Biodiversity targets and whole biodiversity assemblage monitoring for SSSI

Exploring the potential for ‘Regional Biodiversity Targets’ and ‘Whole biodiversity assemblage monitoring for Sites of Special Scientific Interest’ in England

July 2023

Natural England Commissioned Report NECR485

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Catalogue code: NECR485

Report details

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Keywords

Biodiversity, monitoring, protected sites, climate change, nature recovery network

Citation

Galbraith, C.A. & Stroud, D.A. 2023. 2023. Biodiversity targets and whole biodiversity assemblage monitoring for SSSI. NECR485. Natural England.

Foreword

This think piece was commissioned in order to support the Natural England SSSI Future Reforms project. The requirement was to further explore the development of ‘whole biodiversity assemblage monitoring’ and what this could entail, in the form of a mini think-piece. More thinking is required and advice on next steps, investigating the practicalities and challenges associated with developing and implementing ‘whole biodiversity assemblage monitoring’ as a method used to assess SSSI / protected area condition.

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Executive summary

As climate change continues to impact on biodiversity around the world, the distribution and abundance of species and habitats is changing. The need for innovative approaches to the conservation of species, especially through the designation and continuing management of protected areas, is increasingly urgent. In this changing situation it is necessary to effectively target resources available for the conservation and recovery of species, habitats, and wider ecosystems. It is important to anticipate likely changes in distribution resulting from climate change and to respond by both establishing effective conservation action within existing protected areas, as well as by creating new areas where species and habitats may occur in future.

This short report takes two of the key issues involved and considers them in more detail from a practical perspective:

- how to develop an approach to create regional biodiversity targets, and
- how to develop monitoring of the whole biodiversity assemblage on protected areas.

This report forms part of an initiative to develop and apply resilience indicators with respect to landscapes, and the SSSIs within these, building on work already carried out within the English Nature Recovery Network programme.

In undertaking this work, information has been sought from other countries to review how they are addressing these issues and to learn from any successful approaches adopted elsewhere.

In developing any new system of priority setting it is important that firstly, existing management practices judged to be effective are maintained, and secondly, that any new system is piloted to ensure its long-term effectiveness.

In particular, we set out the following recommendations:

- A review of the key interest features held in protected areas across pilot areas could be undertaken.
- Deciding on the scale of assessment will be key for delivery at the regional scale, hence addressing issues at the landscape scale, site level or smaller, will influence how the work is undertaken.
- Essentially analysing the predictive models for a range of priority species and habitats and then layering these distributions will, progressively, reveal key areas for future protected areas or at least for focussed management effort.

The predicted range shift of Dartford Warbler *Sylvia undata* and the distribution of its heathland habitat, is used as an example in this report to demonstrate an approach that could be used.

Contents

1. Introduction

As climate change continues to impact on biodiversity around the world, the distribution and abundance of species and habitats is changing. The need for innovative approaches to the conservation of species, especially through the designation and continuing management of protected areas, is increasingly urgent. In this changing situation it is necessary to effectively target resources available for the conservation and recovery of species, habitats, and wider ecosystems. It is important to anticipate likely changes in distribution resulting from climate change and to respond by both establishing effective conservation action within existing protected areas, as well as by creating new areas where species and habitats may occur in future.

Recent work for Natural England has considered how to enhance the resilience of protected areas with respect to climate change and has considered the range of issues involved in developing a programme of action for the effective future management of protected areas.

This short report takes two of the key issues involved and considers them in more detail from a practical perspective:

- how to develop an approach to create regional biodiversity targets, and
- how to develop monitoring of the whole biodiversity assemblage on protected areas.

This report forms part of an initiative to develop and apply resilience indicators with respect to landscapes, and the SSSIs within these, building on work already carried out within the English Nature Recovery Network programme.

This particular investigation has been prompted by a request from Defra for recommendations to support an adaptive designation framework in response to climate change, so as to inform possible changes to site protection practices in future.

In undertaking this work, information has been sought from other countries to review how they are addressing these issues and to learn from any successful approaches adopted elsewhere.

2. Regional biodiversity targets

2.1 Background

As species and habitats change in abundance and distribution in response to climate then ecological assemblages found within protected areas will also change, sometimes relatively quickly. Identifying the “typical” assemblages found in different parts of the country derived from previous historic distributions therefore becomes problematic. Whilst

what is ecologically ‘characteristic’ within the English countryside has changed slowly since the end of the last glaciation (Rackham 1986), recent changes caused initially by post-war land-use developments, and most recently from changing climate, are occurring very much more rapidly.

