appropriate spatial scales.
- Indicators should be transparent and readily interpretable by laymen and scientists alike.
- Indicators should be easy to compare with agreed baselines and targets: indeed, indicators define them.
- Indicators should ideally enhance our understanding of the system, and aid in prediction of future states.
- Long lists of indicators should be avoided. Aggregating indicators is difficult and should be done in a framework which allows important details to be conveyed, and not subsumed.
- Indicators should be cost-effective, i.e. based on consideration of the cost required to obtain the required data if it is not currently available.

Review of biodiversity indicators and stakeholder opinion

In this section we review those indicators which have already been established. First we focus on three indicators sets which are very similar: global, European and UK. We then consider those of Scotland and Switzerland, which offer a contrast to the first three.

Global, European and UK indicators

Very similar indicators are used to monitor progress towards the 2010 targets at the international (Convention on Biological Diversity), European (European Environment Agency) and UK (Joint Nature Conservancy Council) levels, with only minor variations (Table 1). The indicators are grouped into seven focal areas, six of which are common to all three levels. Those most directly relevant to Outcome 19 are highlighted in bold in Table 1. In the table, the indicators are also cross-mapped onto the Wales Environment Strategy by noting those indicators for which a similar indicator is listed in the 2008 State of the Environment report (Statistical Directorate 2008). Each set includes indicators pertaining to several levels (from genes to ecosystems) and facets (diversity, abundance, distribution and integrity) of biodiversity, and all categories of the DPSIR framework. Thus only a relatively few indicators are directly relevant to outcome 19 as currently defined.

Despite this broad coverage, the indicators are usually rather selective, reflecting the available data, and are somewhat ad hoc. Particularly at the European and UK levels, little attempt has been made to develop synthetic indicators. Instead indicators are nearly always based on pre-existing data sets. The most notable exceptions are the Living Planet Index and the Red List Index, developed at the global level (and now being applied at regional and national levels).

At the international level, many of the indicators are based on rather sparse data. For example, the invasive species indicator is only derived from Nordic countries at present, whilst other indicators rely on remote-sensed or modelled data (forest fragmentation, nitrogen deposition) for selected regions. It seems likely that the way in which such indicators are calculated will change considerably over the coming years. Even at the European and UK levels, the indicators of state are highly selective both taxonomically (only birds and butterflies are used by the EEA) and in terms of the facets evaluated (only the UK includes a measure of diversity, in addition to abundance, and this only for plants[3]).

At all three levels numerous indicators and sub-indicators are used[4], with no attempt being made to weight or aggregate the indicators. Since at least some indicators are improving while others are deteriorating, any assessment is unlikely to be clear-cut. This reliance on a

[3] Confusingly, the EEA's indicator of bird and butterfly abundance is labelled "species diversity", but is in fact an indicator of abundance.

[4] CBD has 15 headline indicators, the EEA 26, and the UK 18. In each case there are also several sub-indicators, which are not aggregated. For example, the UK's abundance indicator consists of three separate indicators for birds, butterflies and bats.

long list of un-weighted (i.e. equally weighted) indicators is a common "mistake" noted by Failing and Gregory (2003).

Indicators of abundance and distribution

At the international level, the Living Planet Index (LPI) is used to aggregate existing data on vertebrate population sizes or ranges, from published sources, for 3,000 species of vertebrates (Collen et al 2009). Because inclusion in the index is determined by the availability of published data, the species and populations selected may not be representative, although Collen et al (2009) argue that the selection of species is not obviously biased by threat status, and the index is crudely stratified by biome (temperate, tropical, marine) to partially offset the paucity of data from the tropical regions.

The LPI is the geometric mean of relative population sizes. This is the formulation used for most indices of abundance, including the bird, butterfly and bat indicators used in Europe, the UK, Scotland and Wales. It has two important properties. First, because the geometric rather than arithmetic mean is used, the indicator is relatively robust to large changes in a single species (though see Figure 8, below). Second, and more fundamentally, because relative population sizes are used, a given percentage rise or fall in any species' population has the same effect on the indicator's value, irrespective of its absolute population size. This has the advantage of allowing species from different trophic levels (which may differ greatly in their population density) to be aggregated without high density species swamping the others. The disadvantage, illustrated in Figure 8 below, is that when applied regionally rather than globally, the indicator can be substantially affected by changes in the population size of marginal species with very small populations in the region. Below we discuss possible modifications to the indicator to address this issue, but the approach taken at present with the UK and Welsh wild birds indicators is to exclude species from the indicator if they are not found in a minimum number of survey sites. This has the effect of excluding species with limited distribution, but also excludes rare species which might be geographically widespread. It also takes no account of the importance of the domestic population relative to global populations of the species.

Threatened and priority species

All indicator sets highlight the status of endangered and or priority species. Two main approaches are used. Globally, and in Europe, the Red List Index is used to track changes in the status of certain groups of species – to date the index is only presented for birds, although it has been applied to other groups (Butchart et al 2007). This index claims to "track trends in the projected overall extinction risk of sets of species" (Butchart et al 2007). In fact, the index is based on the IUCN threat categories (IUCN 2001), which are adjectival rather than providing extinction probabilities, and often based on expert opinion as well as data[5]. For any given group of species, the Red List Index is calculated by assigning arbitrary weights to each

[5] The IUCN advises that "Assessors should resist an evidentiary attitude and adopt a precautionary but realistic attitude to uncertainty when applying the criteria, for example, by using plausible lower bounds, rather than best estimates, in determining population size, especially if it is fluctuating." IUCN 2001

threat category[6], and summing the threat category of each species in the group, before normalising to a scale from zero to one, where zero represents universal extinction, and 1 means that all species are classified as "Least Concern" (Butchart et al 2007).

The index, and the IUCN assessment procedure on which it is based, provide one way for expert opinion to be used, in cases where data are lacking. However, they are relatively opaque and as the quotes above demonstrate their quantitative nature may be misinterpreted. It may therefore be difficult to assess and easy to overstate their information content. Because of the precautionary approach taken, the index would be expected to rise (improve) over time if knowledge about species populations improved, even if their true populations had not changed.

The Red Listing process has been adapted for regional, rather than global use, and the European indicators include a Red List Index of European birds. To date, Red Listing has been applied at the Welsh level for vascular plants (Dines 2008), though no Index has yet been constructed[7]. Red Listing at regional levels requires further subjectivity, in that the assessor must make a judgment about the probability of domestic populations being boosted by immigration from neighbouring populations (except in the case of endemics, see Dines 2008).

The alternative approach used by the EEA, the UK and Wales (Indicator 19a) is to use assessments carried out on Biodiversity Action Plan species (species are assessed as: Unknown, Decreasing, Stable or Increasing) and to simply provide stacked bar charts showing the number of species in each category, at each successive assessment (Defra 2009, Statistics Wales 2008). This indicator has similar information content as the Red List Index, but by presenting the data qualitatively is perhaps more transparent. Nevertheless, the information content of the index is hard to assess, because it is not easy to determine what information has gone into species assessments.

Indicators of diversity

It is somewhat surprising that biodiversity indicator sets include few measures of diversity (i.e. the number and often the relative abundance of species). Global, EEA and UK indicator sets all include an indicator of genetic diversity of economically important species, but this is a small subset of biodiversity and the indicators are either undeveloped (globally) or limited to a very restricted range of livestock (sheep and cattle for the EEA and UK). The only true

[6] Least Concern =0, Near Threatened =0.0005, Vulnerable =0.005, Endangered = 0.05, Critically Endangered =0.5, Extinct and Extinct in the Wild =1;

[7] Red Listing requires information from at least two points in time (in order to determine changes in population size). To calculate a trend in Red List Index therefore requires information from at least three points in time (given two values for the Red List Index).

indicator of 'native' diversity is the UK's plant diversity indicator[8], based on data on species richness from the Countryside Survey[9].

Invasive species

All three sets contain proposed indicators for invasive species. However, at the global level data are presented only on the number of invasive non-native species found in the Nordic countries, by taxonomic group and biome (terrestrial, marine, freshwater). At the EU level, the number of the 168 "worst" terrestrial and freshwater species in each country is calculated. In the UK, there are two sub indicators. The first is "Proportion of non-native species in samples of birds, mammals, plants and marine organisms, 1990 to 2007" (JNCC 2009)[10]. The second is the change in extent over time of the 49 non-native species considered to pose the greatest threat to biodiversity by an expert panel.

Calculation and presentation

The CBD and EEA indicators are presented as a report illustrated by selected figures and tables: the precise formulations of the indicators, and the data used to calculate them, are not clearly defined. By implication therefore, the 2010 targets, even for individual indicators, remain undefined. The CBD report provides a summary table, detailing which indicators are improving or deteriorating, with symbols representing the degree of confidence in the trend and in the data[11].

In the UK indicator set, there is a tighter relationship between named indicators and 'lines on graphs', though here again no weighting is considered. This has led to the UK list of indicators being reported qualitatively in the form "x up, y down, z stable" by Defra itself (2009) as well as secondary sources (e.g. Institute of Biology 2009). This approach combines indicators of pressure, state and response[12], so that responses to a worsening biodiversity state (e.g. through greater spending and increased conservation volunteering) help to cancel out deteriorating indicators of state. The structure of the indicators therefore makes it difficult to for users to make a clear assessment of the likely state of biodiversity, either now or in the future.

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[8] The Red List Index can be construed as an indirect measure of species richness.

[9] Supplementary data are provided on changes in extent of plant species from the Botanical Society of the British Isles between 1987-88 and 2003-04 (See http://www.jncc.gov.uk/page-4237).

[10] The samples are from: BTO Breeding Birds Survey, and Mammal Survey on BBS squares; vascular plants from Countryside Survey; Bryophytes from the Biological Record Centre dataset and marine organisms from the Marine Life Information Network dataset.

[11] The criteria for these are not immediately apparent, and appear to be quite subjective. For example, a high degree of confidence is expressed in the trend of increasing invasive species, despite the indicator still being under development, with data only presented for the Nordic countries.

[12] "Of 33 component measures assessed within the indicators: 11 measures show long-term deterioration; 9 show long-term improvement; one shows little or no overall long-term change; 11 had insufficient data for long-term assessment; and one is not assessed." (Institute of Biology 2009).

Table 1. Biodiversity indicators used by globally (CBD), by Europe, the UK and Wales. Brief notes on the coverage (spatial, taxonomic etc) of an indicator are provided in parentheses, where these are not explicit in the indicator name. Sources: CBD (2006), EEA (2009), Defra (2009), Statistical Directorate (2008). Those most directly relevant to Outcome 19 are shown in bold. Grey shading indicates that no indicator is currently available.

Indicator	**CBD**	**EEA**[13]	**UK**	**Wales**
Focal Area: Status and trends of the components of biological diversity				
Trends in extent of selected biomes, ecosystems, and habitats	Forest and live coral cover	4. Ecosystem coverage (area of major habitats) 5. habitats of European interest	4. UK Priority Habitats	19a Trends in BAP habitats 21 Condition of features on Natura 2000 sites
Trends in abundance and distribution of selected species	**Living Planet Index: abundance and distribution of 3,000 vertebrate populations**	**1a. birds (common)** **1b. butterflies (grassland)**	**1a. Birds**[14] **1b. Butterflies** **1c. Bats**	**19b Common wild birds**
Change in status of threatened / priority species	**Red List Index for Birds (is being extended to mammals, amphibians, conifers, cycads and a random sample of other taxa)**	**2. Red List Index of European Species (Birds)** **3. Species of European interest (no trend data)**	**3. UK Priority Species**	**19a. Trends in BAP species**
Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance	Under development	6. Livestock genetic diversity (cattle & sheep, 5 countries)	5. Livestock genetic diversity (cattle & sheep)	
Coverage of protected areas	Areas of IUCN management categories	7. Area of Nationally Designated PAs 8. EU habitats & birds directive sites (no trend data)	6. Extent and condition of protected sites (insufficient data on condition)	

[13] The UK provides data for 21/24 EEA indicators (EEA 2009).

[14] Disaggregated into farmland, woodland, water & wetland, seabirds and wintering waterbirds.

Species diversity			**2. Plant diversity**	
Focal Area: Ecosystem integrity and ecosystem goods and services				
Marine Trophic Index	For N. Atlantic and coastal waters globally	12. Marine Trophic Index	13. Marine ecosystem integrity	
Connectivity – fragmentation of ecosystems	Forest fragmentation and dam-based river fragmentation (both selected areas only)	13. Fragmentation of natural and semi-natural areas 14. Fragmentation of river systems	14. Habitat connectivity (not assessed)	
Water quality of aquatic ecosystems	Status and trends in biological oxygen demand of major rivers in 5 regions	15. Nutrients in transitional, coastal and marine waters 16. Freshwater quality	15. Biological river quality	13. Water resources 22d Input of hazardous substances to marine environment 35/36 Water quality
Focal Area: Threats to biodiversity				
Air pollution	Creation of reactive nitrogen	9. Critical load exceedance for nitrogen	10. Acidity and Nitrogen	33. Air pollutants inc. acidity and nitrogen
Trends in invasive alien species	**Aliens spp. Recorded in Nordic environments**	**10. Invasive alien species in Europe**	**11. Invasive spp. (freshwater, marine, terrestrial)**	
Impact of climate change on biodiversity		11. Impact of climatic change on bird populations	12. Spring Index	
Focal Area: Sustainable use				
Area of forest, agricultural and aquaculture ecosystems under sustainable management	Under development. FAO Global Forest Resources Assessment considered, along with certification schemes e.g. Forest Stewardship Council	17. Forest: growing stock, increment and fellings 18. Forest: deadwood 19. Agriculture: nitrogen balance 20. Agriculture: area under management practices potentially supporting biodiversity 21. Fisheries: European commercial fish stocks	7. Woodland management 8. Agri-environment land (higher and entry level) 9. Sustainable fisheries	20a. proportion of land under agri-environment / organic 20b proportion certified woodland 22b Marine Stewardship Council / ICES certified fisheries

		22. Aquaculture: effluent water quality from finfish farms		
Ecological footprint and related concepts	Ecological Footprint	24. Ecological Footprint of European countries		2a. Ecological Footprint
Focal Area: Status of traditional knowledge, innovations and practices (CBD only)				
Status and trends of linguistic diversity and numbers of speakers of indigenous languages	Under development			
Focal Area: Public awareness and participation (EEA and UK only – in place of traditional knowledge, innovations and practices)				
Public awareness		26. Public awareness		
Conservation volunteering			18. Conservation volunteering	(5/6a People taking environmental action)
Focal Area: Status of access and benefit sharing				
Access and benefit sharing	Under development	24. Patent applications based on genetic resources		27/29. People able to access green space / rights of way etc
Focal Area: Status of resources transfers				
External biodiversity spending	Aid targeting CBD objectives, from 16 countries	25. Financing biodiversity management	17. Global biodiversity expenditure by UK	
Domestic biodiversity spending			16. UK Biodiversity spending	

Scotland

Scotland has adopted a broader range of state indicators than the sets previously discussed. Although most of the Scottish indicators are produced in some form at the UK level some have not been adopted as part of the UK's Biodiversity Indicator set (Table 2). The only indicator of state used at the UK level which is not included in the Scottish indicators is the abundance of bats. Scotland does not explicitly have any indicators of threat (though the invasive species indicator is included as an indicator of state) or response (though some of the engagement indicators could be considered to be response indicators).

As with the other indicator sets considered above, these are based on pre-existing datasets and indicators, and little synthesis across datasets. Even data on very similar organisms, such as moths and butterflies, are separated.

Scotland's biodiversity indicators are produced by Scottish National Heritage, and presented on their SNHi website in a similar way to the UK indicators. As for the UK, there is a clear relationship between the headline indicator and the data and formulation used. For each indicator, the trend is presented, together with supplementary information following a standardised format, including an adjectival data confidence statement, background information and comparison with the relevant UK indicator (Figure 3). This offers a useful model which might be adopted, with modifications, by Wales.

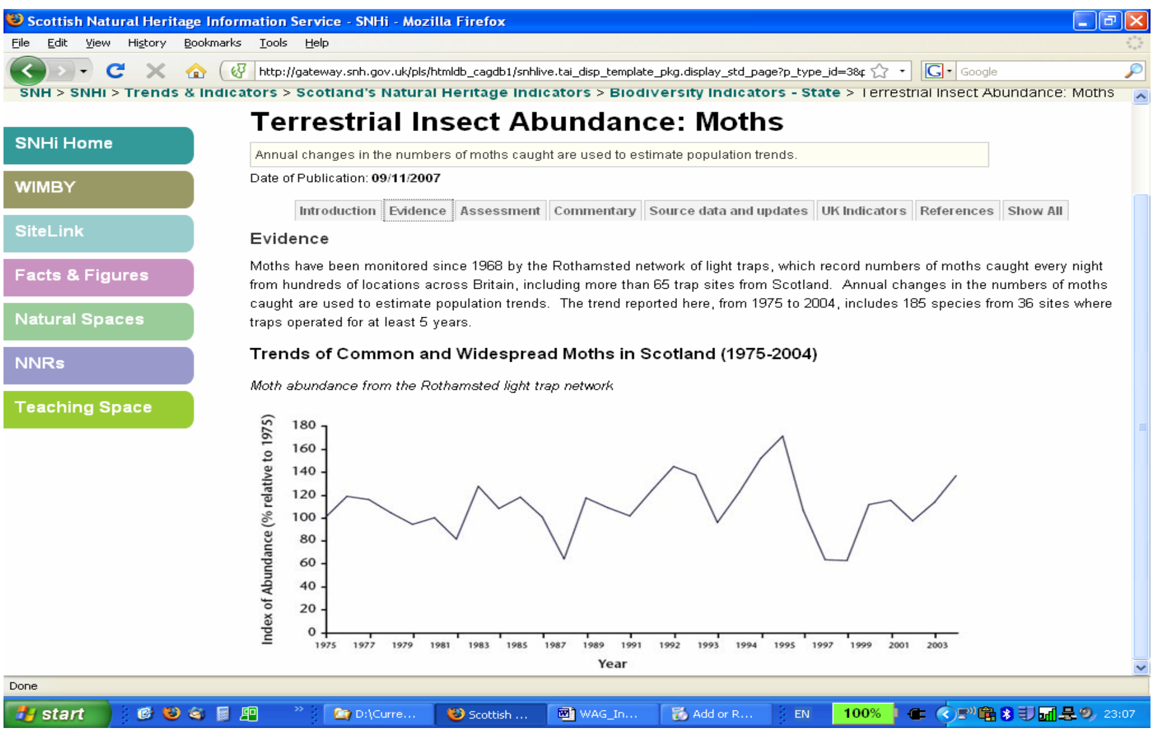

Figure 3 Screen shot of Scottish Natural Heritage's Indicator Site.

