



**JNCC Report 730**

**A landscape monitoring and change detection tool for protected areas –  
towards operationalising the use of Sentinel data in Scotland**

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## Summary

Monitoring the condition of habitats and protected sites is crucial for the assessment of climate change impacts and to inform environmental policy design and delivery. Site visits and ground surveys provide detailed, invaluable information but for gaining evidence over broader scales and to account for accelerating rates of change, other tools are needed. Satellite remote sensing, for example in form of data from the EU Copernicus programme, has been successfully used to monitor habitats and detect landscape changes. The possibility to access optical and radar data with large spatial coverage on a weekly basis presents opportunities for operationalising site monitoring and for targeting ground resources, resulting in more effective ways of assessing habitat condition. The expert knowledge and computational resources required to derive meaningful information from satellite data has to-date restricted its use for wider countryside monitoring. However, an increasing number of tools are being developed to make this information accessible to non-expert users.

This project builds on earlier work of NatureScot, JNCC and other partners who developed a web-delivered tool for detecting landscape changes. This uses satellite derived indices for monitoring changes to vegetation productivity, structure, and water content as well as surface water. With the aim of developing the existing prototype into an operational tool, further indices for the enhanced monitoring of vegetation productivity as well as burn scars were added to the tool and a five-year time series of optical and radar data was processed for nine test sites. The work focused on National Nature Reserves (NNRs) where site specialists and ground validation data were available to evaluate the functionality of the tool and assess its applicability for different monitoring needs. Two spatial frameworks, one derived from traditional survey methods, and a second derived from Earth Observation (EO) data classified using artificial intelligence (AI), were included for users to choose and assess strengths and weaknesses of each approach.

The tool was tested by a variety of NNR staff and habitat experts from four organisations who assessed the performance and effectiveness of the app for their own areas of work. This user involvement aimed to:

1. Gather feedback on the accuracy and effectiveness of the individual frameworks, indices, and statistics for analysing time series information and detecting change.
2. Collect detailed user feedback to assess the usability of the app and understand the requirements for a wider roll-out.
3. Generate an understanding of the possibilities and limitations of EO data among future users of the tool.

Overall, the user engagement included an introductory seminar, testing of the app in small groups, and an online questionnaire to collect feedback on further user needs such as additional data that should be available in the app or further regions of interest to which the tool should be scaled. Of the 27 users engaged through testing sessions, 10 people provided more detailed feedback on its functionality. This included a preference for the survey-derived spatial framework which was more intuitive to understand than the EO derived map. When asked about the intended use of the app, most users stated they would apply it to monitor long term changes in habitat and to assess changes in response to management action. All this will enable NatureScot to plan the wider roll-out of the tool which includes the selection of priority sites and case studies for further upscaling to a regional level and ultimately the development of the app for future operational use on a national level. This could contribute significantly to NatureScot's needs for monitoring large areas and report on the condition of priority habitats in protected areas and in the wider countryside,

assess the response to management interventions or provide evidence for planning future management priorities such as 30 x 30.

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# 1 Introduction

Assessing the extent and condition of habitats and monitoring landscape changes in response to human activity is essential for effective development, delivery, and evaluation of environmental policy. Changes due to land use and management practices or climatic events can have impacts on biodiversity and ecosystem services and must be understood to make informed decisions on land management and habitat restoration. Gathering evidence via traditional site condition monitoring is resource intensive and limited by the ability to visit sites frequently enough but monitoring habitat changes remotely using Earth Observation (EO) data could aid management and target field resources more effectively.

Remote sensing satellites are able to cover large areas and can provide data as frequently as once a week. This data can then be used to detect large impact changes such as flooding or wildfires, while time-series information can also be used to gain insights into more subtle, longer-term trends relating to habitat conversions and ecosystem services.

Satellite data in the form of radar (Sentinel-1) and multispectral imagery (Sentinel-2) is made available free-of-charge by the European Union's Copernicus programme, which provides high-quality, high-resolution imagery on a weekly basis. The raw data is routinely processed to 'analysis-ready' format by the Defra Earth Observation Data Service and JNCC's Simple ARD Service and already used operationally to create regional or national scale habitat maps (Kilcoyne *et al.* 2017, 2020) or to detect landscape features such as bare peat or moorland burns (Blake *et al.* 2021; Trippier *et al.* 2020).

Previous JNCC work under the Copernicus User Uptake scheme (CUU) also included the development of a landscape monitoring tool in the form of a prototype app which delivers EO-derived statistics for individual habitat parcels directly to non-specialist end users (Lightfoot *et al.* 2021). The project used a five-year time series of Sentinel-1 (S1) and Sentinel-2 (S2) data to generate vegetation indices such as the Normalised Difference Vegetation Index (NDVI) and highlight land parcels for which an index differed by more than 10% from one month to the next. This enabled the users to investigate site-level change on a monthly basis, as well as to detect deviation from annual trends.

The methodology behind the prototype app is described in detail in Lightfoot *et al.* (2021), which also highlights the benefits of bringing together EO specialists, data analysts, ecologists, and land managers to interpret the EO-derived variations in a collaborative approach. Whilst the pilot study demonstrated the potential of making satellite-derived information easily accessible to non-experts, it had several technical and methodological limitations and only included four sites in Scotland.

## 2 Aims and Objectives

To gain further insight into user needs and to develop the tool toward operational use, NatureScot and JNCC have built on the proof-of-concept work. This project therefore focused on Scottish NNRs where there is a staff resource and a wealth of other data available to improve on three key areas that are needed before upscaling the tool to regional or national level:

- Trial the use of two habitat maps, one derived from detailed site-based survey data and one derived from EO data, classified using machine learning (ML). This will allow users to choose the spatial framework that is most useful and understand strengths and limitations of each.
- Gain further insights into the performance of the individual vegetation indices and statistics to understand which type of change they detect most accurately. In addition

to the five indices that were included in the pilot study, another two indices for improved monitoring of vegetation productivity and burn scars have been added to the app.

- Evaluate the usability and effectiveness of the tool for monitoring of NNRs and the wider countryside. Feedback from field experts on what functionality needs to be developed to support their activities will be an important aspect of further development and helps to understand what areas of work can benefit from the tool. Therefore, several engagement events with staff from NatureScot, RSPB and the National Trust for Scotland were organised to collect user feedback.

Overall, this project aimed to test the tool across a variety of protected areas and with habitat and site experts to develop and operationalise the method in Scotland. In future, NatureScot are particularly interested in using the tool for detecting change in inaccessible upland areas and to evaluate management practises as well as for planning future management. Further development could include the addition of ancillary data sources, for example, from historic archives to create a long enough time-series of data to gather evidence of long-term change caused by the climate emergency or monitor the impacts of climate change and drought. This report outlines the methodology of the project, including the site selection, data generation and changes to the technical infrastructure of the pilot app, and presents the design of the user engagement sessions and their findings.