In developing a system of adaptive management that recognises and works with change, it is timely first to analyse likely alterations in distribution, and then identify “adaptive priorities” in terms of future protected area designation and management – simply put, the management of many protected areas across England will need to evolve from the *status quo* if critical elements of biodiversity are to be maintained (including the recovery of past losses) and if protected areas are to prepare for the potential of incoming species and change in habitat types.

2.2 Developing a new approach

In developing any new system of priority setting it is important that firstly, existing management practices judged to be effective are maintained, and secondly, that any new system is piloted to ensure its long-term effectiveness.

Piloting new systems is recognised as good practice adaptive management, allowing cost-effective learning through practical experience. There is scope (and time) to trial different approaches in different areas, selecting the most effective elements from these pilot exercises for a national programme.

2.2.1 Baseline and trends

A review of the key interest features held in protected areas across pilot areas could be undertaken. So, for example, existing data gathered as part of long-term monitoring on protected areas could be analysed to identify the extent of biodiversity currently present, and to reveal trends over time. Whilst care would be needed with such analysis, it could provide an insight into the nature and rate of change occurring over recent years. Noting, however, that the rate of change is increasing in many cases, such an analysis could still be revealing in terms of the direction of future biodiversity change. Similarly, examining the nature of change being observed in other more southerly European countries could also be educational in this regard – see section 2.6 below.

2.2.2 Scale

Deciding on the scale of assessment will be key for delivery at the regional scale, hence addressing issues at the landscape scale, site level or smaller, will influence how the work is undertaken.

At a landscape scale, protected areas in different parts of the country hold differing assemblages of species and habitats. So, for example, uplands hold important peatlands and upland heaths, whilst lowlands support distinct woodlands, fens, and grasslands, and

coasts a range of unique habitats. Whilst there is good predictive modelling for some species groups as to climate change implications[1], there is limited understanding of future habitat scale change. Predictive models need to be developed for each key species and habitat, considering especially existing species and habitat assemblages in adjacent countries in continental Europe, to help reveal what changes are likely over, say the next 10-, 20-, and 50-year, periods. Importantly planning needs to start now if such an adaptive system is to be developed.

2.2.3 Developing regional layers

Essentially analysing the predictive models for a range of priority species and habitats and then layering these distributions will, progressively, reveal key areas for future protected areas or at least for focussed management effort. This could also reveal those areas where losses in biodiversity may occur if no action is taken, hence providing guidance for future protected area management in both “gain” and “loss” situations with the likely continued move northwards of existing and new species and habitat assemblages.

2.3 An example of change

The following example, of Dartford Warbler *Sylvia undata* and the distribution of its heathland habitat, demonstrates an approach that could be used. Note that it is not suggested that every species needs to be considered in isolation, but that species and habitat assemblages currently found on protected areas could be considered as groups with similar ecological requirements, for example, upland birds, woodland invertebrates *etc.*

Dartford Warblers occur on heathland and heathland-related habitats and have high mortality in severe winters. Three national breeding bird atlases from 1968-72 to 2007-2011[2] have recorded a significant expansion of Dartford Warbler range in England involving:

i. the species moving northwards into habitats that are clearly suitable but have been climatically ‘unavailable’, in this case likely consequent on past severe winters; but
ii. to allow full exploitation of potential (modelled) distribution, the species will also likely need heathland habitat creation or restoration – to increase habitat

[1] See Johnston et al. 2013 for future climate change implications for birds within the UK SPA network, and Huntley et al. 1998 for all European breeding birds

[2] Sharrock 1976 and Balmer et al. 2013

availability in northern areas now climatically ‘available’ but where heathland is currently limited in extent.

In considering future management options for this species then if a policy of no action is followed the consequence is that the existing protected site network remains centred in the south of England with no sites further north. If, however, an adaptive site management approach is implemented then a series of sites north of the species’ present distribution would be identified and managed for heathland habitat. Considering both the Dartford Warbler and its heathland habitat together, will bring wider benefits for other heathland-dependent species.

This process could be repeated for other species (across taxa) and habitats, including potential incoming species and habitats, to produce a series of overlays that collectively will indicate where, and potentially how, conservation action could be prioritised at regional level.

