Developing a "complex, multi-species" Ecosystem Health Indicator using bryophyte and lichen data

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Background and rationale for indicator

The purpose of the Ecosystem Health Indicators (EHIs) is to measure the state of Scotland's ecosystems with regards to their condition, function and resilience (sustainability). These indicators must operate at national and regional levels, as it is intended that they will be used to help to identify priority regions or catchments for restoration, and assess progress in maintaining or enhancing ecosystem health.

Biodiversity data, for example occurrence or abundance data for certain species groups, has been a long-term mainstay of reporting on policies such as the Scottish Biodiversity Strategy and the CBD, or for more general monitoring of the state of the environment. A good example of this is the recent State of Nature report which bases its conclusions about the state of the UK (and Scotland's) biodiversity on trends in the abundance of key species groups such as birds, vascular plants and butterflies. Concentration on these species groups is not surprising as in many cases these are the groups for which the best quality data are available, not least because of systematic monitoring regimes such as the Breeding Birds Survey.

However, for the future development of the EHIs there is a desire to move beyond this focus on the commonly-used species groups. These data are already well-reported, and so using them again in the EHIs would simply duplicate monitoring and reporting that is already done elsewhere. In addition, although important, these common groupings overlook some elements of biodiversity which are particularly important in Scotland, in particular bryophytes and lichens. Can we use these data as the basis for developing a new Ecosystem Health Indicator?

Ecosystem Health Indicators are intended to tell us about more than simply the number or diversity of organisms present in the environment; they are intended to "inform our understanding at an ecosystem level rather than focussing on individual species, species groups or particular habitats". If we are to use bryophyte and lichen data as the basis for a new EHI, it must be able to tell us more than simply information on the abundance and diversity of lichens and bryophytes across Scotland.

In this note we consider how lichen and bryophyte data are currently being used for environmental monitoring, and possible options for using them as the basis for a new EHI.

Current state of play for indicators based on lichen and/or bryophyte data

Current use of lichens for environmental monitoring

The use of lichens as the basis of environmental monitoring is widespread, and the range of uses is very large. As noted by Nimis et al.[1] "The literature on lichens as biomonitors is huge." The benefits of using lichens as biomonitors include their longevity (and hence ability to integrate environmental conditions over a long period), their lack of seasonality (enabling assessments of lichen communities throughout the year), potential high diversity, and - because of their relative physiological simplicity and limited capacity for internal buffering - high sensitivity to environmental drivers such as climate and pollutants.

The best known use of lichens as indicators is for monitoring air pollution (for example see Jovan 2008[2] and Cioffi 2009[3]) because of the high sensitivity of some lichen species to pollutants such as NO_x and SO_x. Other studies take lichens as being an indicator of the overall diversity of an ecosystem, and comparisons of lichen and overall biodiversity have in some cases supported this assumption (e.g. Rogers et al. 2016[4]).

Despite the potential uses of lichens as indicators, to the best of our knowledge lichens are not currently being used as the basis for wide-spread environmental monitoring in Scotland. Monitoring is instead focussed for example on sensitive and internationally important habitats, such as Atlantic oakwoods[5]. Some schemes for using lichens as pollution indicators exist in the UK. For example APIS (the Air Pollution Information System) developed a web app to help people use lichens to assess atmospheric nitrogen pollution. However, such monitoring is highly dependent on the effort put in by volunteer recorders and can be spatially biased, either towards areas of high population density or – in the case of air quality monitoring – to areas where air pollution is perceived to be a problem.

Overall, given the current state-of-play with respect to the use of lichens for environmental monitoring within the UK and/or Scotland, we suggest the development of national-level EHIs based on lichen data would not be limited by the occurrence of existing schemes that already fulfil the same role.

Current use of bryophytes for environmental monitoring

Similarly, bryophytes have been used as indicators of atmospheric pollution. The reliance of many species on rainfall for their water and nutrients means that they are directly impacted by pollutants; in contrast vascular plant responses are mediated to some extent by soil processes. Monitoring has been focussed on metal pollution[6] as bryophytes accumulate a range of heavy metals, and on

[1] Nimis, P.L., Scheidegger, C. & Wolseley, P.A. eds. (2002) *Monitoring with lichens - monitoring lichens*. NATO Science Series. IV. Earth and Environmental Sciences, 7. The Netherlands: Dordrecht, Kluwer Academic Publishers. 408 p.

[2] Jovan, S. (2008) *Lichen bioindication of biodiversity, air quality, and climate: baseline results from monitoring in Washington, Oregon and California.* Gen. Tech. Rep. PNW-GTR-737. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 115 p.

[3] Cioffi, M. (2009) Air Quality Monitoring with the Lichen Biodiversity Index (LBI) in the district of Faenza, (Italy). *EQA - International Journal of Environmental Quality* **1**, 1-6

[4] Rogers et al. (2016) Lichen monitoring delineates biodiversity on a Great Barrier Reef coral cay. *Forests* **6**, 1557-1575.

[5] Ellis, C. J. & Hope, J. (2012). *Lichen epiphyte dynamics in Scottish Atlantic oakwoods – The effect of tree age and historical continuity.* Scottish Natural Heritage Commissioned Report No. 426.