### 3 Methodology

To extend the coverage of the CUU app, this project included nine National Nature Reserve (NNR) sites over Scotland. Statistics were generated using two habitat focussed land classification spatial frameworks:

- [The Habitat Map of Scotland \(HabMoS\)](#). HabMoS constitutes the clearest example of a central repository for habitat data in Scotland. Having adopted internationally recognised data and habitat classification standards, the map is considered to be the most comprehensive survey-based and accessible map of Scotland's main habitats. This dataset combines existing survey data, including NVC surveys, saltmarsh, sand dune and native woodland surveys, and presents information as EUNIS/Annex 1 habitats. As a composite dataset composed of various data sources with different spatial and temporal scales, HabMoS' use for monitoring protected habitats in Scotland is limited. Whilst the intention is that the dataset is updated as new surveys are carried out, the reality is that it has become a static and somewhat dated snapshot of Scotland's habitats.
- [The Scotland Habitat and Land cover map \(2020\)](#). This dataset was developed by [Space Intelligence](#) in partnership with NatureScot, using Artificial Intelligence classification techniques to generate a EUNIS level 2 habitat map for the whole of Scotland at a resolution of 20 x 20 m. As a fairly recent machine learning derived land classification map, there currently is a limited understanding of how accurate the map is. However, given its coverage and ability to be repeated and improved through annual iterations, the map has great potential for monitoring habitat change across Scotland.

The statistics for these sites were generated using JNCC's automated workflow for calculating EO indices data from the S1 and S2 archive. The results are presented in an R Shiny app, which follows the same structure as the original CUU app. The app was further developed to dynamically generate thumbnails using HTTP range requests.

## 3.1 Outline

### 3.1.1 Site selection

Nine NNR sites were selected across Scotland to complement ongoing conservation projects. See section 3.2 for details.

### 3.1.2 Processing of Copernicus data

A single orbit of Sentinel-1 data and seven granules of Sentinel-2 data provided full coverage of the NNR sites included. All Analysis Ready Data (ARD) hosted on CEDA were incorporated and additional Sentinel-1 data were processed using JNCC's Simple ARD Service methodology to fill gaps in the temporal coverage.

### 3.1.3 Preparation of spatial frameworks

The HabMoS and Scotland Habitat and Land cover map spatial frameworks were pre-processed to ensure the datasets were suitable for the statistics generation workflow. This included removing polygons less than 400 m<sup>2</sup> in area, removing overlapping polygons and splitting large polygons into smaller subsections.

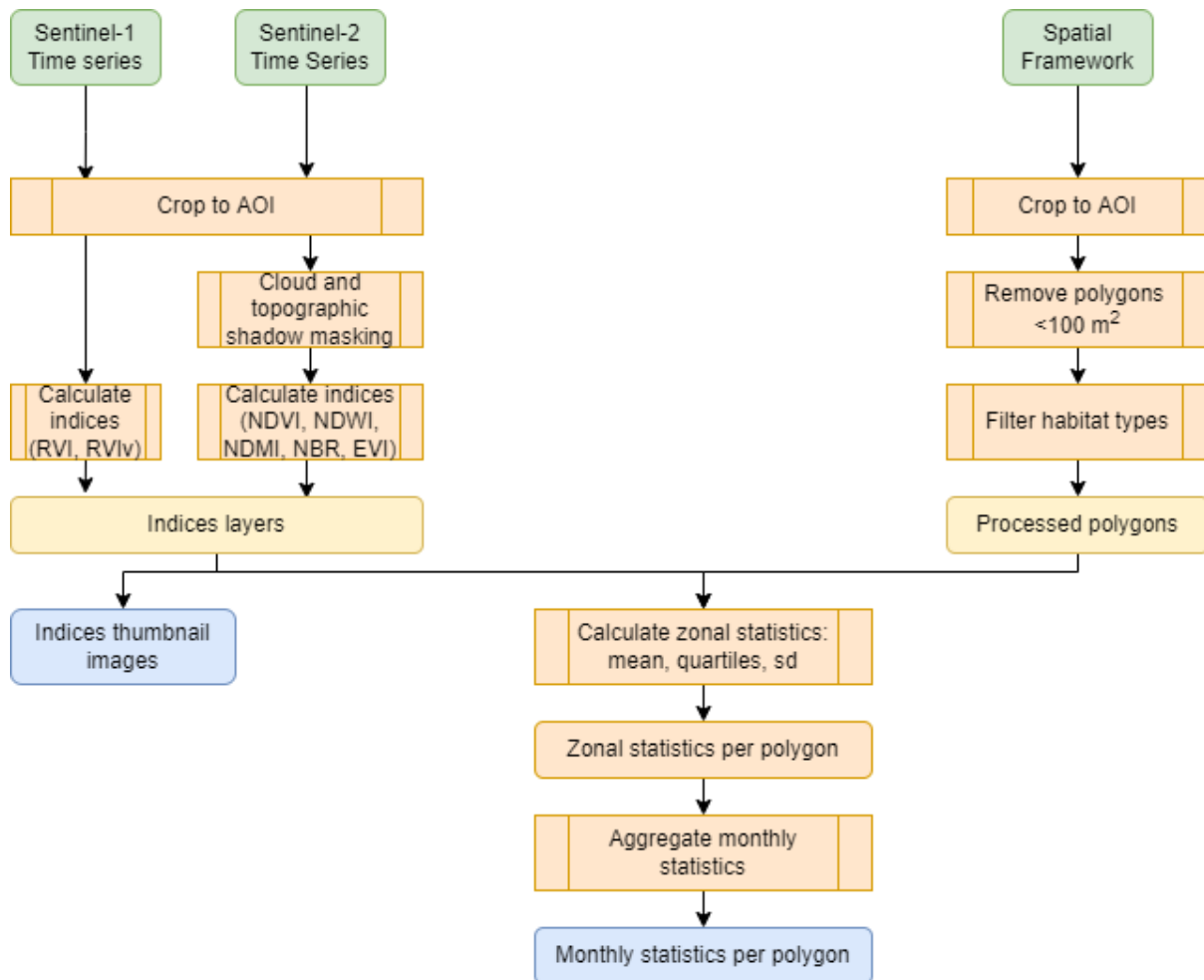
### 3.1.4 Generation of indices and statistics

All available ARD were processed using an automated, containerised workflow to mask Sentinel-2 data, produce EO indices layers, and combine these data with the spatial framework polygons to generate zonal statistics for each land parcel (Figure 1).