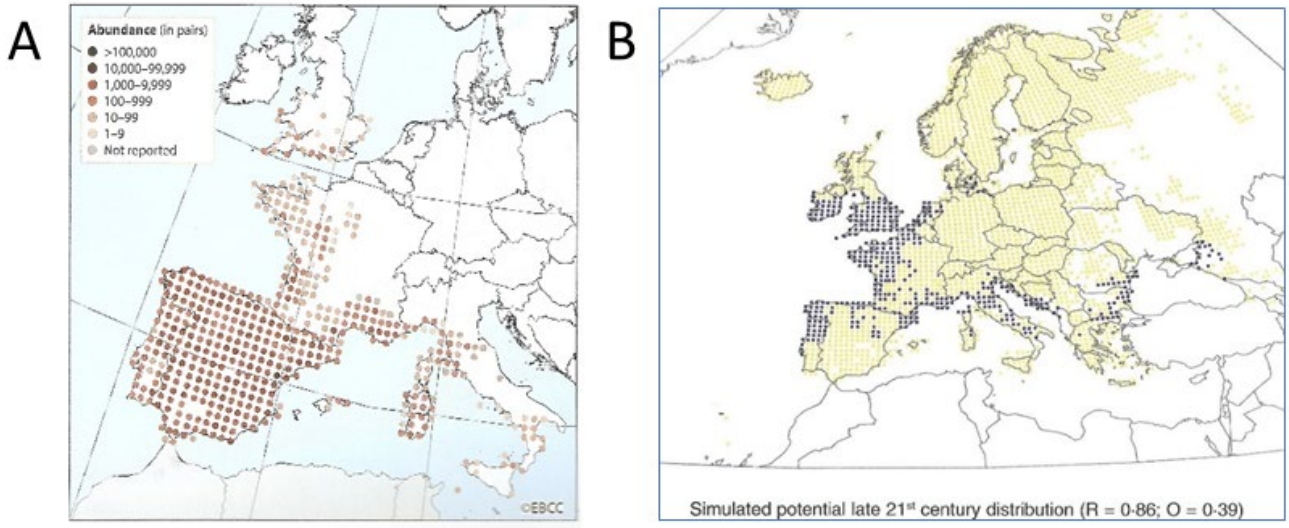

Figure 1. Current (A) and future (B) European distribution of Dartford Warbler. (A) European distribution of Dartford Warbler 2013 – 2017 (Keller et al. 2020). (B) Predicted distribution of Dartford Warbler showing generally northwards displacement of range with disappearance from present range in southern Iberia and other areas (Huntley et al. 1998). Maps reproduced under the Creative Commons Licence (A) and with permission from Lynx Edicions (B).

2.4 How to select species and habitats?

2.4.1 Identifying key species and expansion options

The selection of species and habitats to be assessed in this way is clearly a key decision for the focus of the work and will influence the overall cost-effectiveness of the approach. Whilst a range of approaches could be used, it is suggested that a useful starting list from

which focal species and habitats could be selected is the Section 41 (S41) list of the 2006 Natural Environment and Rural Communities (NERC) Act.

Outcome 3 of the Government's Biodiversity 2020 strategy contains an ambition to ensure that "By 2020, we will see an overall improvement in the status of our wildlife and will have prevented further human-induced extinctions of known threatened species." Protecting and enhancing England's S41 species and habitats is key to delivering this government aspiration.

The value of using these lists as a starting point is that they tie directly into an existing statutory process with associated lists of necessary actions already developed and agreed, and with the conservation status of various groups already clear.

The S41 list includes:

Group 1: globally threatened or near-threatened species (115 species).

Group 2: European threatened or near-threatened species (78 species).

Group 3: nationally threatened species in rapid decline or IUCN Critically Endangered (320 species) in the UK or GB.

Group 4: other nationally threatened species (430 species).

Fifty-six habitats of principal importance, all previously identified as requiring action in the UK Biodiversity Action Plan (BAP).

Given that these S41 lists are rather dated they may need revision as part of this process, especially to include colonising species, as it is clearly undesirable, given rapid ecological change, to have relatively static priority lists.