Table 2. Scotland's Biodiversity Indicators of State

Indicator	Wales	UK?
S1. Status of UK biodiversity action plan priority species	✓	✓
S2. Status of UK biodiversity action plan priority habitats	✓	✓
S3. Abundance of terrestrial breeding birds	✓	✓
S4. Abundance of wintering waterbirds	×	✓
S5. Abundance of breeding seabirds	×	✓
S6. Vascular plant diversity	×	✓
S7. Woodland diversity indicator	×	×[15]
S8. Terrestrial insect abundance: butterflies	×	✓
S9. Terrestrial insect abundance: moths	×	×[16]
S10. Notified species in favourable condition	×	×[17]
S11. Notified habitats in favourable condition	×	×
S12. Otter	×	×[18]
S12. Freshwater macroinvertebrate diversity	×	✓[19]
S14. Marine plankton	×	×
S15. Estuarine fish	×	×
S16. Proportion of commercially exploited fish stocks which are at full reproductive capacity	✓	✓
S17. Non-native species: terrestrial, freshwater and marine environments *(Considered a threat indicator at UK level)*	×	✓

[15] Included in the Forestry Commission's *Indicators for Sustainable Forestry* (Forestry Commission 2007)

[16] Moths are monitored as part of the *Changes in Abundance of Climate Sensitive Species for Environmental Change Network sites in England* (Defra, 2006).

[17] Monitored by SNH for JNCC as part of Common Standards Monitoring, as is S11.

[18] Similar indicator produced by the Environment Agency (2007) for England and Wales.

[19] This information forms part of the UK's "Biological Quality of Rivers" indicator.

Switzerland

The Swiss approach to biodiversity indicators contrasts strongly with the previous approaches in several ways. Most significantly, the choice of headline biodiversity indicators has been made on conceptual grounds, rather than being determined by data availability: indeed, the Swiss federal government has carried out a significant amount of new monitoring for the express purpose of creating biodiversity indicators. A complete survey round of the Swiss Biodiversity Monitoring project costs around 17.5m CHF (=£10m) over five years[20].

In total 34 indicators are used, and are divided into three categories: pressure indicators, state indicators, and response indicators. In contrast to other approaches, the indicators of pressure include many indicators of habitat quality and extent[21], and indicators such as the size of protected areas are classed as response indicators rather than being considered proxies for state, as in some of the indicator sets considered above. The approach is therefore rigorously focussed on true indicators of state and is also rather species-focussed, and therefore similar in focus to Outcome 19.

Although the total number of indicators is large, there are just 11 indicators of state, of which three are emphasised as being of greatest importance. These are closely related, each being a measure of species diversity at three different scales. This is in contrast to other sets of indicators, where abundance, rather than diversity, has played a dominant role in species-based indicators of state.

[20] Switzerland has almost exactly twice the land area of Wales, and has a more challenging topography, but of course lacks any marine area.

[21] e.g. "E10: Changes in the amounts of deadwood found in various forest types in Switzerland as a whole and in individual regions." Though some of these, e.g. "E1: Size of valuable habitats" are also considered to be state indicators, underlining the fact that an indicator of state for one level of biodiversity (e.g. habitats) may be an indicator or pressure for another (species). Biodiversity Monitoring Switzerland (2009).

Table 3. Switzerland's Indicators of State. From Biodiversity Monitoring Switzerland (2009) http://www.biodiversitymonitoring.ch/english/daten/liste.php. * denotes most important indicators

Indicator	**Wales?**	**UK?**
Z1: Number of livestock breeds and plant varieties. Change in the number of all domesticated livestock breeds and agricultural plant varieties recognized in Switzerland.	×	×
Z2: Proportion of livestock breeds and plant varieties. Change in the proportion of livestock breeds and plant varieties within the total population/total production of the breed/variety in Switzerland.	×	×
***Z3: Species diversity at national and regional level.** Change in the total number of species of selected taxa living in the wild.	×	×
Z4: Number of species in Switzerland facing global extinction. Change in the total number of globally endangered species occurring in Switzerland	×	×
Z5: Change in the endangerment status of species. Number of species now less endangered in Switzerland minus number of species now in greater danger.	✓	✓[22]
Z6: Population size of endangered species. Change in population size of species endangered worldwide, in Europe or in Switzerland.	×	×
***Z7: Species diversity in landscapes.** Change in the mean species diversity of selected species per 1km2.	×	×
Z8: Population size of common species. Change in population sizes of common species in Switzerland.	✓	✓[23]
***Z9: Species diversity in habitats.** Change in average species diversity of selected species within 10m2 areas.	×	×/✓[24]
Z10: Size of valuable habitats. Change in the size of habitats of national importance. *(=Pressure indicator E1)*	×✓	✓
Z11: Quality of valuable habitats. Change in the mean quality of each of the valuable habitat types.	✓	✓
Z12: Diversity of Species Communities. Change in the diversity of Species Communities.	×	×

[22] Changes in status of Welsh/UK priority species

[23] Wild birds only in Wales at present, birds, butterflies and bats in the UK

[24] Plant diversity only, from Countryside Survey

Lessons from the review

It is clear that for the most part (with the exception of Switzerland), the starting point for indicator development has been existing datasets, rather than a consideration of what should be measured. This was noted by Failing and Gregory (2003) as one of the ten common mistakes in creating indicators. The apparent driving force behind these sets of indicators has been to marshal whatever information could easily be made available in the run up to the 2010 deadline, rather than develop indicators from scratch for the long term. The indicator sets may evolve considerably post-2010 (Mace & Baillie 2007, Countdown 2010 2009). This represents a very different position to that faced by Wales, which has chosen a more ambitious target to be evaluated over a longer period of time (to 2026). Under these circumstances, the indicators are likely to play a larger role in *ex ante* policy development and selection, rather than simply being used to evaluate government performance *ex post*. This makes it essential that the Welsh indicators are close and robust proxies of the underlying state of biodiversity.

Most of the indicator sets comprised long lists of indicators, with no clear hierarchy or means of aggregating them, another mistake noted by Failing and Gregory (2003). It is interesting to note that a subset of the UK biodiversity indicators is included in the Sustainable Development indicators, produced by Defra, and three of the Scottish indicators are included in the 45 Indicators of Performance in Scotland. This illustrates an important point; where a long list of biodiversity indicators are not aggregated or arranged in a hierarchy as part of the development process, there is a risk that a much smaller number will be chosen to represent biodiversity at a higher level. The partial exception to this was Switzerland, which emphasises just three indicators of state (out of 34 in total) as being most important. In addition, the names of some indicators are misleading, and it isn't always clear what the indicator is supposed to be measuring. State indicators are not always clearly separated from the others and some proxies for state are included (e.g. area protected).

Despite the long lists of indicators, the above indicator sets tend to be quite selective in terms of their description of the state of biodiversity. Scotland has succeeded in including a majority of the available datasets, but at the expense of having a long list of state indicators, which it is difficult to summarise.

There is no consistent approach to disaggregation, for example within the UK's abundance indicator, the birds sub-indicator is disaggregated by habitat type (farmland etc) while butterflies are disaggregated into specialists and generalists, while the bats sub-indicator is not disaggregated at all. There is no attempt to synthesise across groups, either in aggregate or by habitat type.

In general there is a predominance of abundance measures, rather than measures of diversity, the notable exception being Switzerland where all three major indicators report species richness at different scales. There have only been very limited attempts to represent genetic diversity, and these have been limited to a limited selection of livestock.

A serious concern is that uncertainty is rarely presented in graphical form, and only measures of central tendency are plotted in most indicator sets. Uncertainty is represented only by adjectival grades of uncertain meaning, and the distinction between confidence in a trend, given the data, and confidence in the data, is not always clear. For example, the Scottish butterfly indicator claims that "Butterflies fluctuated appreciably but increased in abundance by 35% between 1979 and 2005", with the data rated as satisfactory, when the trend presented is very clearly cyclical, the 51% increase over baseline being due to the baseline year being at the bottom of a cycle, while the latest year (2005) is near the top (Figure 4)

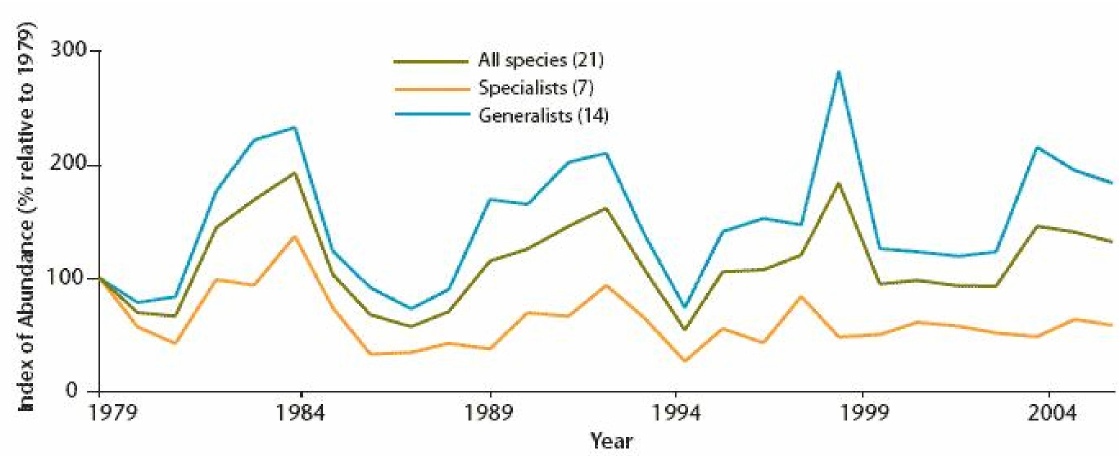

Figure 4. Scotland's butterfly indicator. A 35% increase in butterfly species (51% for generalists) is claimed, despite the very clearly cyclical nature of the data, and the fact that the baseline year (1979) occurs near the bottom of a cycle, while the year of assessment (2005) appears to be near a peak. This example illustrates the need to clearly and rigorously present uncertainty in an appropriate way for each indicator: a smoothed trend with confidence intervals for this indicator would be unlikely to show an increase in any year.

Stakeholder opinions

We solicited stakeholder opinions on biodiversity indicators for Wales through a one-day workshop held in the Environment Centre Wales, Bangor, on the 21st April 2009. The report of the workshop is included as Appendix 1, but the main findings were as follows.

- It is possible to design a meaningful biodiversity indicator, although no indicator can reflect species across all taxa and habitats
- Any such indicator is likely to be a compound indicator
- Due to the complexity of the task, and the gaps in our understanding of species interactions, development of the indicators involves subjective decisions using the best knowledge available. This subjectivity must be made explicit.
- An indicator needs to be accompanied by a measure of uncertainty/variability
- The headline set of indicators needs to be presented in a manner that communicates clearly to non-specialists, and needs to be backed up by a technical report

- Somewhere between 5 and 15 lines on a smaller number of graphs are enough to capture Welsh biodiversity meaningfully
- We should not confine ourselves to extending existing data sets; novel monitoring may be needed
- It is not possible to objectively exclude or include individual species, and there is no sound scientific basis for preferring to include one group of species over another, except on the grounds of cost.

Specific suggestions of parameters to be measured by indicators included:

- Measures of the population status of:
    - threatened species or important species (e.g. BAP species)
    - Widespread species
- Total species richness
- Measure of (relative) abundance of the species, to report as 'evenness'
- Phylogenetic diversity
- The distinctiveness of Welsh biodiversity: i.e. that species should be weighted in the indicator on the basis of the international importance of their Welsh population

Candidate indicators for Outcome 19

> "*no scientific consensus measure [of biodiversity] exists, although several candidate measures have been proposed*". Scholes and Biggs (2005)

The quote above remains true, but some themes do emerge from the review. In the following section we refer to the original project brief.

Abundance

Despite not being included in the original brief for this project, indicators of abundance dominate many of the indicator sets discussed above. Usually geometric means of relative changes in abundance (as per the LPI, also known as the Buckland geometric index) are used (Buckland et al 2003, Lamb et al 2008). The LPI is an example of an aggregate indicator, comprising data from many different vertebrate groups, while most other sets have segregated indicators according to the underlying datasets. Indicators have been produced for many groups other than birds, the only group for which Wales currently has an indicator of abundance.

Diversity

Diversity indices are rarer, being absent from the European and global indicators, and represented by only a single indicator at the UK level. Scotland has three indicators of diversity: woodland, vascular plants and Freshwater macroinvertebrate (compared with nine indicators of abundance). Switzerland, on the other hand, has focussed its entire indicator set around diversity, with all three headline indicators measures species richness of a broad range of species, at several spatial scales. As well as indicators of mean species richness in sites, one of the Swiss indicators is the total species richness of the country (and regions), a possibility suggested in the project brief.

Range

The geographic range of species (area occupied by that species) was specifically mentioned in the project brief, but is not presented as a standalone indicator in any of the indicator sets we reviewed (data on range are used as a proxy for abundance where abundance data is lacking e.g. some species in the LPI). Information on range size can also be used to assess species' threat categories for the Red List Indicator.

Endangered / priority species

The project brief specifically mentions endangered species, and this was also noted as important by stakeholders. All indicator sets include specific indicators for endangered species. However, we find these measures to be somewhat unsatisfactory. The Red List Index begins with quantitative data, mixes it with expert opinion to produce adjectives, then takes the adjectives, combines them with arbitrary weights and turns them back into quantitative data. The 'bar graph' approach followed by the UK and Scotland is perhaps more transparent, but still conceals the quality of the data used to make assessments. Although we recognise that data on endangered / priority species may be sparse, we would prefer that this situation is communicated clearly, through quantitative measures of uncertainty, so that the need for greater resources in this area becomes clear. There may be a role for expert opinion in the meantime, but there is no reason why this expert opinion cannot be used to generate quantitative data (e.g. on estimated population sizes) directly, allowing endangered/priority species to be included alongside common species in quantitative indicators and in a specific sub-indicator disaggregated from them, as long as sensitivity analysis was performed to determine the effect of expert opinions on the headline trends.

Non-native invasive species

Again these were specifically mentioned in the project brief. In most indicator sets invasive species indicators are included as measures pressure (ecosystem integrity), and non-native species are generally excluded from most indicators of state. We discuss the issue of species inclusion in more detail below, but simply note here that it is not always a straightforward task to determine which species should be included.

Other aspects noted by stakeholders

In addition to the above, stakeholders also mentioned phylogenetic diversity, and distinctiveness, and disaggregations by trophic levels (rather than taxonomic group or habitat type).

Other facets of biodiversity

Other facets of biodiversity which may not directly relate to Outcome 19 but which are represented in other indicator sets include measures of ecosystem integrity or pressures on biodiversity (e.g. Marine Trophic Index, habitat fragmentation, invasive species), and the diversity and abundance of other levels of biodiversity such as communities, habitats and ecosystems. These aspects are not currently represented in the Welsh indicators (see recommendations).

In the next section we develop and explore these emerging options for headline indicators.

Statistical exploration of potential indicators

Having identified some potential indicators for Outcome 19, the next stage of the project was to carry out a statistical exploration of these indicators, to highlight some important issues and to determine the level of uncertainty present when estimating these indicators from some Welsh datasets.

General description of modelling approaches

We used two example data sets from the marine and terrestrial environments. First, the British Trust for Ornithology (BTO) kindly supplied the Welsh results for the Breeding Birds Survey (BBS), 1994-2007. These data are counts of abundance for 48 bird species for 338 random locations in Wales. Not all species are represented at all sites and not all sites were visited in all years. To make things computationally easier, we excluded one species because of low numbers in all years. Note that we are not necessarily proposing that rare species be systematically excluded from an indicator, but this does highlight the statistical difficulties associated with rare species. Second, CEFAS kindly supplied International Bottom Trawl Survey (IBTS) fish data for Irish Sea sites 1986-2008. The data are fish counts for 135 fish species for 96 locations. Our analysis of this data was restricted to the most common 39 fish species and to the period coinciding with the BTO data (1994-2007).

The figures below are included in order to illustrate pertinent aspects of the indicators, and we emphasise that none of the following should be interpreted as indicative of individual species or biodiversity trends in Wales.

Abundance

The abundance analysis had two stages; trends in the abundance of individual species are first estimated and then aggregated together. As far as possible we followed the BTO methodology for estimating individual species trends: generalized additive models (GAM; Fewster et al. 2000) were used to estimate the trend in abundance over time for each bird and fish species. For estimating the aggregated trend over time we chose 1994 as the base year with an index value of 100; all other years were then expressed relative to 1994. A value less than 100 would suggest a decline relative to 1994 and a value greater than 100 an increase. In the work below we present a range of indices of abundance proposed by others (Buckland et al. 2005; Lamb et al. 2009). We use index to refer to the way in which count data for a single species is transformed into a trend on a common scale (usually with base year =100, and extinction =0), and also to the way in which single-species trends are aggregated into a summary indicator, including the arithmetic and geometric means, and median / percentiles.

Thus, the “Buckland arithmetic” is the *arithmetic* mean of the *relative* trend in each species; the “Buckland geometric” is the *geometric* mean of the *relative* trend for each species and the Nielsen index is based on the *absolute* difference in numbers for each species. Note that the Nielsen index has the additional property that any change in abundance (increase or decrease) results in a decline in the index. The Nielsen index is therefore a measure of intactness. This type of index may be appropriate where a meaningful pristine baseline can be determined (unlikely in Wales).