### 3.1.5 Development of app

An R Shiny app interface was developed using the R package's 'shiny' version 1.5.0 (Chang *et al.* 2020) and 'shinydashboard' version 0.7.1 (Chang *et al.* 2018) to present the statistics and thumbnail images for each polygon in the spatial frameworks. The updated app utilised HTTP range requests to dynamically generate polygon-level thumbnail images.

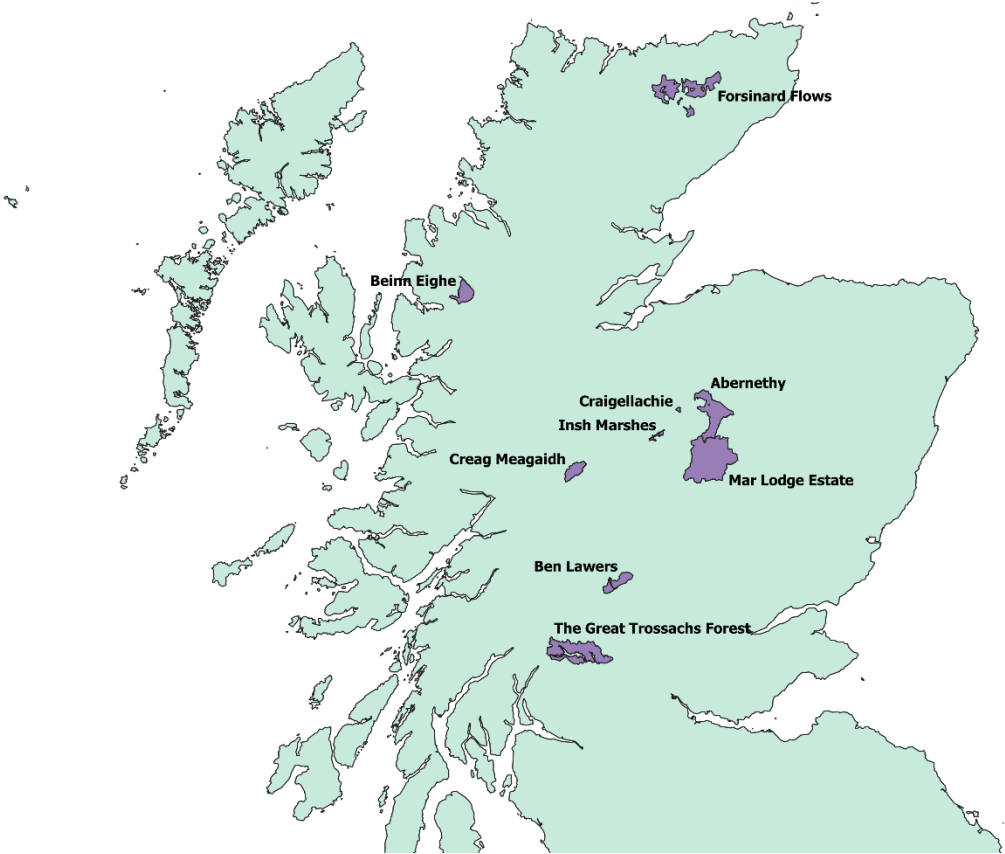




**Figure 1.** Diagram illustrating the workflow to process data for use in the landscape monitoring app.

### 3.2 Site selection

To maximise benefits, sites were selected to complement ongoing conservation projects across Scotland, as the app has the potential to deliver EO-derived information that could support current research. The nine selected NNRs encompass a range of habitats and topographic/climatic conditions for satellite data acquisition, ensuring this pilot was a reasonable trial for the landscape monitoring methodology. Due to the large size of some sites and the data constraints of R Shiny, only one spatial framework (HabMoS) could be included in the app for Abernethy, Forsinard Flows, Mar Lodge Estate, and The Great Trossachs Forest. For all other sites both the HabMoS and Scotland Habitat and Land cover map (2020) were used. Figure 2 shows the spatial distribution of the selected sites and Table 1 provides further detail for each site.



**Figure 2.** Map showing the locations of the nine pilot sites in Scotland.

**Table 1.** Pilot sites used in this project.

Site name	Total area [ha]	No. of polygons (HabMoS/ Habitat & Landcover map)	Description	Reason to include
Forsinard Flows	15,380.8	2,726 / N/A	A vast expanse of blanket bog, sheltered straths and mountains known as the Flow Country.	To support World Heritage Site (WHS) bid and provide long term monitoring.
Beinn Eighe	4,758	716 / 6,408	The reserve stretches from the loch-side to mountain top and most notably conserves ancient Caledonian pinewoods and uplands habitats.	To monitor on-going woodland regeneration. Beinne Eighe is also a Darwin Tree of Life collection site.
Abernethy	12,754.59	2,283 / N/A	Abernethy NNR encompasses one of the largest remnants of Caledonian pinewood, as well as moorland, wetlands and mountains.	Woodland and associated habitat monitoring
Craigellachie	257	89 / 393	The reserve boasts birch woodland, open glades, tree-fringed lochs and slopes rising to a craggy summit	Bioscan pilot site <a href="https://ibol.org/programs/bioscan/">https://ibol.org/programs/bioscan/</a>
Insh Marshes	695	275 / 1,038	Covering 10 km <sup>2</sup> of the River Spey floodplain, Insh Marshes is one of the most important wetland areas in Europe, supporting populations of breeding waders.	Good example of a flood plain site and looked after by RSPB
Mar Lodge Estate	29,324.6	2,046 / N/A	Mar Lodge Estate is made up of more than 29,000 hectares of heather-covered moorland, Caledonian pine forest, mountains and the Quoich wetlands, home to wading birds and otters.	Woodland regeneration and grazing pressure reduction.

<b>Site name</b>	<b>Total area [ha]</b>	<b>No. of polygons (HabMoS/ Habitat &amp; Landcover map)</b>	<b>Description</b>	<b>Reason to include</b>
Creag Meagaidh	3,948	235 / 5,118	Covering land from 250 m in height to 1,130 m, Creag Meagaidh encompasses a wide range of species and habitats from mountain top to loch-side.	Also test site for verifying Habitat & Landcover map
Ben Lawers	4,441.5	1,019 / 5,712	Scenic mountains and ridges, and the best collection of rare mountain plants in Britain.	Good examples of improving upland habitats.
The Great Trossachs Forest	16,541.75	2,996 / N/A	Covering 160 km <sup>2</sup> , this continuous area managed for the benefit of wildlife and people is creating a forest landscape large enough to include a range of habitats.	Pilot site for developing habitat scale eDNA monitoring

### 3.3 Processing of Copernicus data

All available Sentinel-2 ARD generated by JNCC's Simple ARD Service were incorporated. The selected NNRs were covered by seven Sentinel-2 granules. The Sentinel-2 ARD granules were masked to remove cloud and topographic shadow.