This approach has dual objectives. Firstly, to ensure the conservation of these species as a primary objective in their own right, but then also to use these species as higher-level indicators of the condition of their habitats. Thus, the presence of Dartford Warblers would highlight heathland availability, whilst breeding Common Snipe *Gallinago gallinago* are sensitive indicators of the presence of good wet grassland habitat for example. In this latter indicator context, monitoring Snipe distribution might be a good, cost-effective alternative (proxy) to undertaking wide-scale surveys of habitat. However, it will be important to assess whether any other habitats important for S41 species, yet not included within the S41 list of priority habitats, also need to be included.

2.4.2 Identifying key habitats on protected areas and develop expansion options

For regional targets, priority habitats on which to focus could include:

- habitats typical (currently representative) of the region, as noted above;
- habitats likely to expand their distribution/extent in a region because of climate change (e.g., southern heathland types in the English midlands). Typically, these

are likely to be examples of habitats at the current northern edge of distribution, in some cases with the potential to colonise from mainland Europe; and

- habitats that are currently at risk of change or severe climate change impact where there is need for enhanced management inputs to sustain their distribution (including northerly habitats at the southern edge of their distribution).

Overlaying the future distribution of habitats along with the species level analysis above will produce a series of ecosystem complexes (species and habitat assemblage "weather maps" of the countryside), thereby informing the targeting of effort in future.

2.5 Ecosystem-scale adaptative responses

There will be a need also to consider adaptation at scales greater than that of individual BAP/S41 habitats, as noted in Section 2.2.2 above, especially in the context of the widescale hydrological impacts of climate change. These water-related effects, both from too much water leading to flooding, too-little water resulting in drought-related stresses, and/or changes in the seasonality of precipitation and waterflows will affect multiple habitats (and their species) at river basin scales. Similarly, sea-level rise will impact multiple habitats within estuarine and other coastal systems and will need integrated responses.

Whole system, 'joined up' planning will be needed as management for some habitats will impact on others and trade-offs are likely to be needed. A framework for such trade-offs will be needed to ensure consistent approaches.

2.6 Current adaptive management activity in other countries

There is now widespread appreciation of the need for adaptation at the scale of protected area networks both theoretically (*e.g.,* Hannah 2008) and based on analyses derived from particular national situations. A small selection of published examples includes studies from the UK (Johnston et al. 2013); Canada (Lemieux & Scott 2005; Scott & Lemieux 2005); Columbia (van Kerkhoff et al. 2019); Egypt (Leach et al. 2013); México, South Africa, and USA (Mawdsley 2011); and Australia (Graham et al. 2019).

Whilst Geyer et al. (2015) assessed the degree of implementation of adaptation with Brandenburg's (Germany) protected area network, all other studies essentially report on future needs rather than about concrete examples of actual changed policies. There is therefore currently an opportunity for Natural England to play a leading role in wider international thinking about protected areas and adaptation to climate change.

We have contacted several protected area experts within European countries seeking information on any existing national programmes of practical adaptation actions at network

scale. No such practical policies currently seem to exist in Italy, Ireland, Finland, Lithuania or elsewhere within the Central and Eastern European region.

Innovative approaches are being developed by the Finnish SUMI project (Aapala et al. 2020 - see p. 6 for English summary) and in France. The latter is implementing a LIFE-funded project to develop a range of methods and tools for managers, and to establish a community of experts and practitioners that share knowledge and experience in the implementation of actions related to climate change adaptation in protected areas. The project runs from 2018 to 2023 with ten partners. The approach seeks to develop adaptation through promotion of relevant management measures 'bottom up' through site-related actions, rather than a directed 'top down' approach.

Typically, there is a high degree of commonality as to those elements promoted as supporting protected area adaptation either at site or network scale. Many of these are reflected within Natural England & the Royal Society for the Protection of Birds (RSPB) (2019) guidance.

2.7 Ecological anticipation – what does this mean in practice?

Given the unprecedented rate and nature of current change, it is important to make space for natural processes to operate (thus more, bigger, and better-connected sites as recommended to government by Lawton et al. in 2010) and to act in anticipation of changes in the range of species and in the extent of habitats. This is essentially the primary basis of climate change adaptation – as expressed in the 'Hopkins principles' (Smithers et al. 2008) and elsewhere (Natural England and RSPB 2019): 'space for nature to do its own thing'. Acting across England on a regional basis to anticipate change is key to the overall survival and recovery of biodiversity across the country.