Range

We have calculated indices of range (proportion of sites in which a species is found) in a similar way to those of abundance, described above.

Diversity

To represent diversity we have constructed indices of alpha and beta diversity. Alpha diversity was estimated as the arithmetic mean species richness (number of species at each site) while beta diversity was estimated as the arithmetic mean of the 1-Jaccard pairwise dissimilarity. Essentially, alpha diversity here is the average number of bird species one would expect to see on visiting any location in Wales and beta diversity the average similarity of any given site to all others in Wales. 1994 was assigned an index of 100 and other years estimated relative to 100. We do not combine the marine and terrestrial diversity indicators as there are no common species among the marine and terrestrial sites. However, if the datasets were broadened, e.g. through including seabirds, there would be some degree of overlap, allowing a combined indicator.

Uncertainty

The analyses below illustrate the effect of multiple sources of uncertainty on detection of change in Welsh biodiversity. This uncertainty arises because data are incomplete both in terms of coverage of species and geographical coverage. Hence, trends in biodiversity must be estimated from an incomplete sample of Welsh species and Welsh locations. This sample may vary from year to year. To construct an indicator we must then assume that the data available are representative of all Welsh species and locations. With this assumption we can then use the variation between species and within species (i.e. between sites) to estimate the level of these two sources of uncertainty in any aggregated trend. The majority of existing indicators assume that there is no uncertainty in within species trends, so the latter work is of particular importance.

Between species uncertainty was estimated by bootstrap sampling of species to give 95% confidence intervals for the indicator. Narrow intervals suggest a high confidence in the indicator value, wide intervals low confidence. Estimating within species uncertainty is far more computationally intensive than for between species uncertainty. For between species uncertainty a GAM needs to be estimated for each species once, for within species uncertainty a GAM must be estimated multiple times (1000 in this case). Within species estimation for the bird and fish data took roughly 4 weeks on a desktop PC.

In fact, while the locations are selected using stratified random sampling, and might be expected to be representative of Welsh locations, the species are not selected at random and there is no reason to expect that they will be representative. These analyses cannot therefore estimate the bias which might arise because of this – this source of bias and uncertainty has not been estimated for any indicator to our knowledge, but may be important. Given data from more taxonomic groups (preferably selected at random), we would be able to bootstrap groups, as well as species, to derive some estimate of the uncertainty due to taxonomic selectivity. We were not able to gain access to any other suitable datasets during this project.

The choice of index matters greatly: indices of abundance

Figure 5 shows three indices of abundance, for the BBS data (Figure 6 is rescaled to show more clearly the difference between the Buckland geometric and Nielsen measures). This simple example illustrates that the apparently esoteric business of choosing a specific formula for calculating aggregate indices matters hugely. Any index which combines more than one species to produce a single value allows increases in the abundance of one species to compensate for declines in the value of another. The choice of index determines the exchange rate between species, or the relative weight placed on each species. It is important that the ecological meaning of each index is well understood.

For indicators based on relative changes in abundance (e.g. the Buckland indices) a given percentage decrease in abundance will have the same effect on the index, regardless of how common or rare a species is. This is a desirable property when aggregating data from species which are equally widespread, but which, due to their body size or trophic level, may differ considerably in abundance, for example buzzards and blue tits. However, this is not self-evidently a good thing when data also comes from marginal species, e.g. little egrets. In this case, a 50% decrease in the little egret population, which is on the edge of its range in Wales, would 'count' for as much as a 50% decrease in buzzard or blue tit populations, yet the latter may be more important. In addition, for rare species a small change in absolute numbers will result in a very large percentage increase. Indicators based on absolute changes in abundance, such as the Nielsen index, avoid this problem, but are dominated by small or low trophic-level species, which tend to be more numerous, while top predators such as raptors have little effect on the index. No perfect solution exists, and the choice of index inevitably implies a value judgment about the relative 'worth' of each species. However, partial solutions might be to:

i) use indices based on absolute changes, which are rescaled according to body size or trophic level

ii) use indices based on relative changes in abundance, but make subjective judgments about whether species are 'important' enough to justify inclusion in the index. This is broadly the approach taken by BTO in constructing wild bird indicators, but is not without its difficulties, given its inherently subjective nature.

iii) weight species according to the relative international importance of the Welsh population, as suggested during the stakeholder workshop. Under this approach, distinctively Welsh species (for which Wales is relatively important) would carry a heavier weight than species for whom Wales is a relatively marginal territory.

iv) use non-parametric measures to aggregate trends across species, such as percentiles (this approach is illustrated in Figure 19, below).

Each of the adjustments i-iii above could be applied to either the arithmetic or geometric mean, or to non-parametric statistics like percentiles. An advantage of using either percentiles or arithmetic means is that they are more readily understood, and as Figure 8 illustrates, the geometric mean is not immune to the problems posed by marginal species.

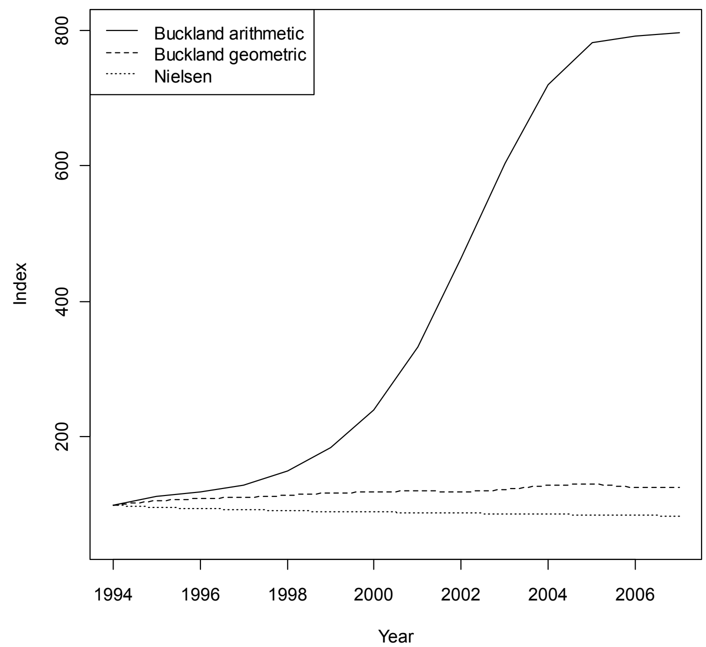

Figure 5. Buckland arithmetic, Buckland geometric and Nielsen indices of abundance based on changes in species abundance estimated for 47 bird species from the BTO Breeding Bird Survey. Data are scaled so 1994 has an index of 100.

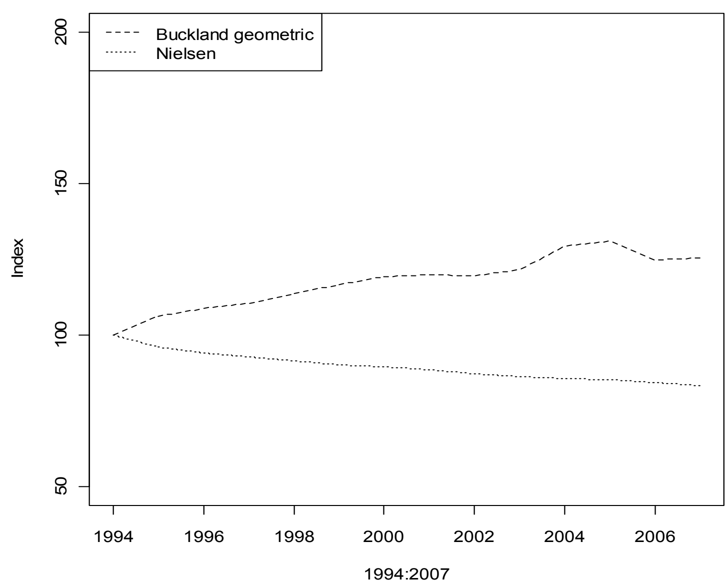

Figure 6. Buckland geometric and Nielsen indices of abundance calculated as in Figure 5, rescaled to allow comparison. Note that Nielsen can never go above 100 as any change from the base results in a decline. Nevertheless, the baseline could be set to represent the optimum situation, rather than the starting year, meaning that the index could increase from the initial value, as the species abundances approached the "optimal" level. This type of indicator offers one option for dealing with native invasives.

The sensitivity of the Buckland arithmetic index to large changes in a single species is shown in Figure 7, which recalculates the three indices, excluding the little egret, which has recently increased from zero, to a handful of individuals in Wales, an almost infinite relative increase in abundance[25]. This effect is attenuated in the Buckland geometric index, but Figure 7 demonstrates that the value of this index is nevertheless strongly affected by small absolute increases in marginal species (including the little egret inflates the index value by approximately 20 percentage points).

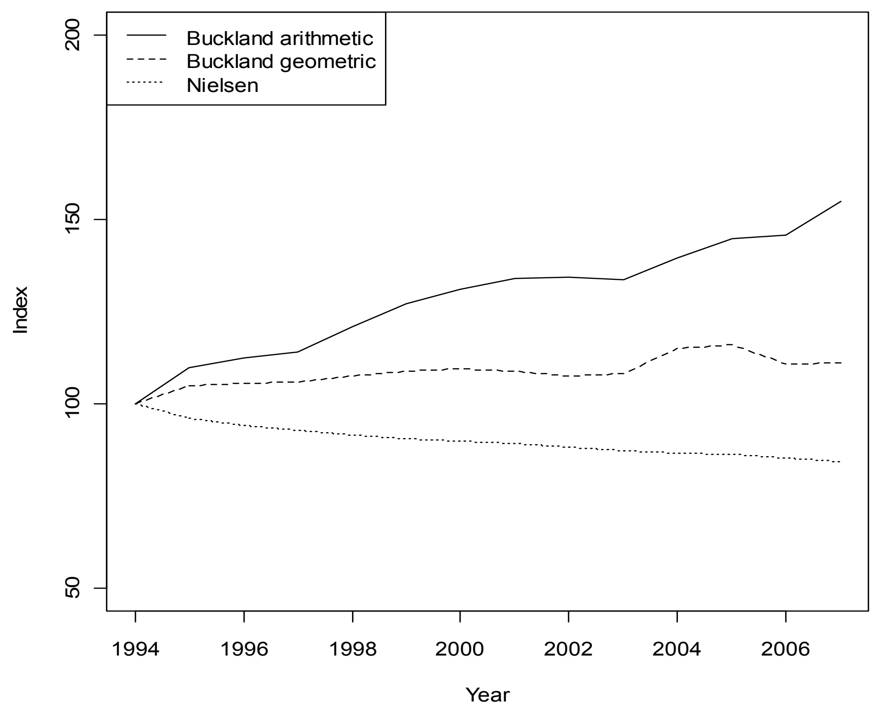

Figure 7. Indices calculated as for Figure 5, excluding the little egret, a recent newcomer to Wales which has seen large relative, but small absolute changes in its abundance over the period.

[25] *Almost* infinite, because zero values must have a small correction added to them to avoid taking the log of zero.

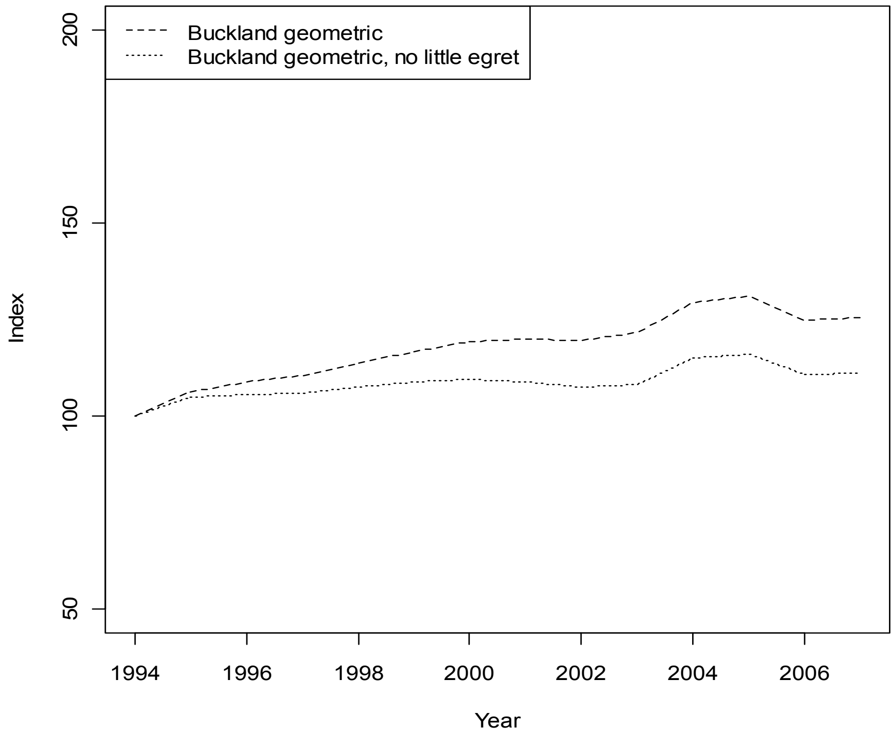

Figure 8. Buckland geometric index calculated with and without the little egret.

Figure 9 shows the three indices calculated for common fish species from the IBTS data series, as per Figure 5, demonstrating that the sensitivity to the choice of index is not confined to the BBS data, or indeed to data series that include rare or marginal species.

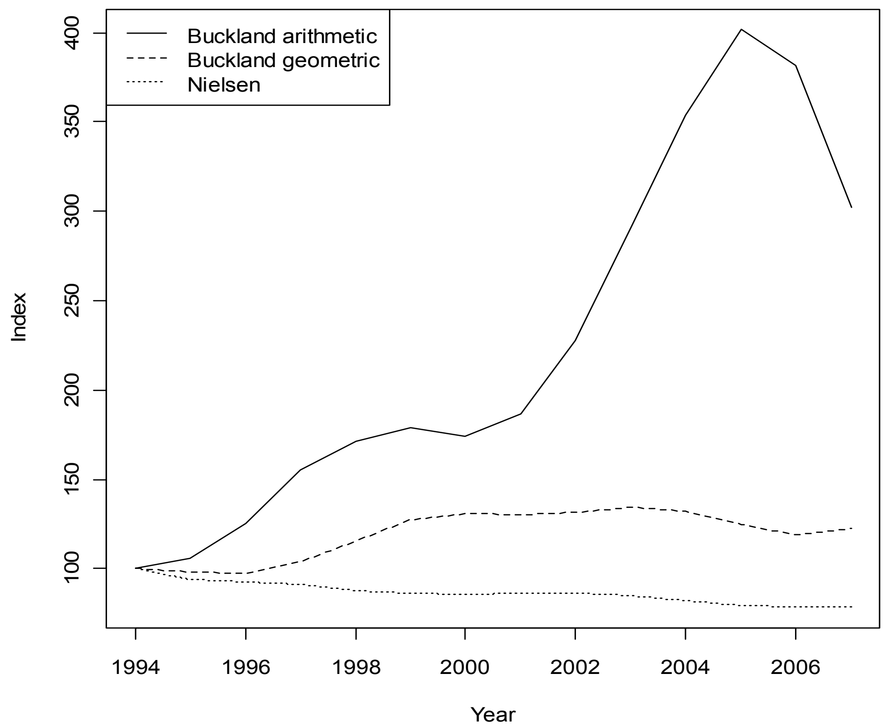

Figure 9: Indices based on changes in species abundance estimated for 39 Irish Sea fish species, data from the International Bottom Trawl Survey, supplied by CEFAS.

Aggregation of multiple taxonomic groups

Just as data on multiple species can be aggregated within taxonomic groups such as birds and fish, data can be aggregated across groups, as in Figure 10, which shows an aggregate abundance index for birds and fish. This approach is taken by the Living Planet Index (Collen et al 2009), which aggregates data across all vertebrate taxa, but has been avoided by most national and regional indicators (e.g. the UK and Scottish Indicators). Aggregation reduces the number of indicators, but also reduces the information content of the indicator set. The question is not whether to aggregate (all indicators aggregate in some sense) but which aggregations are most useful?

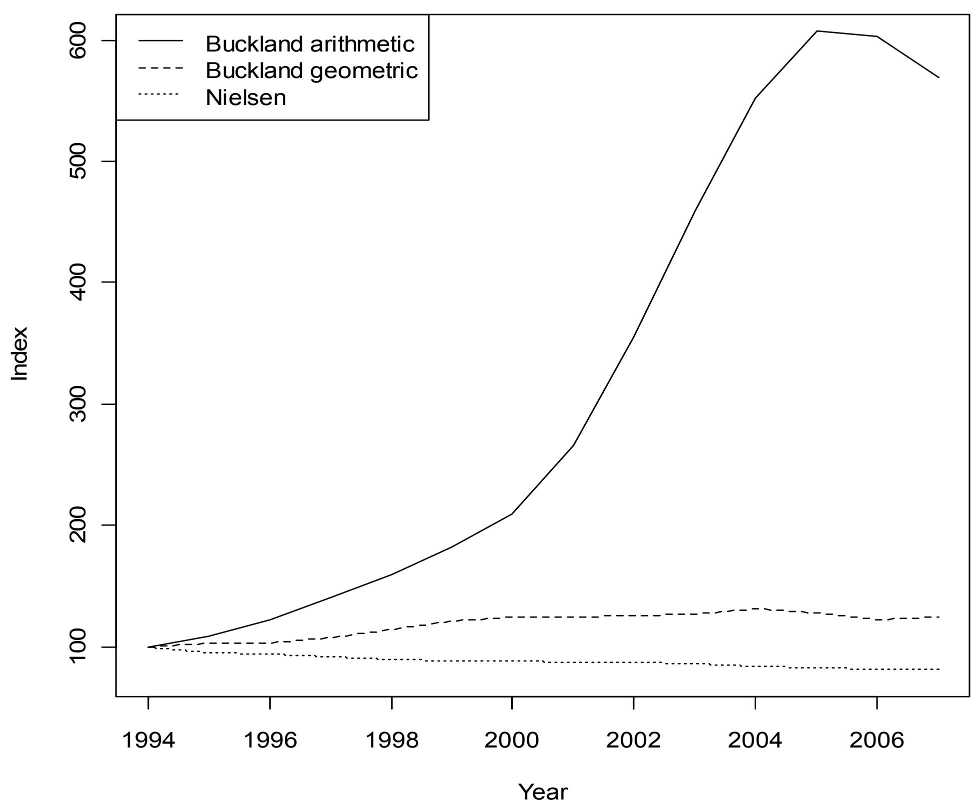

Figure 10. Indices based on species abundance estimated by combining bird and fish data.