A single orbit of Sentinel-1 was selected (orbit 30 ascending) as this orbit provided full coverage of the NNRs included in the app. Any gaps in the ARD archive were processed to provide data every 12 days for the period 07/2015 to 07/2021. Sentinel-1 ARD scenes were divided into sections using the OSGB 100 km grid and these sections were fed into the processing workflow.

### 3.4 Preparation of spatial frameworks

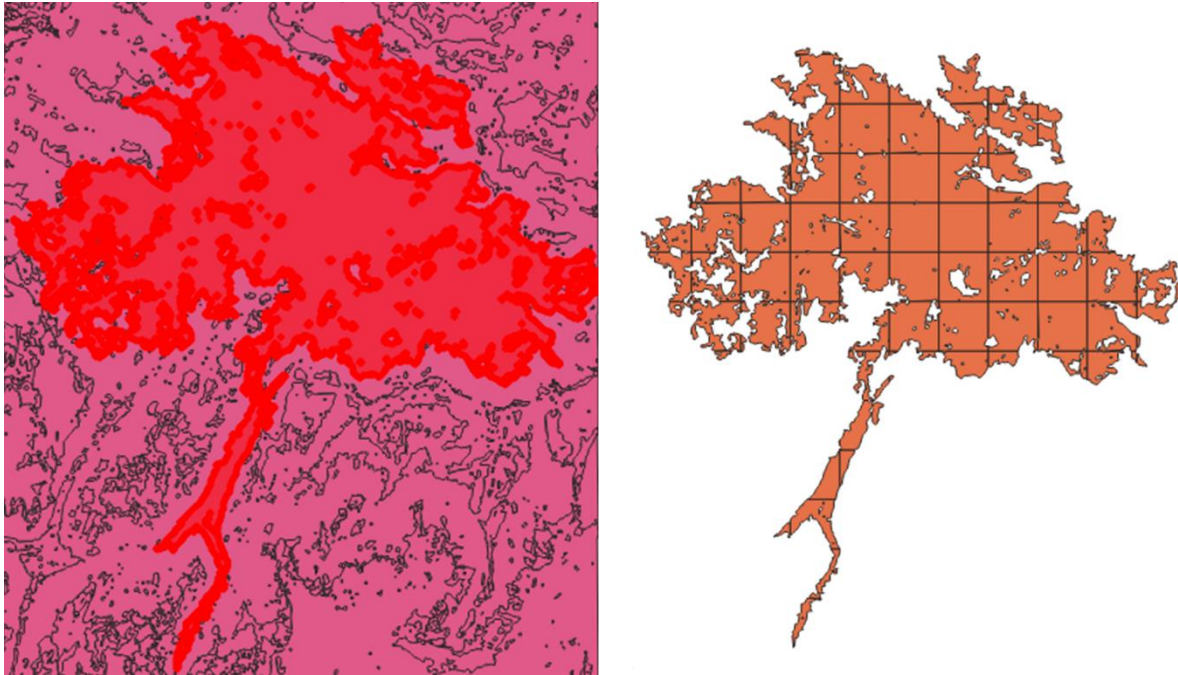
To ensure each spatial framework was suitable for the processing workflow, pre-processing steps were required.

#### 3.4.1 Habitat Map of Scotland

The HabMoS included overlapping surveys and some polygons were assigned multiple habitat classes if the area was a mosaic habitat. This made the original layer unsuitable for the landscape monitoring processing, which requires non-overlapping polygons with one habitat type associated with the polygon. NatureScot prioritised the surveys within each NNR and erased them from each other to form one non-overlapping polygon layer. Gaps in coverage in the NNRs remained. The majority habitat type was selected for the mosaic polygons (unless this was 50:50 coverage, in which case one had to be selected at random) and the app displayed the proportion of that habitat for information. Polygons less than 100 m<sup>2</sup> in area were also removed.

#### 3.4.2 Scotland Habitat and Land cover map (2020)

The Scotland Habitat and Land cover map (2020) raster data were clipped to each NNR boundary and polygonised to produce a shapefile for each site. This process produced very large polygons of the same habitat type, which in some cases dominated the entire NNR boundary. Such large polygons were unsuitable for the landscape monitoring workflow, which relies on comparing polygon-level statistics with habitat mean values. As an interim solution for this pilot project, large polygons were manually selected by comparing sizes with habitat maps used in the CUU pilot app and HabMoS polygons to ascertain a reasonable land parcel size to present in the app and were divided into subsections using a 1 ha grid. Figure 3 demonstrates this solution. Each polygon was assigned a unique identifier and sliver polygons less than 10 m wide were removed. Finally, polygons less than 400 m<sup>2</sup> in area were also removed to match the minimum map area in Scotland Habitat and Land cover map.



**Figure 3.** On the left, a large polygon is highlighted in red, and on the right the same polygon is shown divided into sections using a 1 ha grid.

### 3.5 Generation of indices and zonal statistics

All ARD were accessed directly from the [CEDA archive](#) as part of the processing workflow conducted using JASMIN, a scientific data analysis platform. Five indices were generated for all masked Sentinel-2 granules, and two indices were generated for the Sentinel-1 frames (Table 2). The Sentinel-2 indices provide information on vegetation productivity (Normalised Difference Vegetation Index and Enhanced Vegetation Index), vegetation moisture (Normalised Difference Moisture Index), burned vegetation (Normalised Burn Ratio) and surface water (Normalised Difference Water Index). The Sentinel-1 indices (Radar Vegetation Indices) provide information on vegetation structure.

The indices layers were combined with the HabMoS and the Habitat and Land cover spatial frameworks to generate zonal statistics for each land parcel polygon, including the mean, median, first quartile, third quartile, minimum and maximum values. Polygons overlapping masked cloud areas were removed from this process to avoid misleading results.

Zonal statistics for each ARD acquisition date were aggregated to provide a monthly average index value for each polygon. To flag change, a geographically weighted approach is employed, where polygon-level statistics are compared to the average statistics for the 50 nearest polygons of the same habitat. A PostgreSQL query was used to obtain the 50 nearest polygons within each NNR site for each polygon within the spatial framework. In instances where there were fewer than 50 polygons of the same habitat within an NNR site, all polygons of the same habitat type within each site were used. Average statistics were then generated from these 50 nearest polygons and a z-score was generated to measure deviation of the polygon statistics from the habitat mean.

**Table 2.** Details of indices generated, including equations, value ranges and a description of how each index might be used in landscape monitoring.