There are, of course, risks and benefits from the development of a target-driven approach to adaptation. Benefits include that the conservation community already has a good idea as to those management practices and wider policies that will benefit protected area conservation. These are set out in the Natural England & RSPB (2019) guidance, by Duffield et al. (2021) for English National Nature Reserves (NNRs), as well as in multiple published studies from other countries (e.g. section 2.6, page 13). So, a target (at site, region, or country scale) could reasonably express how far from being 'well adapted' or 'resilient' is the current *status quo* of the entity (being either an individual or collection of sites). Such a target could be useful to track the actual implementation of policy.

A risk, however, is that such a target-driven approach could assume too great a prescriptive role. Multiple adaptation studies and previous work stress the importance of 'expecting the unexpected' in an ecological sense. Whilst general principles of adaptation are clear, these should not assume we can pre-plan in all ecological circumstances. There is a need for space for nature to respond to a changed climate in its own way.

Whilst climate change is one driver of change across the English landscape, England's species and habitats have yet to recover from the devastating impacts of over 70 years of unsympathetic land use. Further, the national protected area estate is recognised as being in overall poor condition (Hayhow et al. 2016; Starnes et al. 2021). A necessary first step to achieving a climate change resilient network of protected areas is thus to ensure that existing sites have good status for existing qualifying interests, whilst accepting that some climate induced change will be inevitable. It is recognised, of course, that as the distribution and abundance of species and habitats change due to climate change maintaining this status will be difficult, however, maximising the resilience of the exiting species and habitats present is crucial, as is maximising time for progressive change rather than allowing precipitous change, as this should help to minimise the disruptive effect overall. Making the landscape as resilient as possible by regionally targeted action could be a key part of delivering the wider 30 by 30 commitments for protected areas and has the potential to at least slow the worst effects of climate change, giving nature more time to adapt.

Thus, ecologically based regional targets, anticipating change could be derived from two elements:

1. Information derived from existing Common Standards Monitoring data – this provides information on how well managed the site (or group of sites) is **now**; and
2. Information summarising the degree of implementation of activities that will support **future** interests (i.e., how 'resilient' is the site likely to be to current and future climate impacts.

So, in summary, what "state" is the protected area in now, and what is being done to alleviate any pressures and so facilitate adaptation and resilience.

Figure 2 conceptually shows how a target could be established from the dual 'status quo' and adaptation elements. Further information on possible elements of the process/adaptation component of any such target are given in Appendix 1.