Indicators of range vs. indicators of abundance

Few existing indicator sets include indicators of geographic range (as presence or absence at a site), as opposed to abundance, yet this is an interesting parameter in its own right, and some data series (e.g. the Botanical Society of the British Isles Atlas) lend themselves to monitoring range rather than abundance. Range data can be treated as an approximation of abundance, Figure 11 presents Buckland geometric indices calculated from both abundance and presence-absence information from the BBS data. This demonstrates the point that while abundance and range are related, they are not directly equivalent, and may show different trends: in this case, the positive upward trend apparently seen in the abundance index is more ambiguous in the range index. Although these differences are probably not statistically significant in this case (see below), if they were, such a finding might imply that wildlife was doing relatively well in high quality habitats (e.g. reserves), but declining in the wider countryside, highlighting the value of measuring different facets of biodiversity.

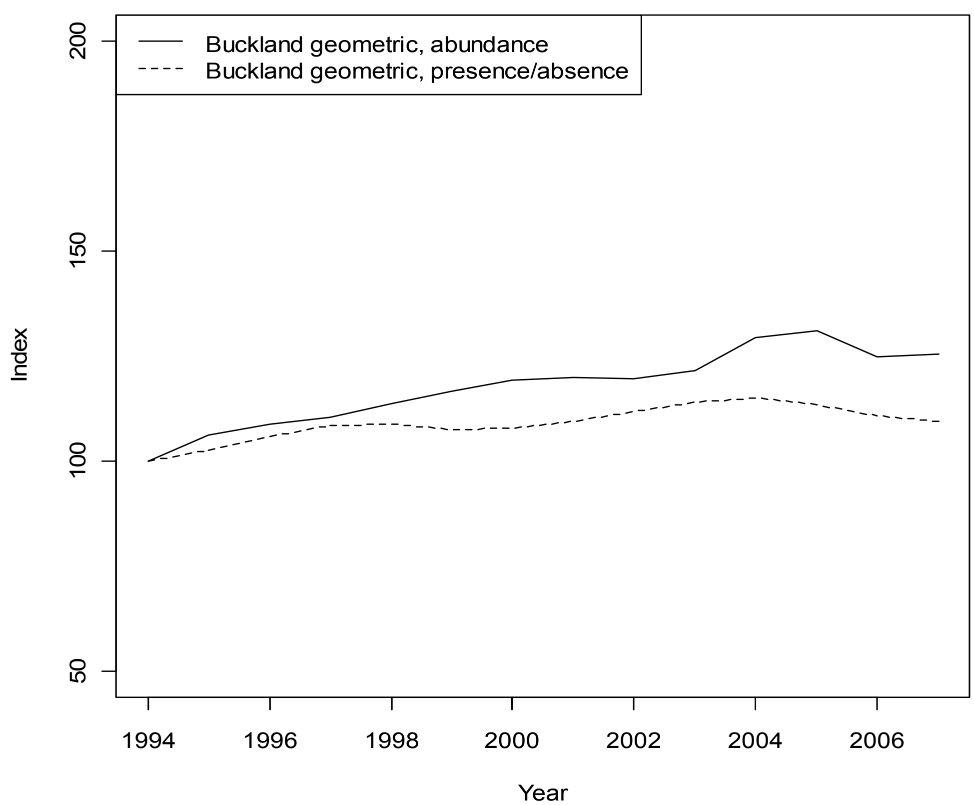

Figure 11. Comparison of Buckland geometric index for BTO data calculated using abundance and presence and absence data.

Indices of diversity

Many possible indices of diversity exist (Magurran 2004), each with their own properties as indicators of the state of biodiversity (Buckland et al 2003). Figure 12 presents mean bird species richness for sites included in the BBS. This is one measure of alpha or within-site diversity, and is very similar to that adopted in the Swiss federal biodiversity indicators program (Weber et al 2004). No consistent trend in species richness is apparent in these data. Other measures of alpha diversity, the Shannon and Simpson indices, are shown in Figure 13 and Figure 14 respectively, and appear to show increasing diversity over time: once again, the choice of index is critical. Unlike the simple measure of species richness in Figure 12, these indices take the evenness of species abundances into account. I.e. they distinguish between a site where there is a mixture of very common and rare species and a site where there is the same number of species but all are equally common.

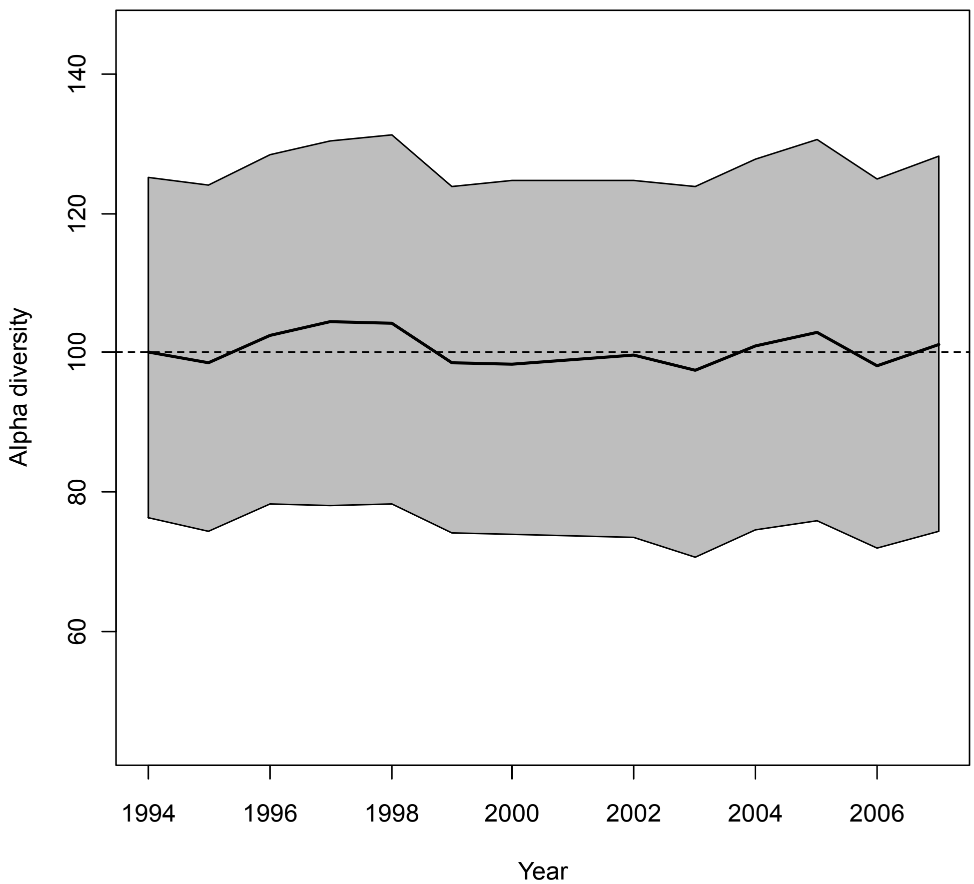

Figure 12. Mean species richness of survey sites from the BBS, with 95% confidence intervals.

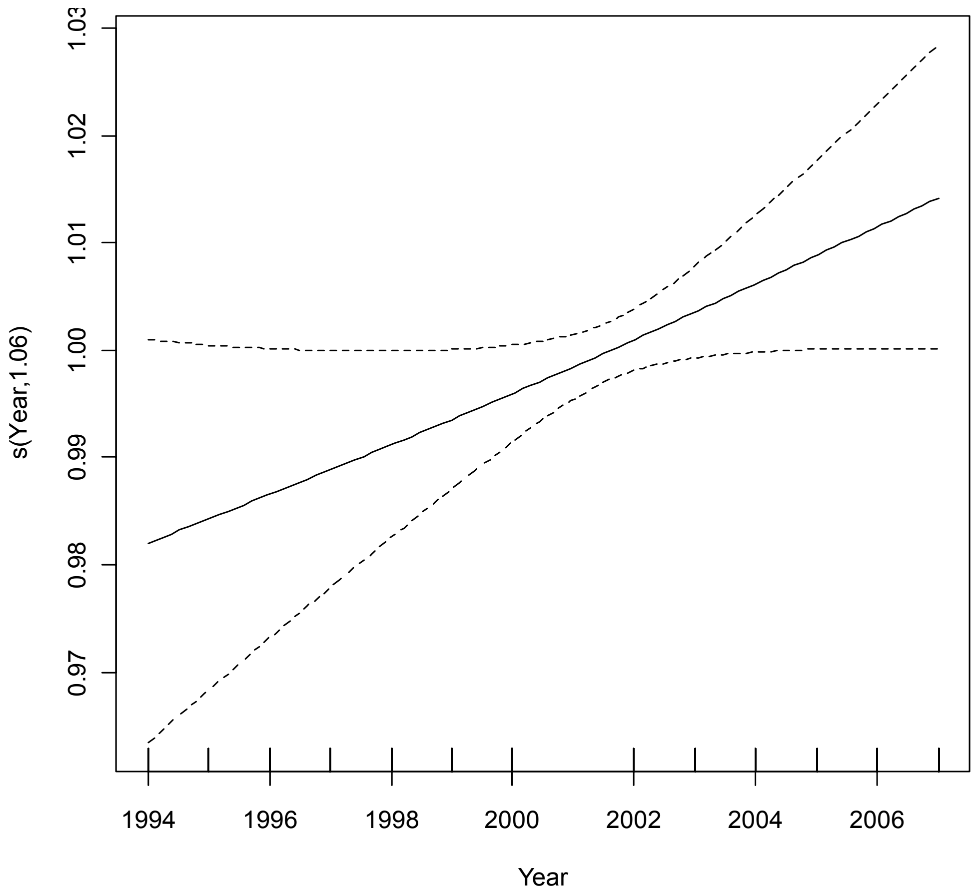

Figure 13. Shannon index of species diversity, calculated from the BBS, with 95% confidence intervals. Note that the y axis has a very small range of values

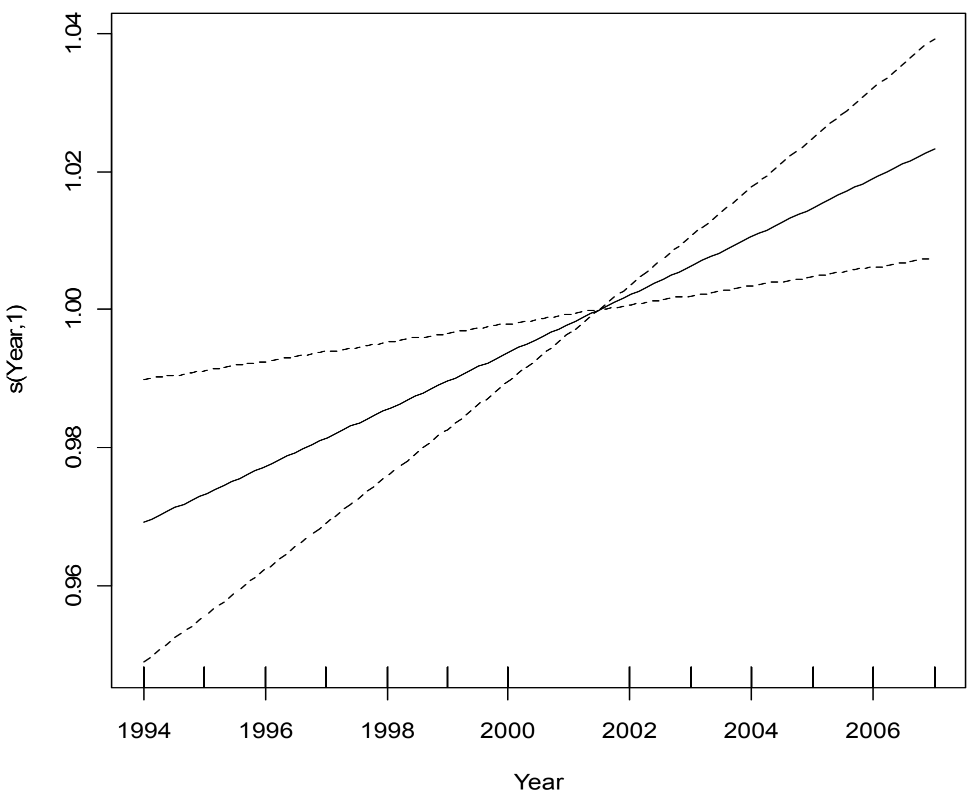

Figure 14. Simpson index of species diversity, calculated from the BBS, with 95% confidence intervals. Note that the apparently tight confidence intervals in the middle of the range are an artefact of missing data for the year 2001 and a purely linear trend. Again note that the y axis has a very small range of values.

However, local species richness is not the only aspect of diversity that is of interest. Diversity at regional or national scales is also important. This could be measured as the species richness of the country (e.g. Weber et al 2004), though this approach encounters definitional problems. An alternative is to calculate a measure of between-site, or beta diversity, to complement the measures presented above. I.e. a measure of whether different species are found at a particular site compared to another site. Figure 15 shows beta diversity through time for the BBS data, complementing Figure 12.

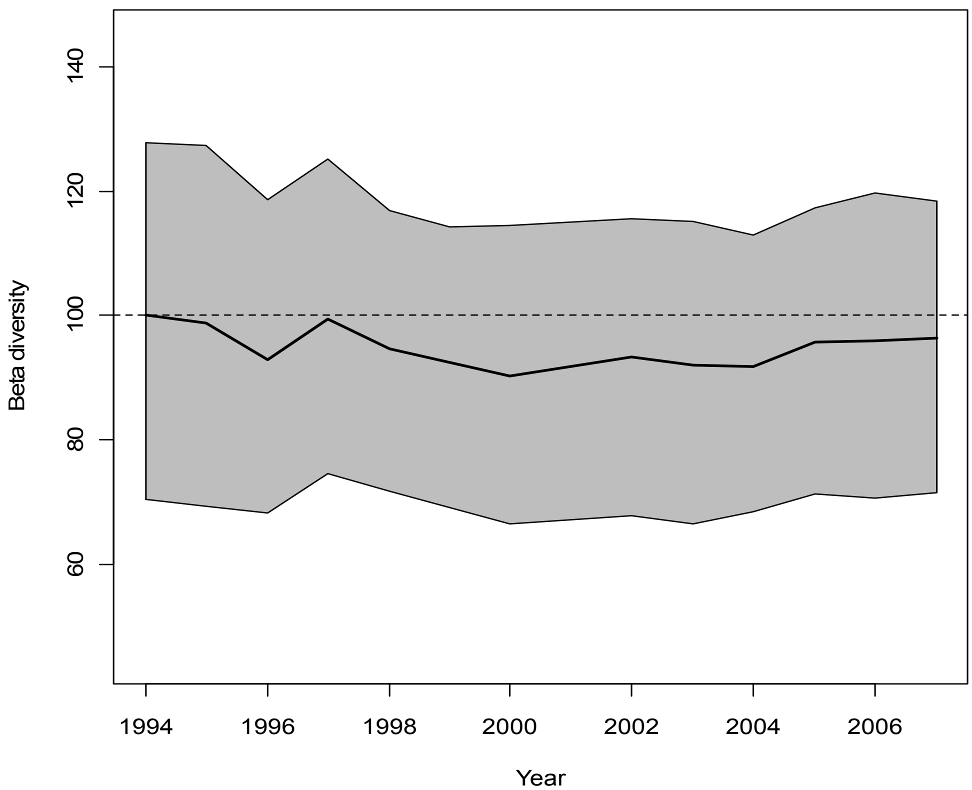

Figure 15. Beta diversity estimated from BTO breeding bird survey data. 95% confidence intervals are an estimated using between-species uncertainty.

For the case of birds, both alpha and beta diversity show no significant trends over time. Figure 16 and Figure 17 repeat these indicators for the marine data from the IBTS. Although alpha diversity again appears to be unchanging, beta diversity appears to follow a downward trend, becoming significant in recent years. Although we reiterate that these results are only illustrative, it is interesting to note that this trend is the opposite of that seen in the relative abundance indicators, which were positive for the fish data. As with the comparison of abundance and range indicators, this highlights the value of monitoring multiple dimensions of biodiversity. It also highlights the fact that aggregating indicators may conceal trends present at the level of an individual group.