Index Name	What does it measure?	How is it calculated?	Range and values	Use in landscape monitoring
Normalised Difference Vegetation Index (NDVI)	Vegetation Productivity	$\frac{(\text{Near Infrared} - \text{Red})}{(\text{Near Infrared} + \text{Red})}$ ARD Bands: $\frac{(\text{Band 7} - \text{Band 3})}{(\text{Band 7} + \text{Band 3})}$ <a href="#">Sentinel-Hub method</a>	-1 to +1 Very low values = water Low values = bare ground, urban areas or snow Medium values = sparse vegetation (e.g. scrub) High values = dense vegetation (e.g. forest)	<p>NDVI is expected to increase in response to spring growth, deciduous woodland coming into leaf, nutrient enrichment of grassland or a change of vegetation cover (e.g. bracken encroachment on grassland).</p> <p>NDVI is expected to decrease in response to management activities such as scrub clearance, mowing, grazing, ploughing or burning.</p> <p>It may also decrease in response to impacts such as erosion, drought, wildfire, storm damage or flooding.</p>
Normalised Difference Water Index (NDWI)	Surface Water	$\frac{(\text{Green} - \text{Near Infrared})}{(\text{Green} + \text{Near Infrared})}$ ARD Bands: $\frac{(\text{Band 2} - \text{Band 7})}{(\text{Band 2} + \text{Band 7})}$ <a href="#">Sentinel-Hub method</a>	-1 to +1 Low values = dry ground Medium values (~0.2) = built-up areas High values (>0.5) = water	<p>NDWI is expected to increase in response to water body expansion and flooding or management activities such as re-wetting peat or fenland.</p> <p>NDWI is expected to decrease in response to floods receding, drought or management activities such as draining wetlands for land reclamation.</p>

Index Name	What does it measure?	How is it calculated?	Range and values	Use in landscape monitoring
Normalised Burn Ratio (NBR)	Burnt vegetation	$\frac{(\text{Near Infrared} - \text{Shortwave Infrared})}{(\text{Near Infrared} + \text{Shortwave Infrared})}$ ARD Bands: $\frac{(\text{Band 7} - \text{Band 10})}{(\text{Band 7} + \text{Band 10})}$ <a href="#">Sentinel-Hub method</a>	-1 to +1 Very low values = Severely burnt areas Low values = burnt areas Medium values (~ 0) = unburnt bare ground High values = healthy vegetation	NBR is expected to decrease in response to burning of vegetation either as a management measure or wildfire. NBR is expected to increase in response to vegetation recovery after a burn. Note that waterbodies also have low NBR values.
Normalised Difference Moisture Index (NDMI)	Vegetation canopy water content	$\frac{(\text{Near Infrared} - \text{Shortwave Infrared})}{(\text{Near Infrared} + \text{Shortwave Infrared})}$ ARD Bands: $\frac{(\text{Band 7} - \text{Band 9})}{(\text{Band 7} + \text{Band 9})}$ <a href="#">Sentinel-Hub method</a>	-1 to +1 Low values = low vegetation water content High values = high vegetation water content	NDMI is expected to increase in response to rain or irrigation, deciduous woodland coming into leaf or a change in habitat type (e.g. scrub encroachment on heathland). NDMI is expected to decrease in response to drought or management activities that reduce vegetation cover. Reduced NDMI can indicate fire risk.



Index Name	What does it measure?	How is it calculated?	Range and values	Use in landscape monitoring
Enhanced Vegetation Index (EVI)	Vegetation Productivity	$2.5 * (\text{Near Infrared} - \text{Red}) / ((\text{Near Infrared} + 6 * \text{Red} - 7.5 * \text{Blue}) + 1)$ <p>ARD Bands:</p> $\text{EVI} = 2.5 * (\text{Band 7} - \text{Band 3}) / ((\text{Band 7} + 6.0 * \text{Band 3} - 7.5 * \text{Band 1}) + 1.0)$ <p><a href="#">Sentinel-Hub method</a></p>	<p>-1 to +1</p> <p><i>(EVI produced for the current prototype app is noisy and has values outside the standard -1 to +1 range)</i></p> <p>Very low values = water</p> <p>Low values = bare ground, urban areas or snow</p> <p>Medium values = sparse vegetation, e.g. scrub</p> <p>High values = dense vegetation, e.g. forest</p>	<p>EVI is expected to respond to change in habitat type or condition in a similar way to NDVI.</p> <p>However, it is less sensitive to effects from different soil backgrounds, atmospheric effects and is less likely to become saturated (i.e. a value of 1) when recording dense vegetation.</p>
Radar Vegetation Index (RVIv)	Vegetation Structural Complexity	$(4 * \text{VH}) / (\text{VV} + \text{VH})$ <p>VV = Band 1, VH = Band 2</p> <p><a href="#">Sentinel-Hub method</a></p>	<p>+2.2 to +2.6</p> <p>High values = high structural complexity</p> <p>Low values = low structural complexity</p>	<p>RVIv is expected to increase in response to increased structural complexity of vegetation, e.g. spring growth, tree planting or scrub encroachment on grassland. It may also increase in response to forest felling or upland burning if the remaining land cover is more structurally complex than the former vegetation, e.g. due to presence of stumps and undergrowth or uneven bare ground.</p> <p>RVIv is expected to decrease in response to vegetation senescence and decreasing water content and may decrease in response to hay cutting or scrub removal.</p> <p>RVIv only produces meaningful results over vegetated ground, not urban areas, snow-covered surfaces or water.</p>

Index Name	What does it measure?	How is it calculated?	Range and values	Use in landscape monitoring
Radar Vegetation Index (RVI)	Vegetation Structural Complexity	$\text{Dop} = (VV / (VV + VH))$ $(\text{Math.sqrt(dop)}) * ((4 * (VH)/(VV + VH)))$ <p>Dop = degree of polarisation                      VV = Band 1, VH = Band 2  <a href="#">Sentinel-Hub method</a></p>	+1.50 to +1.55 High values = high structural complexity, vegetation Low values = low structural complexity, bare ground	<p>The RVI was developed to improve the RVIv and is expected to react to change in a very similar way.</p> <p>Like RVIv, RVI should increase in response to increased structural complexity of vegetation and decrease in response to vegetation senescence and decreasing water content.</p> <p>In contrast to RVIv, RVI uses an additional pre-factor for better separation of urban and bare ground from vegetation and for an improved dynamic range. This pre-factor can result in unusually high values for rough soils (e.g. after tillage) and moving surfaces (e.g. in windy conditions) which limits its applicability in these conditions.</p>

### 3.6 Development of the Landscape Monitoring app

The landscape monitoring app followed the same design as the CUU original R Shiny interface (Lightfoot *et al.* 2021) and includes a map interface to display and select land parcels, a calendar grid showing satellite data acquisition dates, graphs of index values, and a carousel to view polygon-level thumbnails (Figure 4). The user can query the statistics using the selection panel in the app, displaying results for the site, spatial framework, index and habitat of interest. The polygon-level results are displayed in the graph panel, highlighting polygons that have deviated significantly from the habitat mean.