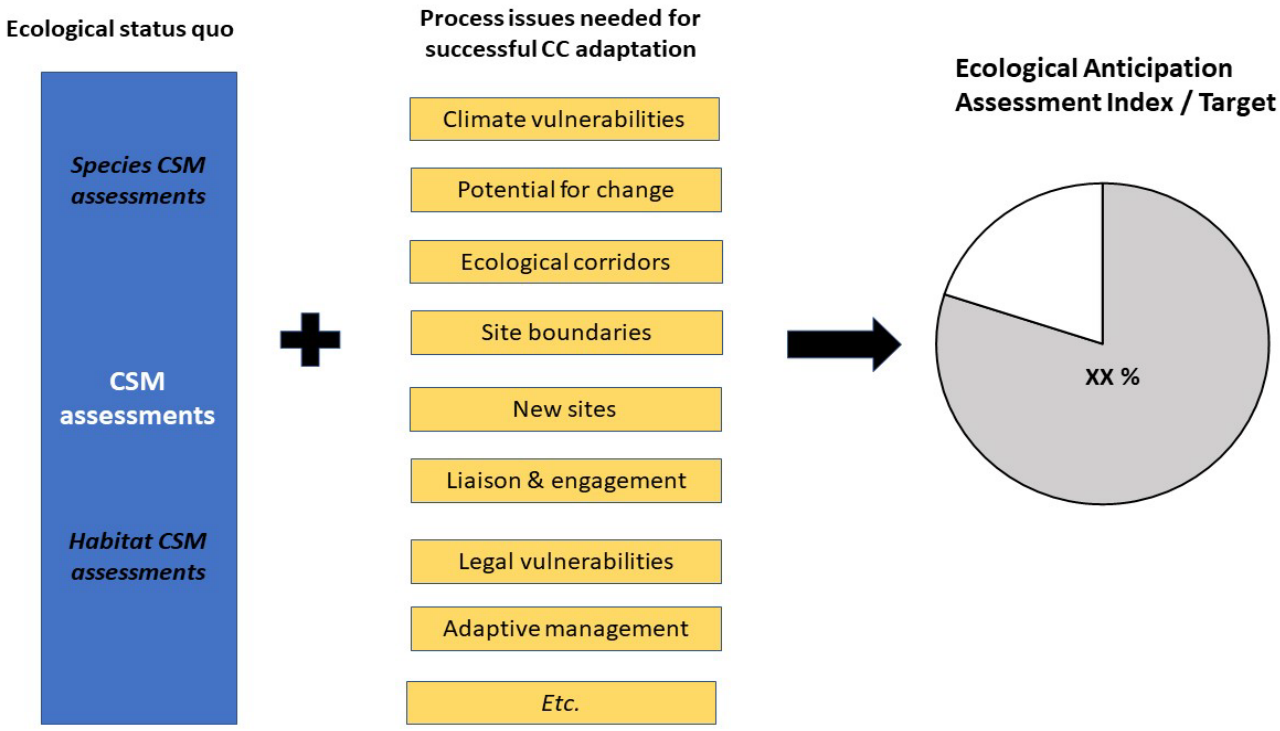

Figure 2. Conceptual outline of an Ecological Anticipation Assessment' target (or index). See also Appendix 1.

The benefit of this approach is that the ultimate target (which could be expressed as an index value) derives from the joint need ***both*** to deliver the favourable status of existing interests - blue shading, (recognised as a priority by government), ***and*** to ensure that sites are fit for future purpose/are climate resilient with the implementation of processes that will support new species/habitats shown in yellow. A high 'score' will depend on delivery of both these enterprises and will, in effect, be a measure of likely future resilience at either protected area or network level. Importantly, the elements in the above diagram link first to a target in Appendix 1 and then to the actions needed in each case (as recognised in Natural England and RSPB 2019). This approach could be developed further to form a decision support framework at the practical level for site management in future.

Such a target could be implemented at either site, regional or country scales. If adopted, future consideration in a development phase would need to be given to the weightings attached to each of the proposed metrics – some are clearly of more importance than others.

2.8 How to develop a country-wide approach at suitable scale

This short report has outlined how regional biodiversity targets could be developed using existing data and information, based on previous conservation assessments (Figure 2). In addition, we suggest that:

- The approach is taken forward in a series of regional piloting exercises[3] to fully evaluate the issues involved.
- That this approach needs a wider UK and international perspective on what are the target species and habitats, where there are climate change impacts or likely distributional shifts.
- There needs to be greater clarity on what are the biogeographic priorities within the islands of Great Britain.
- Not everything will be similarly impacted - hence work is required to evaluate likely change.
- It is imperative that any new system takes account of the work over many decades to develop the current system of nature conservation practices (protected areas plus wider countryside policies). What is needed now is evolution, not revolution.
- The development of any regional (or other scale) targets needs to involve the non-government and land management sectors as well as the wider conservation community to ensure the greatest degree of common ownership.

3. Monitoring the whole biodiversity assemblage

3.1 Background

This section provides further thinking on the practicalities involved in how SSSIs and other protected areas could be 'condition assessed' by monitoring the whole biodiversity assemblage. This builds on taking a "risk based" approach (Galbraith & Stroud 2021) where those protected areas deemed to be most at risk (and/or facing rapid ecological changes needing information to inform adaptive management) will be monitored more intensely, while other relatively stable areas will have a less frequent or less intense monitoring regime. Previous Natural England work (Crick et al. 2020) has outlined the desirability of developing a large-scale linked network of protected areas across England with effective monitoring to detect change as a key part of this development. The current system of monitoring focusses on the legally protected "features" of protected areas, however, as climate change continues to impact, the species and habitats found on SSSIs will change. Developing a wider system of monitoring, considering what to monitor, how

[3] The approach might readily be developed using NNRs as a test-bed sites following the interest in this issue from site managers

frequently to monitor, and how to assess the wider network as well as individual sites, will be key.

The overall challenge is to develop a system of measurement that is both scientifically meaningful and that is cost-effective to deploy in the field.

3.2 The purpose of monitoring

In developing a new approach, it is important at the outset to agree what the monitoring is for? Options (not necessarily mutually exclusive) include:

1. directing management on the site;
2. wider scale performance assessments (condition of features as national targets); and/or
3. to consider in the context of climate change impacts, the adequacy of the network, with respect to changing national (regional) status of species or habitats.

Agreeing the **purpose** and clear **formal objectives** for monitoring will then determine the scale and frequency of the monitoring activity to be put in place on the ground.