[6] Onianwa, P.C. (2001) Monitoring atmospheric metal pollution: a review of the use of mosses as indicators. *Environmental Monitoring and Assessment* **71**, 13-50.

atmospheric pollutants such as compounds of nitrogen[7]. Their use as indicators of climate change has also been put forward.[8]

As for lichens, there is no routine monitoring of bryophytes to assess environmental change in Scotland. They are used in the planning process for assessment of, for example, hydroelectric schemes by SNH and are part of the focus of the snowbed monitoring to assess climate change impacts. As for lichens, there is no existing scheme in Scotland or the UK using bryophytes for environmental monitoring that could be adapted as an EHI.

Options for developing a new EHI based on bryophyte and lichen data

What relevant data do we have in the UK/Scotland?

A key criterion of the EHIs is their ability to act as an index at a national level. The most obvious source of National-level data for the lichens and bryophytes are the occurrence records curated by the British Lichen Society and the British Bryological Society. These data are also available through the National Biodiversity Network website but - as noted by the BLS website - the NBN data may not be the most up-to-date. For the bryophytes, occurrence data have already been used as the basis for producing atlases of bryophytes in Britain and Ireland. There are two atlases, an earlier (1991-1994) three-volume atlas, and a more recent (2014) two-volume atlas. The atlas data has the benefit of already being compiled into two time periods, which allows detection of trends between the recording periods. However, different approaches may allow for the data to be used as a time series.

Although providing information on species occurrence, without any further analysis such data would not meet a key criterion of an EHI, i.e. "to inform our understanding at an ecosystem level rather than focussing on individual species, species groups or particular habitats." We need other data to help us link occurrence records to some metric of ecosystem health. An obvious source for such data exists in the form of species attribute data in the BRYOATT[9] database. This allows the ecology of bryophytes to be assessed through a set of attributes, for example Ellenberg Indicator Values. A similar set of Ellenberg Indicator Values exists for lichens, but it would need assessing for its coverage of Scottish lichens as it is focussed on central Europe[10].

Can we use these data to develop a new EHI?

We suggest that by combining occurrence data from the bryophyte atlases with the attribute data from BRYOATT, and potentially similar data for the lichens, it might be possible to produce assessments of the health of ecosystems, and how these values are changing through time. Part of the process would necessitate deciding what bryophyte and lichen attributes actually tell us about ecosystem health (are high or low scores 'good' or 'bad' in terms of ecosystem health?), but the benefit of such an approach is that it would help to overcome problems of recorder effort: average trait values could be calculated for all bryophytes/lichens recorded within a given area (10 km x 10 km square) and time interval.

The following table considers how this proposal compares to an "ideal" EHI indicator:

[7] Harmens, H. et al. (2011) Nitrogen concentrations in mosses indicate the spatial distribution of atmospheric nitrogen deposition in Europe. *Environmental Pollution* **159**, 2852-2860.
[8] Gignac, L.D. (2001) Bryophytes as indicators of climate change. *The Bryologist* **104**, 410-420.
[9] Hill, M.O. et al. (2007) *BRYOATT: attributes of British and Irish mosses, liverworts and hornworts.* Cambridge, Centre for Ecology and Hydrology
[10] Wirth, V. (2010) Ecological indicator values of lichens – enlarged and updated species list. *Herzogia* **23**, 229-248.

An ideal indicator will…	Assessment of proposal
Inform our understanding at an ecosystem level rather than focussing on individual species, species groups or particular habitats.	Yes, if attribute data are interpretable in terms of ecosystem health.
Be sensitive to or capable of revealing change.	Yes, either by using the two time intervals that currently are the basis for the bryophyte atlases, or by developing some kind of 'moving window' approach to enable production of a continuous metric.
Be either easy or cost effective to gather, or integrate with existing monitoring programmes to improve cost effectiveness.	Yes, given that the proposal uses existing data; investment would be needed in the interpretation of data with respect to ecosystem health and in the analyses.
Communicate a clear message.	Yes, if a clear link can be made between attributes and ecosystem health.
Be scalable.	Atlas data are compiled at a 10 km x 10 km grid square resolution so downscaling would be possible.
Embrace all of Scotland.	Yes, given that atlas data are collected from across Scotland. As with all data of this sort issues exist with varying recorder effort, but this can be overcome by focussing on attribute rather than normal diversity metrics.

Other options exist for extending this analysis further including:

1. Using a rolling time window (rather than a two time-step) approach for exploring changes through time.

2. Classifying bryophyte (and possibly lichen) species according to some form of rarity criterion – analyses could then assess the extent to which areas hold high numbers of rare species, and how the distributions of rare species are changing through time. Routes for selecting rare species might include the recent development of SSSI selection guidelines which is itself linked to IUCN red listing process (D. Genney, pers. comm.).

3. Check coverage of the attribute data for lichens which would enable lichen occurrence data to be interpreted as an indicator of ecosystem health. This could also cover species-specific responses to atmospheric pollution.

Although above we propose sets of data that could be brought together to create an EHI now, there may also be opportunities to develop or amend monitoring activities to provide additional relevant information for the future. These include a push to roll out across Scotland standardised monitoring regimes such as that available on the APIS website for lichen response to pollution.

Next steps

- Further discussion of EHI development options with experts incl. D Genney (SNH) and C Ellis (RBGE).

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