In this version of the app, HTTP range requests are used to generate polygon-level thumbnails dynamically. This process queries the archived imagery and downloads the section of the ARD or index layer that covers the selected polygon, displaying the thumbnail images in a carousel. This process is relatively time-consuming and to limit the waiting time for users, a year of interest must first be selected to limit the number of thumbnails that are generated at one time. Users can download data as a CSV or ESRI Shapefile to further investigate results.

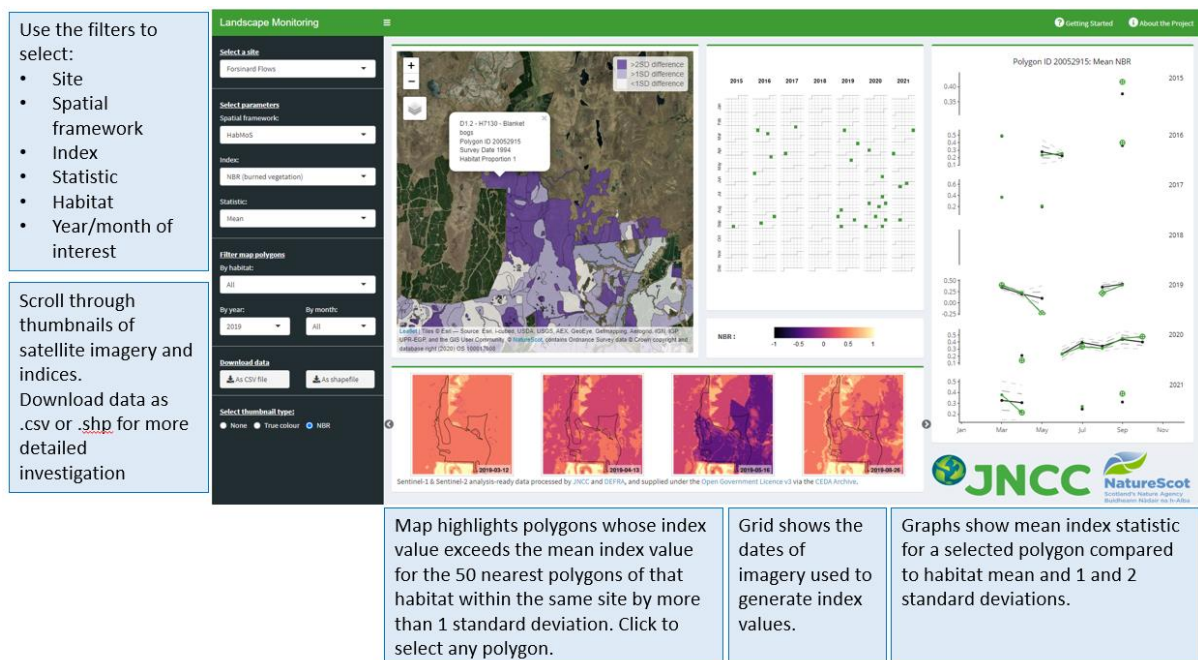


Figure 4. Screenshot of the app interface.

## 4 User testing

One of the main aims of this project was the collection of detailed user feedback to assess the usability of the app and understand the requirements for a wider roll-out of the tool. For this reason, a number of user engagement events were held with the following objectives:

- Generate an understanding of the strength and limitations of EO data and raise awareness of possibilities for applying it to conservation management.
- Gather feedback on accuracy and effectiveness of the individual frameworks, indices, and statistics for change detection.
- Document user demand, impact and further needs to develop the tool in future.

To achieve this, a lunch time webinar was given at NatureScot to introduce the project to a wide audience and to generate interest for further engagement with the tool. This was

followed by several small group sessions with site-based staff from NatureScot, RSPB, National Trust for Scotland and the University of the Highlands and Islands, during which users were guided through the app using pre-selected examples of change. A user testing script was written to structure the testing sessions (Appendix 1). Participants were then given time to explore the app, ask further questions and complete a short questionnaire (Appendix 2) to provide feedback on the different spatial frameworks, vegetation indices and correctly detected or missed changes. Overall, seven sessions were held to engage 27 users from four different organisations. The results of the feedback gathered at these sessions are presented in the following sections.

## 4.1 Overview

Of the 27 staff engaged for testing sessions, ten submitted complete responses and one submitted a partial response. Despite the low response rate feedback received was of high quality and came from a range of user types. The majority (8/11) reported that they had spent 1 to 2 hours testing the tool, with the remaining three spending less than 1 hour. All the sites included within the tool were examined fairly equally bar Mar Lodge Estate, Craigellachie and Insh Marshes, which were only examined by one user each.

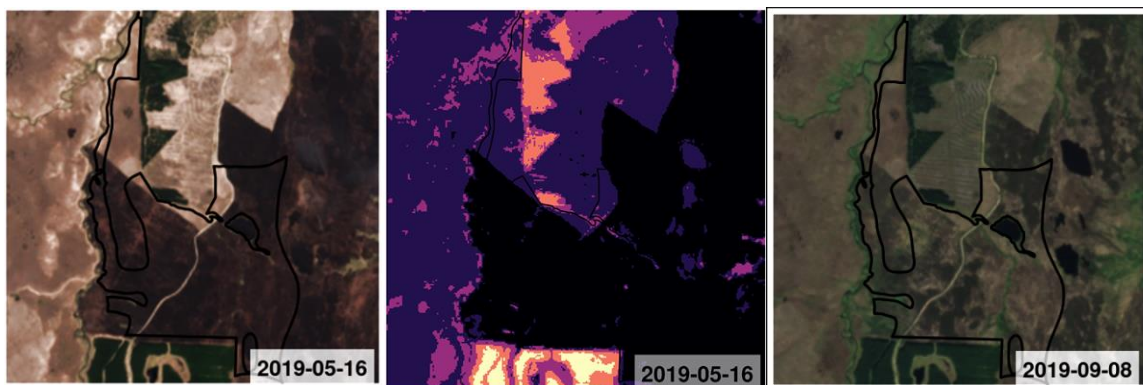
### 4.1.1 Which spatial framework did you use? If you used both, how did they compare?

Both spatial frameworks were explored by 7/11 respondents, all of whom noted a preference for HabMoS and the usefulness of the Habitat and Land Cover Map. More specifically, users felt that HabMoS was easier to interpret but more generalised, less spatially accurate and exhibited temporal decorrelation, particularly with older polygons. Contrastingly, users felt the Habitat and Land Cover map was useful for examining finer scale change although it was harder to interpret given its gridded structure.

### 4.1.2 Can you give one or more examples of where the app correctly detected change?

Three staff were able to 'ground truth' areas of change detected by the tool, whilst the other respondents said they didn't know the sites well enough.