3.3 Choosing what to measure in the biodiversity assemblage?

Whilst 'whole of biodiversity' monitoring is a useful concept; in practice it is likely to be extremely difficult and expensive to achieve. It seems therefore that hard choices will need to be made about how to build a coherent monitoring programme for protected areas. Choices (again not necessarily mutually exclusive) seem to be:

1. Continue as now to monitor listed features only.
2. Develop a series of "indicators" – species and habitats and monitor just these using a "risk-based" approach as outlined in section 3.5 below.
3. Measure selected ecosystem processes[4].
4. Measure the whole biodiversity present on protected areas – probably using a sampling and risk-based approach using a judgement of "resilience to change" to guide the nature and frequency of monitoring.

[4] See section 2.5. Examples might include measures of water quality and quantity within river basins, or metrics related to managed retreat on soft coastlines

3.4 Key factors in monitoring the whole of biodiversity on protected areas

Whilst there are several options in terms of how to develop a whole of biodiversity monitoring system, in practice, we consider the following to be a useful approach:

1. Consider the geographical size of the protected area to be monitored.
2. Consider the relative stability and resilience (to climate change impacts) of the species populations or habitats concerned (based on ecological literature and professional judgement).
3. Consider the accuracy of results that would be acceptable, i.e., the extent of change desired to be detected (sensitivity).
4. Decide on a sampling frequency based on points 1-3. The frequency of survey will probably differ across species and habitats on particular protected areas, hence the need for a pilot project to evaluate such practicalities in the field.
5. Decide on the field survey techniques to be used, and inevitably decide on what range of species and habitats to focus effort on. This may seem somewhat contradictory but in practice a selection of the key species and habitats/geology present would need to be made.
6. Consider if all protected areas in the network holding similar habitat (or species) are to be monitored on the same frequency[5]?
7. If some sites only are to be monitored in detail (or with greater precision), then consider how any wider extrapolation might be undertaken?
8. Consider if any wider survey (protected areas plus surrounding land/sea scape) is to be undertaken to provide context?

3.5 A risk-based approach?

Monitoring in future could be structured using a clear “risk based” approach, where broad scale survey detects any gross change in extent or quality for habitats, or abundance for species, and this is then supported by detailed survey to investigate significant change. Such broad scale survey could be undertaken either via remote sensing[6] and/or by using a focussed citizen science network. Note, this will probably not be possible for many offshore marine ecosystems given the scale and nature of these protected areas. Similarly, the difficultly of identifying many less familiar taxa means that citizen science

[5] Sites in the centre of a distribution might perhaps need to be monitored less frequently that those as the edges of a range.

[6] But note this is only viable for some interests/habitats

approaches will not be viable in many cases, and that professional survey will be essential for robust assessments.

In practice, if a portfolio of protected areas holding similar features and facing similar threats is being monitored, then a risk-based approach could lead to a sampling regime being developed that monitors a subset of areas in detail and does not monitor others unless significant change is detected in the focal areas. The focal areas would therefore act as proxy for the whole portfolio. Historically such approaches have, however, been criticised for being locally specific with limited value in extrapolation but in a resource constrained, rapidly changing environment then perhaps it is timely to test such a system with the initial stage being a full trial of the technique to evaluate the pros and cons of such an approach in practice. Such a trial could be undertaken with the first stage being a post hoc assessment of past monitoring data to reveal the scale and nature of change, and to see if any changes detected were replicated across protected areas holding similar habitats and species assemblages. If this approach was to be considered, then we would recommend the results be formally published in the scientific literature in due course.

For example, for protected areas that have a history of relative stability then:

- **Establish baseline(s).** At the simplest level, assess the **extent** of the habitats and other features possibly via satellite imagery/citizen science *etc.* (but note caveats above). Note also that it could be argued that existing results from Site Condition Monitoring already provide an effective baseline – hence negating the cost of new survey.
- If significant change (positive or negative) from the baseline is detected (possibly by use of indicators in the first instance), then undertake a **rapid on the ground assessment** of the features concerned.
- If significant change is detected via the rapid assessment or suspected (scientific judgement should be recognised as a key part of this decision-making approach), then follow-up detailed survey may be required.

The choices about what approach to use need to be worked though in detail to examine the practicality of each. Much is likely to be driven by the resources available for monitoring in the years to come, hence resource limitation is likely to take the conservation community towards a sampling based (risk-based) approach for protected areas. Establishing a field-based trial now would therefore be timely that explores the issues of sampling frequency and techniques alongside the need for robust data and information.