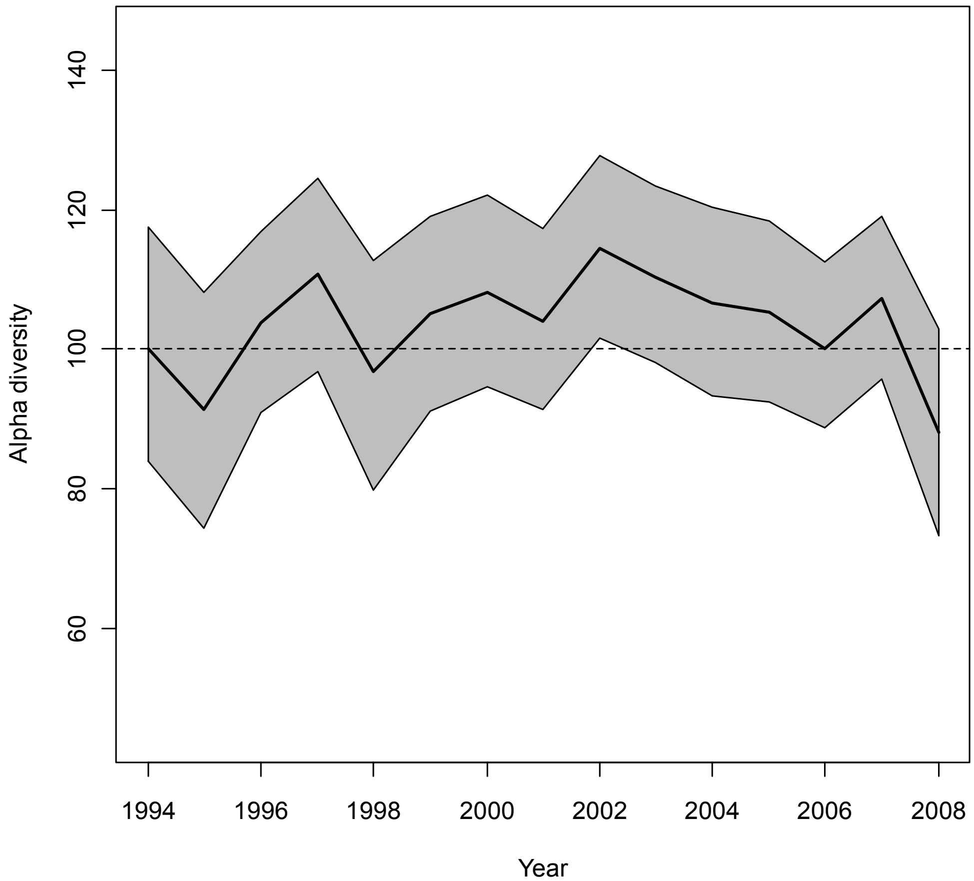

Figure 16. Alpha diversity estimated from CEFAS Irish Sea data. 95% confidence intervals are based on between species uncertainty.

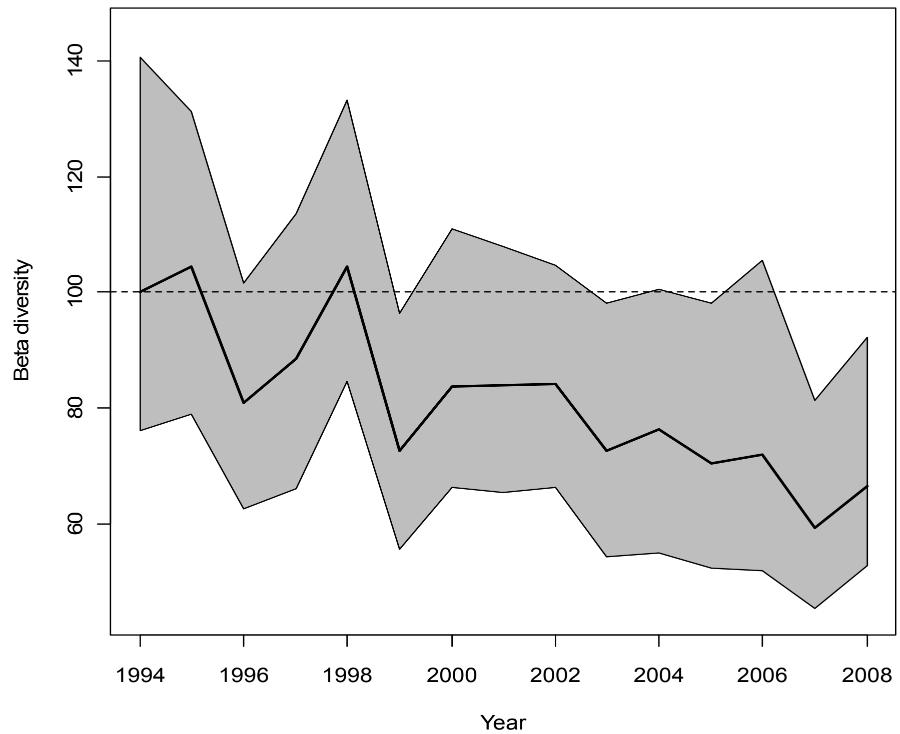

Figure 17. Marine beta diversity estimated from CEFAS supplied Irish Sea data. 95% confidence intervals are based between species uncertainty.

Estimating and communicating uncertainty

An important aim of the project is to estimate the level of uncertainty in indicator values calculated from real Welsh data series, and to propose how this uncertainty can be communicated to policy makers and the public alike. Many of the foregoing figures have included 95% confidence intervals, which can be used to express the degree of certainty with which the indicator's value can be estimated. Although it must be stressed again that the confidence intervals in the preceding graphs do not include intra-species uncertainty, the confidence intervals are in most cases wide relative to the indicator value, and few trends are statistically significant (we demonstrate the effect of incorporating intra-species uncertainty below[26]). This implies that for most indicators, even when restricted to the best-monitored taxa, the power to detect changes may be low, and it is extremely important that this information is communicated to policy makers and the general public. Figure 18 illustrates a more visually attractive way of communicating this uncertainty.

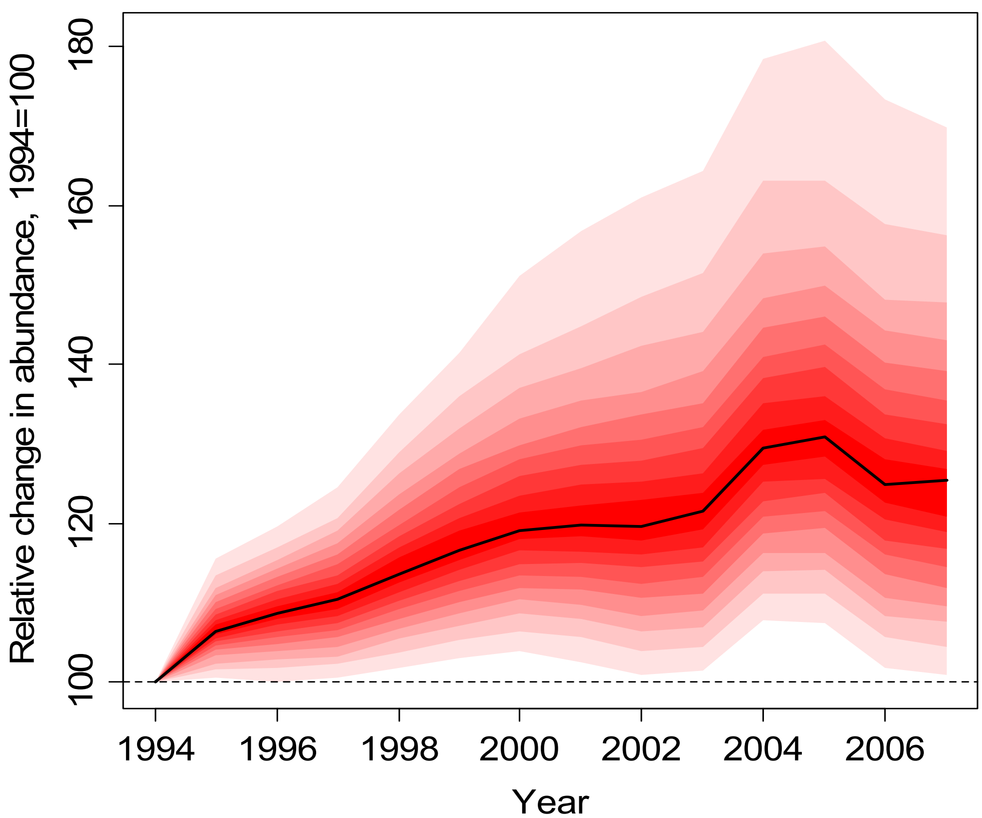

Figure 18. Geometric mean of relative changes in bird abundance (Buckland geometric index) with a representation of uncertainty of trends between species as mean confidence intervals in 10% intervals.

[26] Of course, these estimates of uncertainty also exclude the uncertainty associated with narrow taxonomic representation of the indicator.

Outer bands are 90% confidence intervals. This presentation is similar to that used by the Bank of England for inflation forecasts.

An alternative way to represent uncertainty is to plot percentiles rather than confidence intervals, alongside mean estimates of the indicator's value (Figure 19). The advantage of this approach is that percentiles may be more intuitively understandable, and are more robust to dramatic trends in marginal species. Comparison of these two figures clearly illustrates the important effect of choosing a particular statistic (e.g. geometric mean) to aggregate single-species trends. Using the geometric mean, Figure 18, above shows a statistically significant increase in bird abundance, even though Figure 19, below, shows that over 40% of species have suffered declines.

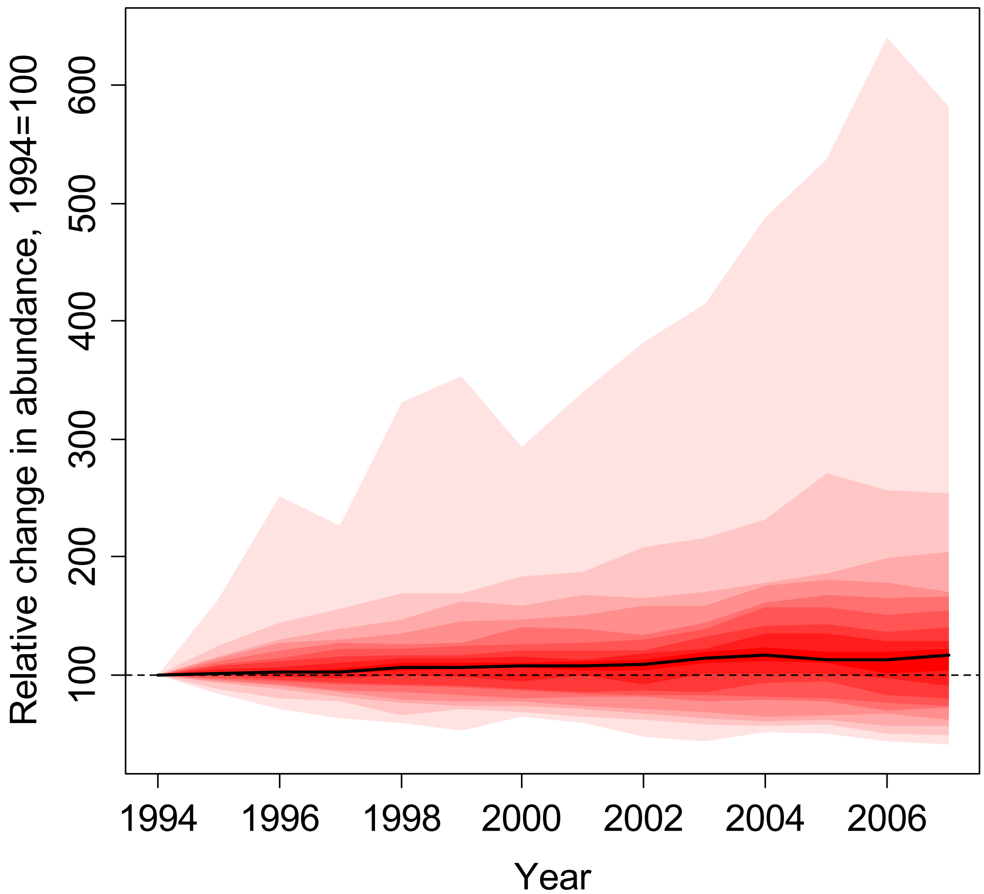

Figure 19. Relative changes in abundance for Welsh birds, using the median to represent central tendency). Solid line is the median trend, bands are percentiles in 10% intervals, so 10% of species lie within the central dark red band while 90% of species lie within the outer light bands.

Communicating the taxonomic range of an indicator

Any indicators will be based on a relatively narrow and probably unrepresentative sample of taxa. The bias and error associated with this non-random sampling is difficult to estimate.

However, the breadth of an indicator could perhaps be communicated visually if each indicator was accompanied by a colour-coded bar, showing all species in Wales (or the habitat of interest), grouped taxonomically, and arranged in order of mean body size or trophic level. This is illustrated in Figure 20 (numbers and taxonomic groups are purely for illustration) and we recommend its use alongside all indicators (see Figure 27 and Figure 28).

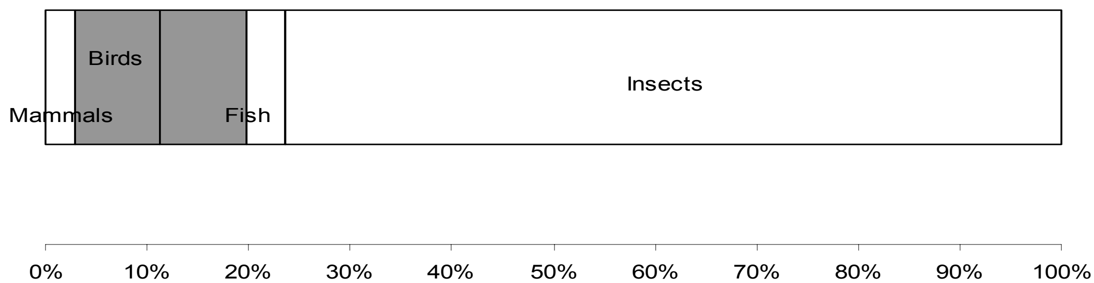

Figure 20. Example taxonomic coverage bar, showing those species included in the index (shaded), as a proportion of the total species found within the area / habitat. Species are grouped taxonomically, and groups are arranged in declining order of mean body size, from right to left. In this example, there is incomplete coverage of fish species, with sampling biased towards larger bodied species. NB: Species numbers are illustrative only.

Within species uncertainty

Within species uncertainty has been calculated for few if any indicators. Figure 21 demonstrates that this hitherto neglected source of uncertainty is extremely important.

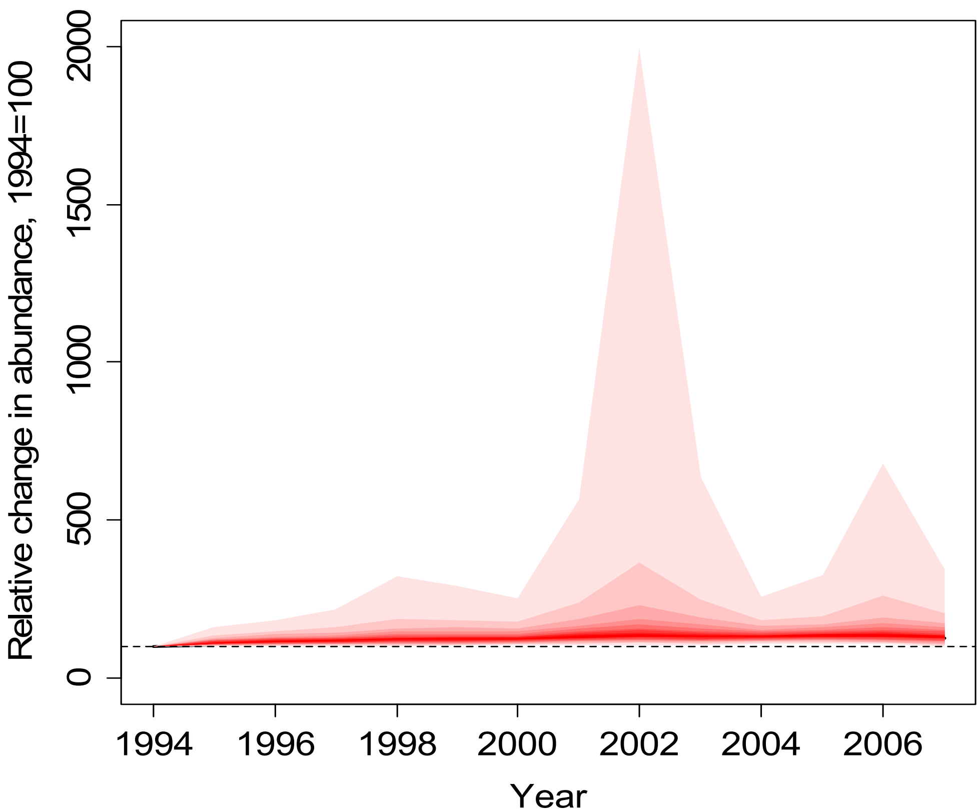

Figure 21. Confidence intervals in 10% intervals for bird abundance data (excluding 2 species) with estimates of combined between and within species uncertainty. Note that the y-axis is scaled differently to preceding diagrams.

Which indicators for Wales?

Based on our review and stakeholder consultation, we have identified three important facets of species-level biodiversity[27]: diversity (number of species), abundance (number of individuals) and range (area occupied by species), and we have explored these above using Welsh data. When precisely defined, each of these is readily understood by ecologists and socially meaningful: to the citizen, they represent, respectively: the variety of different species in their environment; the abundance of wildlife; and the number of different places where a species might be encountered. Holding all else equal, an increase in any of these facets would probably be considered desirable.

To determine how these facets of biodiversity translate into headline indicators, we must consider the types of data that can be collected about a group of species. Generally, two types of data are available: count data in sampled locations (e.g. the BTO Breeding Bird Survey) which provide indices of relative abundance, or data on occupation (presence/absence), either from sampled locations (e.g. Countryside Survey) or from all locations ('atlas' data, e.g. that produced by the Botanical Society of the British Isles). Both types of data may be available for some groups (e.g. birds).

For a given spatial scale and a given occupation dataset, indices of mean range size and mean local species richness must show the same trend: the two indicators contain the same information, and merely present it in slightly different ways (one species focussed, e.g. mean range size, and one site-focussed, e.g. mean species richness). However, there is not complete redundancy in the two indicators if percentiles, rather than simply the median or mean, are displayed. It is possible for some species to increase their range with others decreasing, while *all* sites decline in species richness. In other words, the distribution of each indicator may convey different information, even if the central trend (whether mean or median) in each case is qualitatively the same. This point underlines the importance of presenting distributions, rather than simply measures of central tendency, something we expand on below. Nevertheless, the two indicators are related and so we recommend that the indicator of range be treated as a supplementary indicator, of less importance than the diversity indicator, and attached to the indicator of abundance.