- The first example where the tool correctly detected change was as a result of the 2019 wildfires on Forsinard Flows (as was used as an example in testing – Figure 5). The user noted the tool was successful in capturing both the impact of the burn and the subsequent regeneration through the NBR, RVI and vegetation indexes.



**Figure 5.** Left: True colour thumbnail for May 2019 clearly shows evidence of burning. Middle: NBR thumbnail for May 2019 shows extreme low value for the polygon consistent with burning. Right: True colour thumbnail for September 2019 showing re-vegetation of burnt areas.

- The second example came from the testing example at Beinn Eighe, where the user stated that monthly changes in plant productivity (interpreted from the NDVI index) of *P. sylvestris* woodland shown in the app were as expected, though they did note that it was hard to compare data for the same month over successive years.
- The final example came from Mar Lodge Estate where the user highlighted that the NDVI index values for specific polygons were consistent with woodland regeneration of Caledonian pine forest.

#### 4.1.3 Can you give one or more examples of where the app failed to perform as expected

Only one user was able to identify an example of where the app failed to perform as expected. This was at Ben Lawers NNR using the HabMoS spatial framework, where the respondent expected to have been able to see the result of a known change in water levels following management within the NDVI index within a specific polygon.

There are many reasons as to why only one user was able to identify a perceived failure to perform as expected, for example spatial framework data limitations, unfamiliarity with the indices or limited temporal resolution.

#### 4.1.4 Are there any instances of change that are identified that you find surprising?

Only one respondent noted a surprising instance of change. This was from Creag Meagaidh where the user noted that the average RVI of an area of regenerating woodland (polygon 175) went from above average to way below average and back every two months.

#### 4.1.5 Which designated sites or geographic areas would you most like to see included in future iterations of the app, and why?

Various geographic areas were suggested by users which have been grouped according to their general purpose:

1. For identifying and monitoring responses to specific pressures:
  - a. The impact of deer (e.g. Loch Lomond Woods SAC and SSSIs or Flanders Moss) to examine if there are land cover changes as a result of cull efforts.
2. To include certain habitat types:
  - a. Peatlands (to detect change as a resulting of re-wetting management activities).
  - b. Upland habitats (e.g. Letterewe SSSI and Fannich Hills SSSI & SAC) to track habitat and land use change in upland areas which are pressured and typically data deficient.
  - c. Montane habitats (to decrease monitoring efforts and costs associated with these rare habitats).
  - d. Riparian habitats including in urban areas (to track INNS).
3. To monitor the result of management activities:
  - a. Creag Meagaidh and other sites like it where there is active deer management.
  - b. Peatland ACTION sites (to evaluate management activities both pre- and post-restoration).
4. General:
  - a. National Scenic Areas (to help detect land cover change).
  - b. Lochaber or Argyll (relatively data deficient areas in Scotland).
  - c. All Scottish peatlands (to flag up potential peatland sites that need further investigation for restoration).
  - d. All of Scotland (to provide a custom area for computing statistics).

#### 4.1.6 We aim to integrate data from field surveys into future iterations of the app. What information would you like to see included and how would you use it?

All users suggested various additional data types or sources that could be included within future iterations of the app, as below. Responses as to how users would use these data (asked as a separate question) are in italics.

- Deer count, deer cull, woodland, upland herbivore impact assessment (HIA) and weather data (*allowing users to examine index data in the context of other related data providing opportunity for insight and analysis*).
- Links to NBN data (*to relate indices data to indicator species information*).
- Protected area feature condition data (*to examine and relate indices to feature condition in protected areas*).
- Peat depth and condition surveys (*again to interpret indices but also to use as reference points between sites*).
- INNS data (*for monitoring INNS spread and for helping to target management*).
- Peatland ACTION WMS database (*to allow users to compare indexes with peatland restoration initiatives*).
- An interpretation of change detection by remote sensing (*to inform land management practices and Site Condition Monitoring*).

Some further comments from users included:



*“I think it would be great if we could build on the current functionality to allow many datasets to be examined in parallel to better understand the circumstances which have led to that change. It would be great if there was a simple statistic which would report if the variation observed in one variable was significantly linked with another. E.g., there might be an expected negative correlation between deer population (declining population count surveys) and a significant change/increase in vegetation structure. The more datasets added the better understood the change can be. I think this would benefit deer management and woodland restoration efforts particularly as they are often difficult to survey at the landscape scale required. I think MET weather data might also be good for context. Variations in ambient temperatures and rainfall etc. between years, and things like extreme weather events, could maybe cause observed changes. Other factors like topography and resulting hillshade might also explain different and disproportionate changes to productivity etc. in some areas than others. Including average cloud cover might also allow the observer to determine how trustworthy map outputs are if the survey method is adversely affected by clouds.”*

Similarly, another user noted:

*“Peatland ACTION Data & Evidence team are currently working to produce WMS of (a selection of) the data held on the PA database. This will allow access by project staff to much more detailed spatially explicit information. If the indices data were similarly available, it would make interpretation of notable change in relation to peatland restoration easier.”*

#### 4.1.7 How likely are you to use this app in your work?

Responses to the question 'How likely are you to use this app in your work?' are provided in Figure 6.

How likely are you to use this app in your work?			Response Percent	Response Total
1	Very likely		22%	2
2	Likely		22%	2
3	Somewhat likely		56%	5
4	Unlikely		0%	0

**Figure 6.** Summary of the responses provided to the question 'How likely are you to use this app in your work?'

#### 4.1.8 How would or could you use this app in your work?

Various potential use cases were suggested by respondents:

- To understand the influence of management interventions and observe if there has been change on a protected area as a result.
- To see how protected area feature condition is reflected in the indices and vice versa, on a landscape scale.
- To identify land cover change over time to help with monitoring change at the landscape scale.
- To add more contextual information to the monitoring of peatland restoration at the site level, especially with a temporal component.
- To check in on a peatland ACTION site post restoration each year and highlight areas where additional field visits are required to check out unexpected change. For example, heavily eroded sites may show change in NDVI (bare peat to vegetated peat) but would a change be detected on drained sites where the response to restoration is likely to be more subtle (alteration in plant community).
- To quickly explore and identify change areas to direct and target Site Condition Monitoring work.

#### 4.1.9 Who else do you think would benefit from using this app?

Respondents recommend a number of others user types who they thought would benefit from using the app:

- Aggregated analysis of land cover changes should inform land use policy makers, nationally and regionally.
- Universities and research institutes could benefit.
- In NatureScot, Area Officers involved in SCM and Agri-Environment Climate Scheme.
- Landowners and people leading restoration projects.