4. Conclusions

Finally, we note the value of existing datasets gathered by a range of owners and managers as well as by Natural England staff as part of monitoring protected areas across England. These datasets may be incomplete but could still be an important element of modelling future climate change adaptation, within protected areas (see section 2.7 above), and help understand the changes that are likely due to climate change, adapting

management accordingly. This *status quo* information can be combined with information on management processes (Figure 2) to provide an assessment of adaptation readiness. We note also that reducing the detail and frequency of monitoring through a risk-based approach (above) could limit adaptation readiness. Having less detailed information on the status of species and habitats on protected area could limit understanding and mean that future management decisions would have to be based on a less robust dataset overall.

There is potentially a trade-off between moving to risk-based approaches and the need to collect information to inform responsive management actions at various scales, local, national and international. It is important that this trade-off is explored further as part of regionally based pilot exercises, as these would help to reveal the practical aspects, and costs of different approaches.

Both the development of regional targets for biodiversity and the development of new approaches to monitoring need to be set in a wider UK context, so that larger scale issues of ecological change can be taken account in planning future work. Similarly, linking this work with existing conservation priority action and with species and habitat listing in legislation would help to streamline the overall approach.

In terms of developing regional targets then as noted above, overlaying the future distribution of habitats along with the species level analysis also outlined above will produce a series of ecosystem complexes (species and habitat assemblage “weather maps” of the countryside), that could inform the development of a decision framework, to help prioritise future effort.

In conclusion, climate change is already causing change to occur to protected areas across England and this rate of change will increase. Whilst accepting that change will occur, the underpinning principle that we have adhered to in this report is to suggest practical steps that will reduce the impact of climate change, allow time for nature to adapt and to plan for the inevitable changes in distribution and abundance that will occur.

Importantly, developing a forward- looking, regionally targeted approach, including an ecologically linked network of resilient protected areas, using robust data and information from monitoring will be key to making effective site management decisions in future, and to the delivery of the wider 30 by 30 target.

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Appendix 1. Elements for a possible adaptation index/target drawn from collective international experience

Element[7]	Metric	Comment
Climate vulnerabilities[8]	• Percentage of all sites [nationally/regionally] where on-site climate vulnerabilities assessed following Climate Change Adaptation Manual guidance • Percentage of all sites [nationally/regionally] where off-site climate vulnerabilities to ecosystem functioning assessed	e.g., hydrological inputs to protected wetlands
Potential for change	• [Nationally/regionally] assessment undertaken of projected patterns of ecological and species distributional change as relevant to the protected area estate • Has consideration at [national/regional] scale been made as to which management options are necessary to sustain 'new' ecological or species features has been undertaken?	What can we expect?
Ecological corridors	• Percentage of all sites [nationally/regionally] where potential for ecological corridors assessed • Percentage of sites [nationally/regionally] where corridors assessed as appropriate created/developed	Lawton: better connected
Boundaries	• Percentage of all sites [nationally/regionally] assessed for relevant boundary modifications (including creation of buffer zones)	Lawton: larger

[7] Sources: Duffield et al. 2021; van Kerkhoff et al. 2019; Lemieux & Scott 2005; Natural England and RSPB 2019; Scott & Lemieux 2005.

[8] Vulnerability is a combination of the degree of impact, as above, and the potential for successful adaptation: effective adaptation will reduce vulnerability. Overall risk from climate change would include measures both of the degree of impact, and of vulnerability.

Element[7]	Metric	Comment
	• Percentage of sites [nationally/regionally] where boundary modification needs deemed appropriate have modified boundaries	
New sites	• [National/regional] assessment of potential for additional protected areas[9] to create more coherent and resilient protected area network	Lawton: more
Liaison	• Percentage of all sites [nationally/regionally] active liaison and engagement with surrounding landowners regarding relevant adaptation potential	N/A
Legal vulnerabilities	• Percentage of sites [nationally/regionally] where adaptation to climate change is included within their formal management objectives	N/A
Adaptive management	• Percentage of sites [nationally/regionally] where monitoring and assessment is operational at target frequency • Percentage of sites [nationally/regionally] where non-climatic in-situ threats successfully addressed	Includes potential for risk-based monitoring assessed at site scale

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[9] Especially in proximity to existing sites

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