For many groups of species, only one type of data may be present (either count or atlas data). In such cases, count data can be 'degraded' to presence/absence data, and used in indices of species richness and range (as we demonstrate above) while range size derived from occupation data can be used as a proxy for abundance (e.g. in the Living Planet Index). However, if this is the case, the information content of the indicator set is reduced. This is because in the first instance, the count survey may not employ sufficient effort to determine the presence or absence of rare species, so that any changes which disproportionately affect

[27] In our interim report, we identified a fourth: "structure". On reflection, however, we feel that the disparate elements we grouped under this title are best represented either by indicators of diversity/abundance at other levels of biodiversity (e.g. community diversity, abundance of higher trophic level individuals, biomass, abundance/area of undisturbed landscape), or by pressure indicators of ecological integrity (habitat fragmentation, marine trophic index).

rare species may not be detected, which negates the real advantage of having a separate species richness indicator. In the second instance, using occupation as a proxy for abundance assumes that distribution and abundance are sufficiently correlated that relative changes in one can act as a proxy for relative changes in the other. This may often be true, but if it is the case, information is not increased by having both the range and abundance indicators.

The situation is further complicated by the fact that occurrence data is typically collected with longer intervals (typically decadal) than count data (typically annual), while count data is typically produced for a smaller sample of sites than occurrence data. Thus, while occurrence data would be preferred for the diversity indicator when recently available, the longer the time elapsed since it was last collected, the more preferred count data will be. Similarly, occurrence data, at least when recent, does contain some information which is additional to the count data. There is therefore a case for using both data types, where available, in each indicator, weighting them according to their suitability for the indicator, as well as their recency.

With respect to the diversity indicator, increases in local species richness are not necessarily positive for biodiversity, if they come at the expense of beta diversity (or community / habitat diversity) or of national species richness. Many species-poor habitats are rightly considered to be an important and distinctive part of Welsh biodiversity. Within the scope of Outcome 19, therefore, an indicator of diversity must at minimum incorporate site species richness (=local diversity), inter-site or beta diversity (=regional diversity) and national species richness (=national diversity). It is a subjective issue as to whether to impose strict ordinality on the indicator, i.e. a positive trend is only possible if all three indices are either increasing or stable or whether to allow commensurability, i.e. an increase in one level can compensate for a decrease in another level. Either way, a single combined indicator could be produced. The simplest way to do this would be to present diversity at each of the three levels in panels of the same figure, with clear verbal warnings if either beta diversity or national richness had declined.

Overall, we recommend two headline indicators: diversity and abundance. These would be accompanied by supplementary indicators (as illustrated in Figure 27 and Figure 28 on page 58 below). The diversity indicator would be accompanied by supplementary indicators of beta and national diversity, if these were not incorporated into the main indicator, while the abundance indicator would be accompanied by supplementary indicators for endangered species (equivalent to the main indicator, recalculated for a subset of endangered or priority species) and range. Both indicators would also be accompanied by a bar showing the taxonomic range of the data included in the indicator.

Representing central tendency and dispersion

Even for a given level and facet of biodiversity (the definition of which is in any case somewhat arbitrary), there will always be considerable variation, uncertainty and error in any estimate of the true state of biodiversity. This stems from several sources, for example, in the case of a species level abundance indicator:

1. Measurement error and bias (at a given site)
2. Within species variability (between sites)
3. Within group variability (between species)
4. Between group variability and bias

The first can be minimised through good protocols and sufficient observer effort. We have provided estimates of the second and third sources of uncertainty, and shown them to be important. It will always be difficult to estimate between-group variability, and the bias associated with non-random selection of taxonomic groups, but with data from multiple groups an attempt could be made. While for the report we have not directly included between species and within species uncertainty into the estimate of the median trends a similar methodology (bootstrapping) as used for estimating the confidence intervals for the mean trends could easily applied. For estimating within species variability the procedure would be far less computationally intensive than for estimating intervals for the mean trend as GAM fitting would not be required. Graphically presenting these results would not be straightforward as there would be confidence intervals for each decile. A compromise approach would be to have a central band for uncertainty about the median trend and an outer band incorporating uncertainty about, for example the 50% percentiles, or alternatively to plot probability densities.

It is important to remember that variability between sites and between species only produces uncertainty when central trends are estimated (mean or median). Given that the primary purpose of these indicators is to evaluate and graphically present the state of biodiversity we are unconvinced that measures of central tendency are useful, for two reasons. First, we have demonstrated that the choice of measure (geometric or arithmetic mean, median) greatly affects the trend observed and there seems to be no good objective reason for choosing one over the other. Second, the use of a measure of central tendency creates the need for disaggregations, to ensure that important information is not hidden. Yet there are an almost infinite number of possible disaggregations (by trophic level, habitat type, taxonomic group) and only a small fraction could ever be presented to policy makers or the public without either swamping the end-user or encouraging cherry picking. It would be unsatisfactory to select a small number of 'official' disaggregations, based on a priori assumptions about which species will be similarly affected by as yet unknown factors.

To see how to proceed, it is useful here to distinguish between two purposes, corresponding to the first two roles of indicators identified by Failing and Gregory (2003): tracking performance and discriminating between hypotheses (research). For the former role, it does not especially matter which species are declining or falling (though they may be weighted differently): the aim is rather to determine if any proportion of biodiversity is declining and if so, how much. Thus, for this purpose, rather than choosing one of these measures, and attempting to convey uncertainty over its true value, we recommend that for each indicator only the distribution (in shaded deciles) is presented. This provides almost complete disaggregation in a single headline figure, since it will be clear what percentage of species (or sites) have declined in abundance (or richness). Distributions of species or site trends can be compared to some threshold index value which will trigger an alarm (e.g. 80% of baseline) and would serve adequately to assess performance. In order to communicate this assessment most effectively to the general public, examples of species falling below the threshold index value of 80 might be needed. The important point is that the use of percentiles does not preclude, and in fact aids, the precise specification of targets.

Of course, a secondary purpose of these indicators is to aid our understanding of the system, and the use of percentiles in the headline indicators would not preclude analysis of the data by researchers aiming to discover the causes of declines. Indeed, it would leave it open for such analyses to be carried out as researchers saw fit, rather than being dictated by a priori assumptions.

Weighting and inclusion

For any indicator, there are difficult value judgments to be made about which species are included in the indicator (i.e. whether to include non-native species) and about how species should be weighted relative to one another. This issue was discussed, but not resolved, at the workshop, and we do not draw any definitive conclusions here other than to say that the issue must be addressed. We do offer some comments however.

First, with regard to non-native species, we can see a case for including all species found in the wild, regardless of origin. This avoids the need to make difficult subjective judgments about whether a species is native or not, and about whether climate migrants (which are likely to become more numerous) are ‘natural’ immigrants or introduced by the hand of man (climate change being predominantly anthropogenic). Given that climate change is also out of the control of the Welsh government, it seems sensible to view these species as natural immigrants in an indicator whose primary purpose is to evaluate the performance of that government. It must be remembered that any negative impacts of non-native invasive species will still be reflected in the indicator, in terms of reductions in the populations of native species.

Second, with regard to weighting, we believe the most appropriate way forward would be to weight species by some combination of:

1. Body size or trophic level: to avoid the indicators being swamped by low trophic level species (this is unnecessary for the abundance indicator if relative changes in abundance are used).
2. Phylogeny: taxonomically distinct species would be weighted more (e.g. Arvanitidis et al 2009).

3. International importance of the Welsh population: species for which Wales is at the margin of their range would be weighted less

All three weights would be applied to species in the abundance indicator, but the last might be inappropriate for the diversity indicator.

Review of biodiversity datasets for Wales

Introduction

There is a vast array of biodiversity monitoring going on in Wales, collecting data for a range of taxa across all habitat types. Schemes range from those which focus on single species (e.g. the Greater Horseshoe bat colony counts), through programmes for groups of taxa (e.g. the Butterfly Monitoring Scheme), to schemes which collate records across a range of taxa such as the Environmental Change Network. However, the quality of the data for assessing change in biodiversity is unknown. We undertook a review of existing biodiversity datasets in Wales with the following objectives:

i) assess the potential of existing datasets for use in biodiversity indicators

ii) identify the gaps in existing datasets (taxonomic and spatial coverage)

iii) recommend appropriate (and statistically robust) methods to fill the current gaps in data collection.

Information collation

The starting point for this review was the meta-database of environmental monitoring datasets covering Wales which was produced in 2005 by Reynolds et al. The information in this meta-database was in relation to Great Britain, so had to be revised in relation to Wales only, and updated. All datasets relating to biodiversity were extracted from this meta-database, producing 91 datasets which were prioritised subjectively according to their potential to meet criteria for assessing biodiversity change:

- Sufficient samples in Wales
- Record over time
- Sustainable (is monitoring set to continue into the future)
- Reliable (intertemporal consistency of sites or site selection, standard protocols, objective measurements, trained observers)
- Control for changes in detectability and observer effort

At this stage, 34 datasets were considered high priority (see Table 4). Although much information about the relevant monitoring schemes is available on the internet, this only provides a general introduction and in order to obtain information specific to Wales, individual contacts had to be sought for the 34 prioritised datasets. Contact was made by e-mail/phone and questions asked to obtain the following information:

- Collecting organisation, owning organisation, data series title
- Taxa (which species/composite groups), habitats surveyed in and geographical extent (including number of samples)
- Data format, type of data, collection methods, sampling approach
- Time span and frequency of data collection

- Other uses of data e.g. other indicators/publications
- Access arrangements, costs

Table 4. Datasets prioritised for investigation

Dataset	Organisation	Taxa group
Breeding Birds Survey	BTO	birds
Local Change	BSBI	higher plants
Aquatic Invertebrates in Wales	Environment Agency Wales	invertebrates
Butterfly Monitoring Scheme	Butterfly Conservation	invertebrates
Common Plants Survey	Plantlife	higher plants
Countryside Survey	CEH	higher plants
Priority Species Monitoring	Plantlife	higher plants
Wales Otter Survey	Environment Agency Wales	mammals
MarClim (Marine biodiversity and climate change)	MBA	invertebrates, lower plants
International Bottom Trawl Survey (IBTS)	CEFAS	fish
British Bryological Society National Database	British Bryological Society	lower plants
Threatened bryophyte database	British Bryological Society	lower plants
BioSoil platform (note biodiversity component is optional)	Forestry Commission	higher plants
COFNOD (Local Records Centre)	COFNOD	mammals/birds/fish/rept/higher plants/lower plants
Detecting Pine Martens in England and Wales	Vincent Wildlife Trust	mammals
Distribution of the hazel dormouse in Wales	Vincent Wildlife Trust	mammals
Lesser Horseshoe Bat Summer Roost Surveillance	CCW	mammals
Level II Longterm Intensive Monitoring Programme	Forestry Commission	higher plants
Monitoring of horseshoe bats through the use of automatic bat counters	CCW	mammals
The National Bat Monitoring Programme: Colony Counts	Bat Conservation Trust	mammals
The National Bat Monitoring Programme: Field Transects and Waterway Surveys	Bat Conservation Trust	mammals

The Water Vole and Mink Survey of Great Britain 1982-1998	Vincent Wildlife Trust	mammals
Batsites inventory for Britain	Natural England	mammals
BRC Dragonfly and Damselfly records	BRC	invertebrates
BRC Mammals database	BRC	invertebrates
BRC Mollusca dataset	BRC	invertebrates
BRC Reptiles and Amphibians dataset	BRC	invertebrates
Carabid data for Great Britain from the Ground Beetle Recording Scheme held by BRC	BRC	invertebrates
Dragonfly Recording Network to 2001	British Dragonfly Society	invertebrates
Greater Horseshoe Bat breeding productivity surveillance in Pembrokeshire	CCW	mammals
Marine Life Information Network (MarLIN) marine survey data	MBA	invertebrates, lower plants
Permanent Sample Plot Database & Databank	Forestry Commission	higher plants
The National Dormouse Monitoring Programme	Vincent Wildlife Trust	mammals
Marine & Estuarine Fish Database	CCW	fish

All information was entered into an access database, with extra datasets added and prioritised according to suggestions from conservation practitioners. This resulted in a total of 104 biodiversity datasets, with information obtained about 60 (see meta-database). It is important to note that although the aim was to capture information about the datasets which were most likely to provide useful data for measuring biodiversity in Wales, this is a partial assessment and some important information may have been missed.

Assessment of datasets

Assessments were made of the potential of each dataset to contribute to a biodiversity indicator (the majority of these assessments were made of the meta-data rather than the actual datasets). First the project team assessed whether they met the required criteria listed above (classed as 'A') after which further datasets were identified by participants at the workshop (classed as 'B'). All other datasets are deemed to be of limited used and are classed as 'C'. Almost a quarter of the datasets met the criteria (A), and can currently be used to measure biodiversity (Figure 22). A further 19% of datasets were assessed as useful by workshop participants (B), and hence with some changes could be used to measure biodiversity.

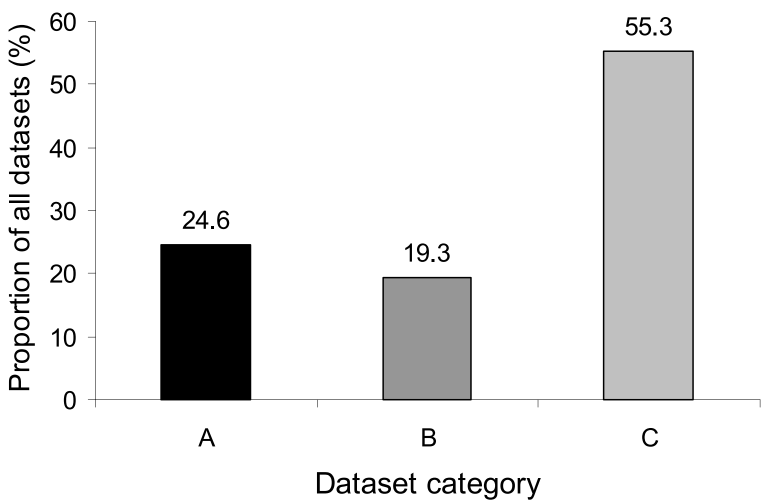

Figure 22. Categorisation of 104 biodiversity datasets for potential use in biodiversity indicator. Category A= meets criteria, category B=potentially useful and category C=limited use.

Following this assessment, all information available about all of the datasets (meta-data) was used to assess the spread of the quality of datasets by taxa, habitat and space. A rough calculation of the size of taxonomic groups in Wales shows that the invertebrates are by far the largest, followed by lower and higher plants (Figure 23). Some taxonomic groups are better covered than others, with invertebrates particularly poorly covered (Figure 24).

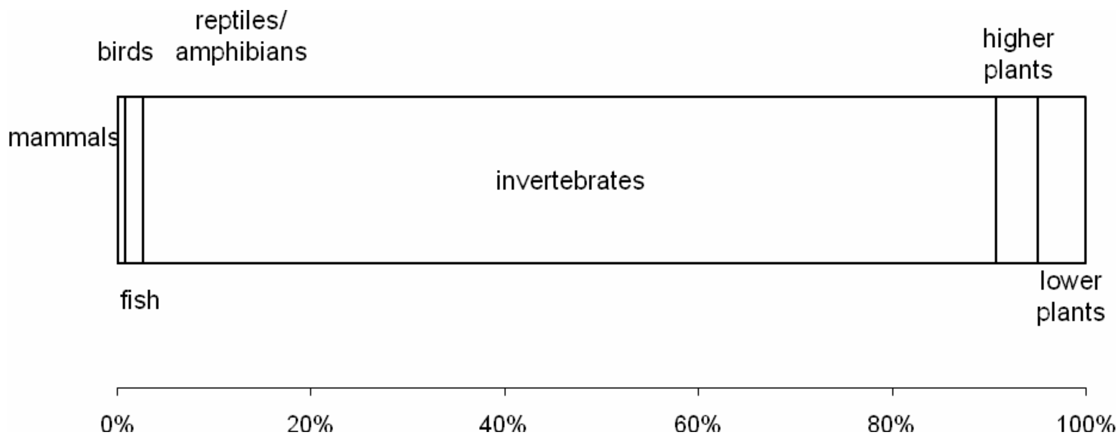

Figure 23. Relative size of taxonomic groups in Wales (based on approximate number of species in each group according to Dines 2008; CCW 2009a,b; Kay and Dipper 2009; Wales Mammal Group 2009). Note that mammals and reptiles/amphibians have so few species that they are only represented by a single line on the chart.

Birds are the best covered taxonomic group; because there is a large number of bird monitoring schemes, they are covered over 700% (seven times) by datasets of varying quality. Invertebrates are the only group in which there are gaps in overall data coverage; 66% of invertebrate species are not included in any monitoring activity. Looking at only the datasets which meet the criteria for use in measuring biodiversity, birds, fish, reptiles/amphibians and higher plants are all well covered (>100%) which leaves gaps in mammals, invertebrates and lower plants/fungi. The gaps in data of sufficient quality are largest in lower plants and invertebrates (with 96% and 93% of species respectively lacking good quality data). These gaps are due to the large numbers of relatively small, hard to identify species in each of these groups.

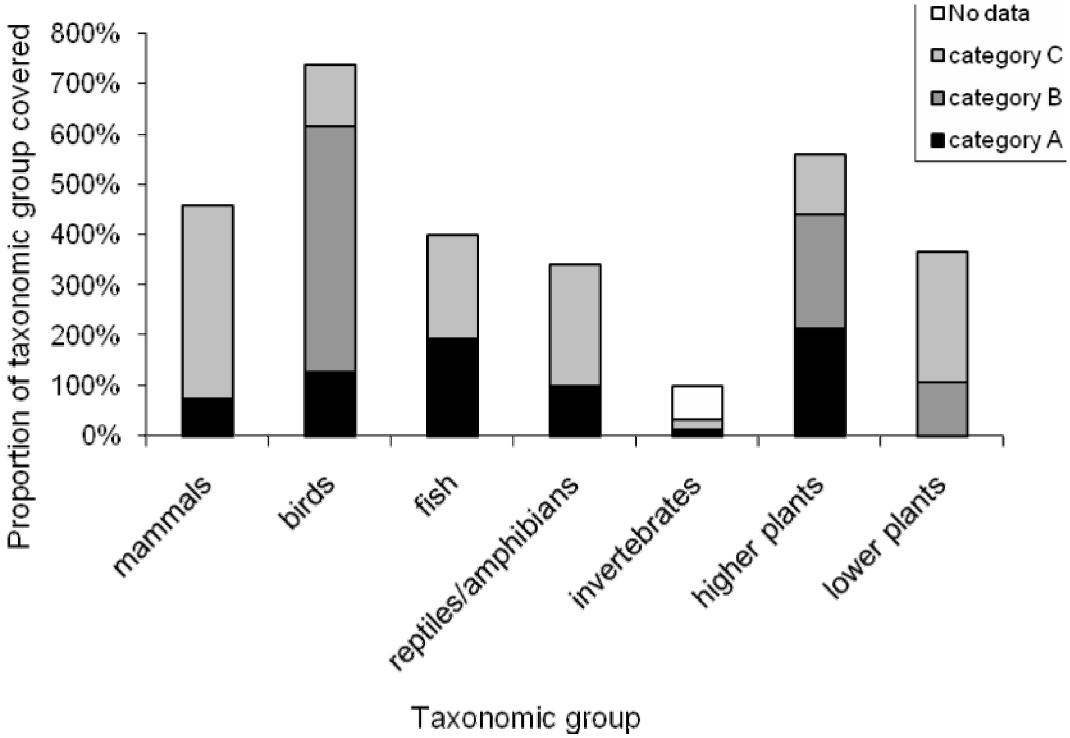

Figure 24. Taxonomic coverage of biodiversity datasets in Wales according to quality of datasets (100% means that all species in a taxonomic group are covered by monitoring, 200% that all species in a taxonomic group are covered two times etc). Bars show proportion of species in each taxonomic group covered by datasets of various qualities, category A= meets criteria, category B= potentially useful and category C= limited use.

Spatial cover of datasets is partially encompassed in the criterion used to assess quality of datasets in Figure 24, but analysis of number of sites included in monitoring schemes reveals more detail. There is a lack of information about spatial extent of datasets in all taxa groups, largely due to the difficulty in obtaining detailed information about this. All taxonomic groups except invertebrates are at least 100% covered by datasets with extensive spatial coverage (Figure 25). It is interesting that lower plants appear to have good spatial coverage, this is because this analysis does not include any information about quality, and lower plants (particularly bryophytes) are well covered by ad hoc recording schemes which are widespread throughout Wales but which do not provide repeatable data for assessing change over time.

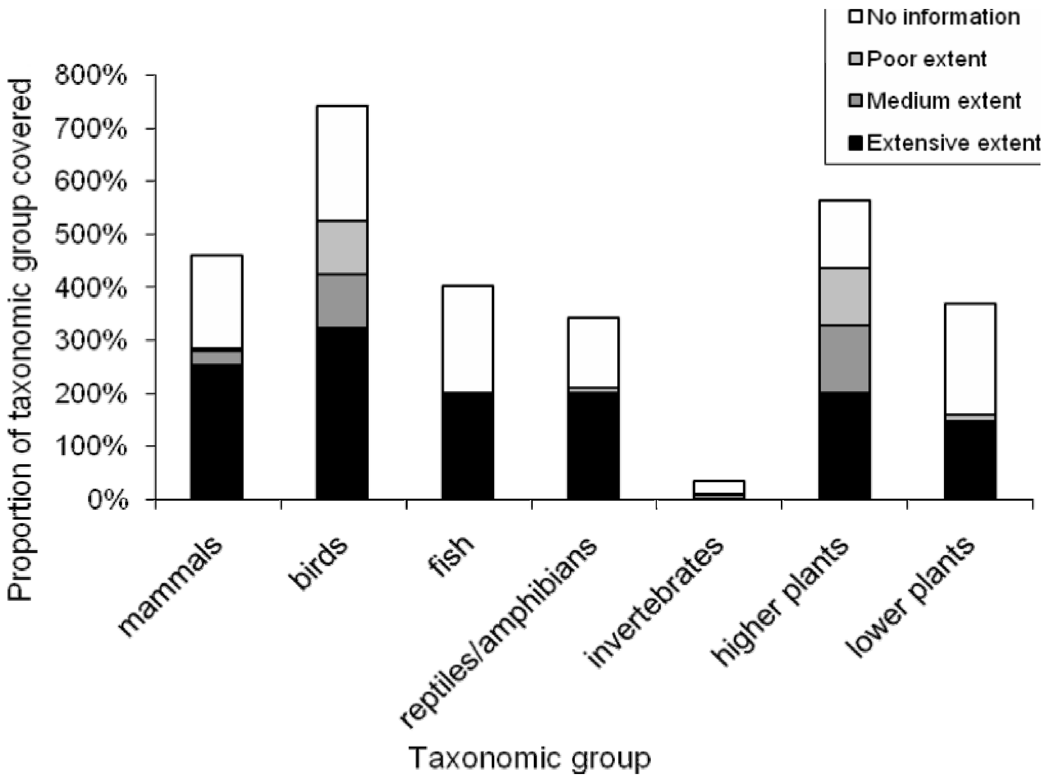

Figure 25. Taxonomic coverage of biodiversity datasets in Wales according to spatial extent of datasets. Bars show proportion of species in each taxonomic group covered by datasets of various spatial extent; extensive extent (51+ sites), medium extent (21-50 sites), poor extent (0-20 sites) and no information available.

Different types of habitats are also monitored at different intensities, with terrestrial habitats better monitored than either freshwater or marine habitats (Figure 26).

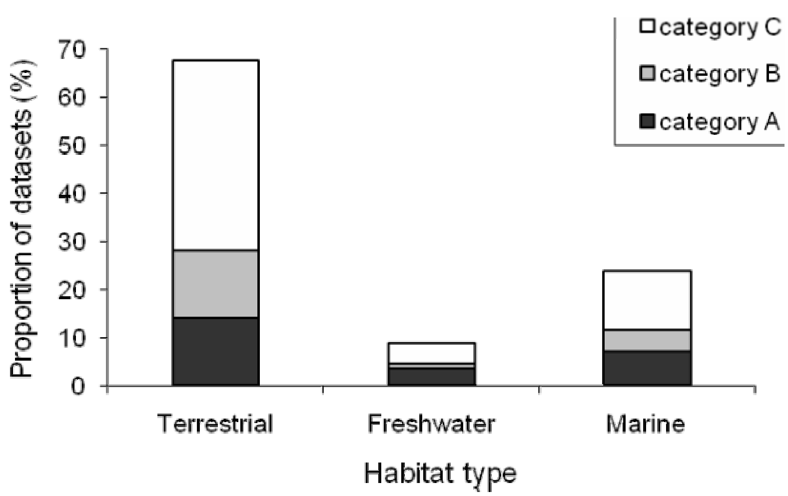

Figure 26. Quality of biodiversity datasets in Wales according to habitat type. Bars show proportion of datasets in each habitat type according to quality, category A= meets criteria, category B= potentially useful and category C= limited use.

This reflects partly their greater diversity and accessibility but also peoples' interest. In terms of the quality of datasets, all types of habitats have some datasets which meet the criteria, and some which could potentially meet the criteria.

Data access

We approached the holders of the relevant data sets to ask if their data could be made available to this project. Initially we contacted two organisations responsible for storage of Welsh biodiversity data: Welsh Local Records Centres (LRCs) and the National Biodiversity Network (NBN) Gateway. The LRCs were unable to provide the required data, due to the system of data collection and storage whereby some local and national recording schemes send data only to LRCs, some schemes hold the data themselves and some send data to LRCs and to the Biological Records Centre and/or the NBN Gateway. This means that data held by LRCs is partial and overlapping with other sources. The majority of data held by LRCs is also in the form of ad hoc sightings which is not collected using consistent sampling or measurement methods and therefore is unsuitable for assessing change over time.

The NBN Gateway was also unsuitable for data provision, for several reasons. Data must be searched species by species, which is not feasible for large groups such as higher plants encompassing 1467 species in Wales (Dines, 2008). Requests for access must then be made to individual dataset providers, and when access is granted, data is provided in separate files for each data provider which involves downloading many files for one species e.g. 22 files for the otter. Finally, data is not disaggregated to Wales, so must be processed prior to further use.

Therefore data providers had to be contacted directly to obtain access to datasets and although individuals were generally keen for the data to be used, several difficulties were encountered in gaining access to the data:

- Disaggregation of datasets from a UK level to a Welsh level; this tends to require expert data manipulation skills.
- Reluctance to provide raw data (possibly due to a fear of misinterpretation). Several organisations prefer to analyse the data and provide access to it at a later stage in the process.
- Timescale of data access process; people are busy and take time to respond.

This meant that, of the 18 datasets for which requests were made for data access, only five datasets were received during the duration of the project. These datasets took between two weeks and two months to obtain access to.

Conclusions from the review of available datasets:

Other potentially useful datasets (category B) could be contacted to see whether they could contribute to assessment of biodiversity change (there was insufficient time in the current project to contact all 101 dataset providers directly).

Even once all possible data sets have been contacted, there is likely to be insufficient quality data available on many groups including mammals, invertebrates and lower plants (category

A) to monitor changes in all these groups. Existing datasets (currently assigned to category B) could be explored to investigate whether small changes in their collection methodology or number of sites sampled could make them more valuable.

A centrally held meta-database holding information about datasets at the Welsh level would make information about biodiversity monitoring activities and also the resulting data more easily accessible. This could be developed in conjunction with the UK-Environmental Observation Framework's and the meta-database constructed as part of this project could provide a starting point for this. However, populating and maintaining such a database represents a considerable commitment of resources and to avoid duplication of effort would require close collaboration with NGO partners.

The British Trust for Ornithology Breeding Birds Survey uses volunteer data supported by professionals who check data quality and support the database. Britain is rich in skilled amateur naturalists, many of whom already contribute to NGO-led monitoring schemes. It may be the case that relatively small investment of resources could ensure that such schemes are made much more useful (more systematic site selection, better data storage, better quality control). This approach would involve the joint working of a range of recording bodies and conservation organisations with the necessary expertise and experience, including the BTO, RSPB, Butterfly Conservation, Botanical Society for the British Isles and the British Bryological Society. This could be overseen by a body such as the Biological Records Centre.

Table 5. Datasets identified for inclusion in the indicators

Count data (abundance)	Occurrence data (presence absence)
Datasets ready to include by 2010	
Aquatic Invertebrates in Wales	Garden Bird Feeding Survey
Breeding Birds Survey	Local Change
Breeding Waders of Wet Meadows	Wetland Bird Survey
Butterfly Monitoring Scheme	Wales Otter Survey
Countryside Survey	
Heronries Survey	
Lesser Horseshoe Bat Summer Roost Surveillance	
Mammal Monitoring through the Breeding Bird Survey	
SAHFOS Continuous Plankton Recorder Survey	
Standardised bird ringing	
The National Bat Monitoring Programme	
Waterways Breeding Birds Survey	
Winter Gull Roost Survey	
Datasets which need to be continued until they provide 10 years of data	
Common Plants Survey	Priority Species Monitoring ('Back from the Brink' species recovery)
International Bottom Trawl Survey (IBTS)	NARRS National Amphibian and Reptile Survey
CEFAS	
MarClim	
Marine Life Information Network (MarLIN) marine survey data: STRUCTURED	
National Fisheries Monitoring Programme	
Recommendations for changes to existing datasets	
BioSoil platform	All Wales Common Scoter Survey
Environmental Change Network	Bird atlases
Level II Longterm Intensive Monitoring Programme	BirdTrack
Predatory Birds Monitoring Scheme	Nest Record Scheme
Ringing Scheme	The National Dormouse Monitoring Programme
The Rothamsted Insect Survey national light-trap network	Upland Birds on CBC Sites
RSPB Cymru species surveys	
Seabird 2000	
Seabird Monitoring Programme	
Statutory Conservation Agencies and RSPB Annual Breeding Bird Surveys (SCARABBS)	
Waterways Bird Survey	
Recommendations for new datasets	
Implement additional monitoring (of abundance and occurrence) for the following taxa groups: Mammals, invertebrates and lower plants	

Summary of key recommendations

Wales should not follow other nations in developing ad hoc lists of indicators driven by the structure of existing datasets. Instead it should develop a coherent set of biodiversity indicators in a deliberative fashion, synthesising existing datasets and developing new ones where appropriate.

Wales' biodiversity indicators should cover all levels of biodiversity (from genes to landscapes) and be organised in a consistent fashion. We recommend using the DPSIR framework to clearly distinguish between indicators of driving forces, pressures, state, impact and response. We suggest a possible structure for all indicators of the biodiversity theme in appendix 2. We note that other levels of biodiversity, including communities, habitats and landscapes, are not yet well represented in the indicators. These might be represented by conceptually similar indicators of abundance (i./e. area, weighted by quality/condition) and diversity.

We recommend two headline indicators for species-level biodiversity: diversity and abundance.

Each indicator should be presented in the form of percentile distributions, without measures of central tendency, and should be accompanied by a graphical representation of the taxonomic breadth of the indicator. Eschewing measures of central tendency removes the need for arbitrary disaggregations and maximises information content. Each indicator would be accompanied by a summary statistic detailing what proportion of biodiversity had increased or decreased over baseline, to aid interpretation.

The diversity measure should incorporate regional and national diversity as well as local diversity, either in a single indicator, or as supplementary indicators.

The abundance indicator should be accompanied by supplementary indicators of endangered/priority species and of geographical range. The status of endangered species should be represented by recalculation of the abundance indicator for this subset of species, to allow direct comparability.

It will probably be necessary to weight species in both indicators. We suggest including all species for which data is available, but weighting according to phylogenetic distinctiveness, trophic level, and the international importance of the species' Welsh population. Genetic diversity will partly be incorporated through the phylogenetic weighting. Future developments in technology may allow genetic diversity to be explicitly considered.

Existing indicators for outcome 19 should be absorbed into these two headline indicators. 19a, BAP species, will be superseded by producing a subset of the abundance indicator, for endangered/priority species, as data and expert knowledge allow. 19b Wild Birds, will be entirely incorporated into the abundance indicator, and therefore redundant

It is vital that all indicators are based on as broad a range of biodiversity as possible. We make detailed recommendations on which datasets are ready to be included in the indicators at launch in 2010, and which might be made suitable by 2016. To this end, we recommend that WAG, through its agencies, consider investing some resources to facilitate and coordinate the collection of biodiversity data in Wales. New data sets can be incorporated as and when they become available, with the level of the indicator being adjusted so that their incorporation per se does not affect the value.

Graphical presentation of proposed indicators

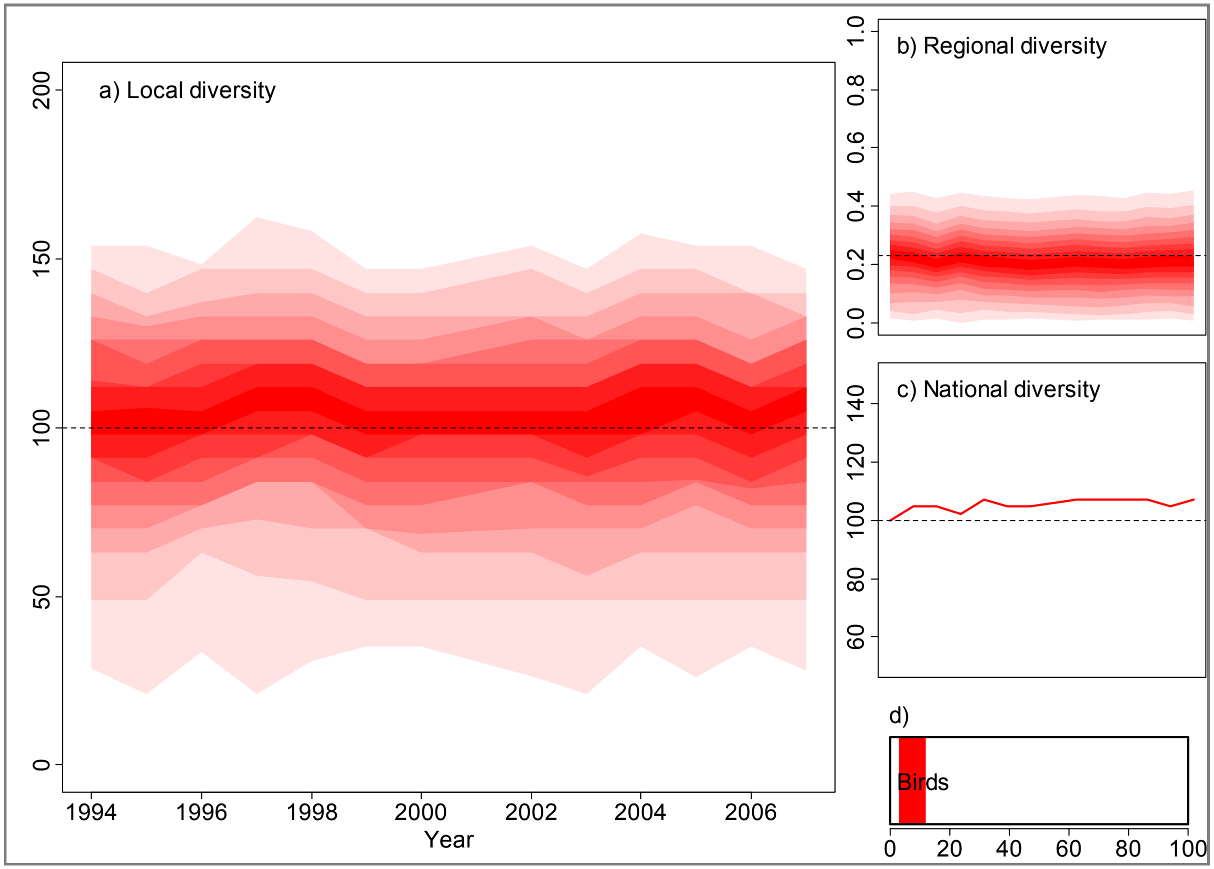

Figure 27. Example presentation of the recommended diversity indicator, using the BTO breeding bird survey. a) headline Indicator species richness at individual sites, b) between-site diversity where 1 is completely different species composition and 0 is the same species composition, c) total number of species at all Welsh sites, d) species coverage of all Welsh species. Shading indicates the percentage of sites for each diversity measure in 10% intervals, Inner darkest bands are the middle 10% of sites, 90% of sites lie within the outer lightest shading.

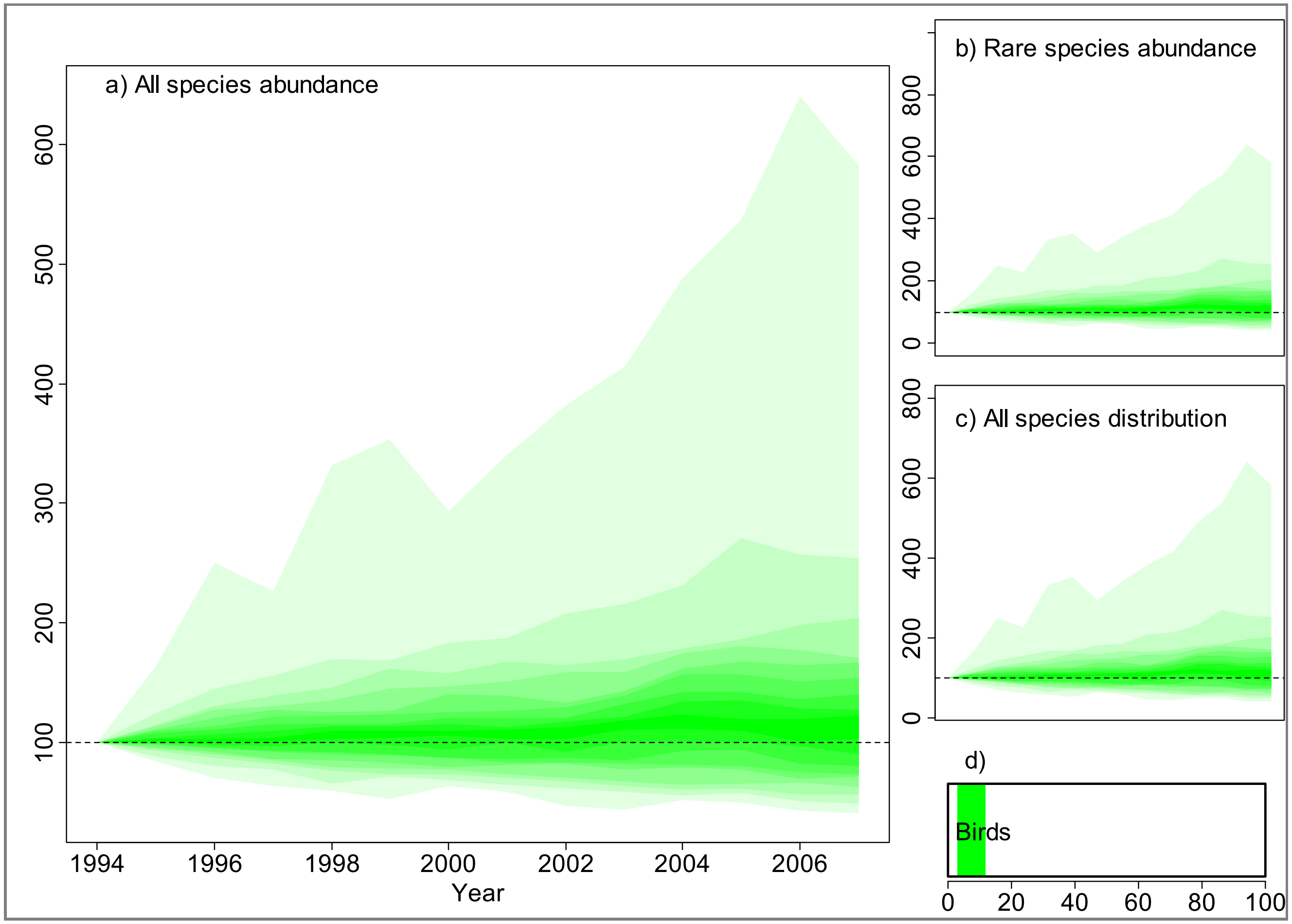

Figure 28. Example presentation of the recommended abundance indicator, illustrated using the BTO breeding bird survey. a) change in abundance for all species (1994=100), b) change in abundance for rare species, c) change in range for all species, d) species coverage of all Welsh species. Note that b) and c) are for illustration only and are the same data as a). Shading as previous figure.

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Appendix 1: Report of the workshop to develop indicators for Welsh wildlife held at the Environment Centre Wales, Bangor, 21st April 2009

Summary of the day

Participants became fully engaged with the complexity of the problem and the many issues that need to be resolved in order to recommend an indicator with up to about 8 components. The following principles were broadly agreed:

- It is possible to design a meaningful biodiversity indicator, although no indicator can reflect species across all taxa and habitats
- Any such indicator is likely to be a compound indicator
- Due to the complexity of the task, and the gaps in our understanding of species interactions, development of the indicators involves subjective decisions using the best knowledge available. This subjectivity must be made explicit.
- An indicator needs to be accompanied by a measure of uncertainty/variability
- The headline set of indicators needs to be presented in a manner that communicates clearly to non-specialists, and needs to be backed up by a technical report
- Somewhere between 5 and 15 lines on a smaller number of graphs are enough to capture Welsh biodiversity meaningfully
- We should not confine ourselves to extending existing data sets; novel monitoring may be needed
- It is not possible to objectively exclude or include individual species

Inevitably a workshop such as this does not have time for a full gap analysis of biodiversity monitoring in Wales, although it did address many of the more obvious gaps in current coverage. Some areas that were still not resolved were: how to deal with new invasives; how to cover a suitable range of habitats; adequate coverage of ecologically important taxa with a low public profile (e.g. macroinvertebrates); and covering freshwater species.

Other points raised outwith breakout sessions

- There was a general view that the existing indicators are not sufficient in their coverage of major taxa or of rare and endangered species; nor was it clear how to cope with new invasives or indeed existing invasives that are widely felt to be undesirable.
- What do WAG want to measure? What is meant by biodiversity? It is important to consider what WAG will use the indicator(s) for as well as what the indicator measures.
- Also need to be clear what is meant by species 'richness' and 'diversity'.

- Genetic diversity- conventional measures of within-species genetic diversity are not feasible, but indicators of population size, and distribution amongst habitat patches (metapopulation concepts etc.) may be useful correlates. One suggestion was that phylogentic diversity could be used but it is clearly between-taxon. For some micro-organisms however, sampling of the metagenome in environmental samples may be the only method of inventory and this incorporates genetic diversity.
- Any indicator needs to retain flexibility so that sub-sets (or what is used to calculate it) can be changed in the future.
- In terms of value judgement/weighting between different facets of biodiversity the criteria in 'A nature conservation review: the selection of biological sites of national importance to nature conservation in Britain' by D. Ratcliffe (1977) could be useful.
- Importance of volunteers and how to use them to collect more information as part of existing schemes. Need for extra monitoring could be met by a WAG funded volunteer based scheme to record all species in a BBS style stratified sample. It was noted that the current funding of BTO by JNCC encourages bird monitoring.
- The search for indicators seems to revolve around numbers that go up and down, with an implication that up is good and down is bad. But there is a clear difference between an increase from a good position, and an increase from a poor position.
- There was discussion about the necessity of a clear hierarchy in structuring a biodiversity indicator. The platform is a well-designed and implemented monitoring programme (can be a composite of existing and new programmes but must be clearly defined). It may be possible to fund from existing resources for monitoring by a WAG-led review of the range of current monitoring programmes and a consequent redistribution of monies. The next component of the hierarchy is a detailed technical report which includes but is not limited to the headline indicators; this is a place where new concerns and needs for reviewing the indicator set should be raised. The final component of the hierarchy is the public domain report on the indicators; this needs to be clear in its communication and include trends, certainty/error, and a trigger warning – are there causes for concern (detailed in the technical report) which are not obvious from the indicator as presented.

Workshop speakers:

John Farrar[1], James Gibbons[2], Sue Hearn[2] and Neal Hockley[2]

[1] School of Biological Sciences, Bangor University; [2] School of the Environment and Natural Resources, Bangor University

Workshop attendees:

David Cowley	Anglesey Council
Trevor Dines	Plantlife
Hugh Evans	Forestry Commission
Angus Garbott	CEH, Bangor
Stephen Hawkins	CNS, Bangor University
John Healey	SENR, Bangor University
Liz Howe	CCW
Ian Johnstone	RSPB
Julia Jones	SENR, Bangor University
Andrew Pullin	CEBC, SENR, Bangor University
Mark Rehfisch	BTO
Ed Rowe	CEH, Bangor
Terry Rowell	Environmental Consultant
Bill Sanderson	CCW
James Skates	WAG
Rob Strachan	Environment Agency Wales
Heather Sugden	CNS, Bangor University
Roy Tapping	COFNOD: North Wales Environmental Information Service
Harvey Tiler-Waters	Marine Biological Association
Alex Turner	CCW
Helen Wilkinson	CCW
Kate Williamson	Snowdonia National Park Authority

Abbreviations

BTO- British Trust for Ornithology

CCW- Countryside Council for Wales

CEBC- Centre for Evidence Based Conservation

CEH- Centre for Ecology and Hydrology

CNS- College of Natural Sciences

WAG- Welsh Assembly Government

RSPB- Royal Society for the Protection of Birds

SENR- School of the Environment and Natural Resources

Discussions in breakout sessions

Group A Rapporteur: John Farrar

Group B Rapporteur: Julia Jones

Group C Rapporteur: Sue Hearn/James Gibbons

Task 1: Species exclusion criteria: can this be decided?

Group A Species to be included: species at risk of extinction, climate sensitive species, invasive species, species responsive to rapid change (e.g. butterflies), species which are slower to change but indicate fundamental change (e.g. plants), charismatic species, fundamental species, species from a range of trophic levels. Also micro-organisms

Species to be excluded: not possible to develop objective criteria

Group B Species should not be explicitly included/excluded

Group C Not possible to develop objective criteria for exclusion of species; should be considered on a case by case basis. Strong feeling in this group that you can't pick indicator species as there's no evidence that some species are any better than others at indicating general state. Note that some species/groups might be cheaper to monitor than others.

Task 2: Given infinite resources and knowledge, what parameters of biodiversity should the indicator(s) measure?

Group A

Marine/terrestrial/freshwater

Detritivores/Producers/herbivores/Predators

Indicators should be based on existing datasets as that will ensure that they are appropriate for current issues

Group B

i. Threatened species: Red List

ii. 'Important' species: BAP

iii. Widespread species

Group C

i. Total species richness

ii. Measure of (relative) abundance of the species, to report as 'evenness'

iii. Phylogenetic diversity (note new tractable measures for this by Paul Sommerfield, recent speaker in Bangor)

iv. A measure of the distinctiveness/rarity/importance of this Welsh biodiversity at a global scale

v. Measures of the population status of known rare or threatened or vulnerable or otherwise 'conservation priority' species (should be covered by the BAP indicator but this may well not be fit for purpose, e.g. in terms of species selection amongst taxa, monitoring methods etc.)

To get more indicator information out of these broad measures they could be sub-divided as follows:

A. Divide i, ii and iii into within habitat versus between habitat (alpha and beta) components as an objective way to get at 'habitat diversity'.
B. Classify species into different biogeogaphical groups/types. Also distinguish any endemic taxa (at least at sub-specific level). This sub-division should be useful for more sensitive indication of the impact of range shifts with environmental change and help distinguish stasis in biodiversity from large positive and negative changes balancing each other out.

Task 3: Can the existing datasets be prioritised? What are the gaps?

Group A Most useful: BBS, WEBS, SCARABBS, NARRS, BMS, EAW aquatic inverts, Countryside Survey, Common Plants and Priority Plants Monitoring (Plantlife), BSBI, all bat, cetacean and fish datasets

Incomplete dataset gaps should be filled; volunteer schemes should receive more funding

Group B i. Threatened species: Red List- got plants, birds and lichens, need to develop all other taxa

ii. 'Important' species: BAP- got all data

iii. Widespread species- got birds, butterflies/moths, bats and plants, need to develop mammals, inverts and fish

Group C Rather than include and eliminate datasets they suggested some criteria for inclusion:

1. Repeated measures over time, annually where appropriate (not necessary for some taxa e.g. plants)
2. Sufficient sites to detect change and to cover taxa distribution adequately
3. A published and reproducible protocol; these can differ among schemes
4. Sampling effort either fixed or quantified
5. Randomly selected sites (this would exclude the Butterfly Monitoring Scheme)
6. Stratified sampling
7. Sufficient expertise in Wales for widespread monitoring

Schemes that did not currently meet the criteria could then be changed if the taxa were felt to be important

Gaps in protocol based invertebrate monitoring activities

Task 4: How should the indicators be presented and how can the uncertainty be communicated?

Group A One headline indicator graph for each trophic level (indices plotted against time) sub-divided into marine/terrestrial, based on a random selection of species (identity of which is kept secret) from each group e.g. five species which are producers etc - - Uncertainty could be incorporated by either plotting the grey band of confidence limits or by plotting the mean and adding a statement about significance of change.
- Indices of abundance and other measures of diversity can be combined into a single compound indicator. Since the index would start at 100 for year 1, there should be no insurmountable problem with combining sub-indicators in this way.

- Confidence should be expressed as low-medium-high

Group B i. Threatened species: Red List Graph: % taxa under threat over time

ii. 'Important' species: BAP Graph: % BAP species meeting target over time

iii. Widespread species: didn't say

Understanding uncertainty in any measure is crucial to drawing conclusions. But there is no need to express it at all to policy-makers and the public. If CLs overlap then we cannot conclude a difference, so we should not conclude that there is a trend. We may, of course, set our CLs at much less than 95%, and we might use more than one level (>50%, >75%, >90%). This is complicated by the multiple measures in indicators, quickly multiplying the uncertainty.

Group C One graph for each indicator

Workshop timetable

0900-0930	**Registration Tea/Coffee** During the lunch and tea breaks, there will be opportunities to register your views and contribute expertise	**Presenters**
0930-0935	**Welcome**	John Farrar
0935-1000	**The policy context and key issues** What are indicators for? What properties should they have?	Neal Hockley
1000-1025	**Some example indicators for Wales** The results of exploratory analyses using Welsh biodiversity data	James Gibbons
1025-1045	**What biodiversity data exists in Wales?** Additions and corrections will be welcomed during the breaks	Sue Hearn
1045-1100	**Tea/Coffee…** …and another opportunity to contribute your expertise	
1100-1115	**Introduction to questions**	Neal Hockley
1115-1215	**Breakout Session 1** Split into 3 small groups to tackle the following tasks: 1: Species exclusion criteria: can this be decided? 2: What parameters of biodiversity should the indicator(s) measure?	
1215-1230	**Feedback** Brief presentations (5 mins/group) to the rest of the workshop	
1230-1330	**Lunch…** …and another opportunity to contribute your expertise	
1330-1430	**Breakout Session 2** 3 small groups to tackle the following tasks: 3: Can the existing datasets be prioritised? What are the gaps? 4: How should the indicators be presented and how can the uncertainty be communicated?	

1430-1445	**Feedback** Brief presentations (5 mins/group) to the rest of the workshop	
1445-1500	**Summing up**	John Farrar
1500-	**Tea/Coffee and departure** You are welcome to linger for further discussion over coffee	

Questions to be addressed:

- Should we have official biodiversity indicators? Are they a useful way of holding governments to account? Can targets and indicators ever be politician-proof?
- If we want to know if the condition of Welsh wildlife is improving, what, ideally, would we measure?
- How many indicators do we need? Can these be prioritised?
- How can data on multiple species best be aggregated or summarised, striking a balance between clarity and information loss?
- How should we deal with current taxonomic biases in data availability?
- How should climate change be reflected in the indicators? What about native and non-native invasive species? Are objective judgments possible?
- How should uncertainty be communicated to decision-makers and the public?

Appendix 2. Suggested structure for Welsh biodiversity indicators.

DPSIR Category	Indicators: Existing or previously proposed Welsh indicators (From SotE 2008, TBD=to be developed, BL=Baseline only);	Indicators proposed in this report relating to outcome 19 and other potential indicators
Drivers	2a Ecological Footprint 14a Per capita consumption of drinking water	
Pressures	13c River flows and water availability (TBD) 16a Soil carbon (BL) 20a Land NOT in AES (BL); 20b Forest NOT certified 22b,c Fisheries NOT certified / landings from uncertified fisheries 28b Fly-tipping 29b damaging impacts of access 33/37 Air quality 35/36 Water quality; 22d Marine pollution 19a BAP Habitats (condition)[28] 21. Condition of Natura 2000 habitats 22e: TBD	Marine Trophic Index Habitat Fragmentation Indicators of climate change in Wales, both abiotic, and perhaps Spring Index / MarClim data Land developed/built on Invasive Species
State: Genes/Species	19a BAP Species: to be replaced by subset of 19c(ii) 19b Wild Birds (to be subsumed into 19c(ii))	19c(i):Diversity (proposed in this report) 19c(ii):Abundance (proposed in this report) Genetic diversity indicators to be developed if techniques improve
State: higher levels	23 quality and diversity 29c tranquil areas	Area of communities etc, particular of given quality Diversity of habitats
Impact	27a (and b) % able to access green space (BS/TBD); 29a ROW access; 29d Outdoor recreation survey (TBD); 31a/b Damage due to flooding	
Response	Indicators 1-6a, 6c (environmental policies, public responses), 8 (adaptation to climate change plan): many are TBD or baseline	

[28] Currently 19a essentially combines species and habitats and area and condition of the latter.