#### 4.1.10 What was the best thing about the app?

- Easy to follow, simple presentation of data.
- Excellent 'Get Started' option, nice intro information and most importantly the tool's ability to show data in a format that few have seen before which could be really useful for site management and assessment.
- Visual identification of potential land cover change. Really excellent potential in this app if developed further.

- Processing speed.
- Being able to engage with satellite-derived indices through a relatively user-friendly tool.
- As a quick way of finding outliers and areas which may need monitoring.
- Ability to filter by habitat type.

#### 4.1.11 What was the worst thing about the app?

- Not being able to overlay data sets.
- Crashing when generating thumbnails.
- Non-matching y-axes.
- Small data windows.
- Lack of ability to look at changes between years.
- Change reported as standard deviations difficult to interpret.
- Loading times for impatient users.

## 5 Discussion

The testing sessions and survey results revealed that the tool served best as a demonstration of ‘the art of the possible’ when it comes to using EO-derived data in nature conservation at the site level, as opposed to a tool ready to be operationalised for decision making. Whilst acknowledging the need for further development, during testing sessions users were positive about the tool, with the majority noting that they saw the tool’s ability or potential for identifying land cover change at the site level. The users’ general enthusiasm and ability to engage with what are novel data products through the tool was, albeit subjective, it’s strongest endorsement. Furthermore, in discussion following testing sessions users expressed an interest in seeing the tool developed further. Therefore, it can be said with confidence that on a basic level, the tool is successful in its primary goal of being able to identify and present land cover change at the site level in a meaningful way.

Further aims of gathering user views on the performance on individual vegetation indices and statistics and evaluating the effectiveness of the tool for monitoring on NNRs were, to some extent, found to be too ambitious for the user testing initiative. For example, only three specific examples of where the app correctly detected change were given by users, two of which had been used as examples in user testing. Further, no instances of where the app failed to detect change were given and only one example of ‘surprising’ change was noted. This was largely due to the fact the tool is a proof-of-concept exercise utilising a data source which was novel to the majority of users. Testing and resultant feedback was therefore focussed at a higher level than these subsidiary aims, which are fairly technical and rely on users having either a high level of familiarity with the data and/ or large amounts of time to test the tool, neither of which were available within limitations of this project. With that said, the engagement with and feedback received from users was generally of high quality, which did allow for a reasonable level of analysis and insight to be generated, as will be discussed.

The first notable point of discussion relates to the indices included within the tool, with results showing that all indices were examined by at least two users. Whilst some respondents called for more information to help with their interpretation, it suggests that once introduced to the concept users are somewhat comfortable in using these indices as proxies for land cover change. For the majority of users engaged this was a novel concept, the success of which demonstrates the ability and potential of the approach in various applications of land cover change identification and monitoring now and in the future.

Another key insight generated from testing sessions related to the spatial framework used. Here, the majority of users tested both frameworks and noted the accompanying strengths



and weaknesses of each. For example, it was frequently noted that the currency of the HabMoS dataset is less than ideal, with some sites predominantly composed of habitat polygons surveyed and classified in the 1980's. Of particular interest was feedback noting the usefulness of the gridded Habitat and Land Cover Map framework from Space Intelligence, showing users' desire to examine change 'beyond the polygon level' as presented in the HabMoS dataset. This is noteworthy given that this level of analysis transcends the traditional notion that habitats exist and change in discrete parcels to a place which acknowledges a level of dynamism in the landscape as land cover responds to short- and long-term pressures. Such an approach aligns more favourably with contemporary research on ecosystem connectivity and resilience and is one which will likely feature in future conservation policy measures such as 30 x 30 and nature networks. This is however not to say a gridded visualisation of habitat and land cover information is an ideal solution, more that it is one way in which such information can be presented in a meaningful way to conservationists, provided that appropriate contextual information is presented.

A further interesting product of the user-testing was an insight into potential use cases of the tool. Some of these use cases could be realised with the tool in its present form, albeit at a cursory level. The majority of potential use cases identified were however conditional upon further app development, which predominantly requires indices data being made available over larger geographical areas with greater consistency over the time periods available. Such recommendations are made with the view that the tool could be used to identify and monitor more subtle change occurring over longer time periods and across broader scales. It is however worth noting that the collection of groundtruthed habitat and land cover data is of equal importance for the future development of the tool, so that data limitations such as those discussed in the previous paragraph can be overcome to ensure change can be identified and monitored accurately across various temporal and spatial scales.

One final insight generated worthy of discussion relates to user feedback regarding the future development of the tool. A common theme of this feedback was the recommendation for the integration of a greater range of contextual datasets in the tool combined with greater analysis functionality, both of which would assist interpretation of the land cover change highlighted by the indices. On a basic level, the notion that users would like to see greater data availability and analytical functionality suggests the tool is user friendly and that it does its job. If this were not the case, recommendations for future development would have been primarily in relation to fixing existing issues. Whilst such recommendations were still present, for example around the size of the data windows, how the graphs were displayed and labelled and thumbnail generation time, the result that users expressed an interest for more contextual data suggests the tool has proven a novel concept as appropriate and meaningful. However, these recommendations do raise a fundamental question about the main aim of the tool itself. For example, if enacted many of these recommendations would push the tool towards a more generic GIS based spatial data viewer, for which many are already available online. With that said, if this is what users wish for, then perhaps a more appropriate course of action would be to integrate current functionality offered by the tool into some form of pre-existing web-based mapping software. One could argue however that this is 'reinventing the wheel' and would detract from the key successes achieved by the project as have been discussed. Therefore, perhaps a more appropriate direction for future development is to concentrate on furthering the tools' unique selling point by focussing on those recommendations which will streamline data visualisation and interpretation, whilst upscaling to a larger area. This of course relies on the acknowledgment and communication of the fact that it is 'one piece of the puzzle' in a wider suite of tools for the visualisation and analysis of habitat and land cover data and how it is changing.

## 6 Conclusions

Overall, it can be said the Landscape Monitoring Tool developed as part of the project has been successful in achieving its main aims.

Firstly, it was successful in its fundamental goal of examining if at the site level, habitat and land cover change can be identified in a meaningful way using a combination of satellite derived indices and land cover data. Whilst user testing and feedback may not have been able to gather quantitative information on the performance on individual vegetation indices and statistics, it was able to elucidate a series of current or potential uses cases in and around the use of the tool for identifying and monitoring change at different spatial and temporal scales within a variety of potential conservation activities.

Secondly, it successfully trialled two habitat spatial frameworks, one derived from detailed site-based survey data and one derived from EO data. Feedback received in relation to the strengths and limitations of both data sources highlighted that in principle both datasets had their place as information upon which habitat and land cover change could be examined using satellite derived indices data. Furthermore, user testing and subsequent feedback provided insights as to how both spatial frameworks could be improved to make the identification and interpretation of change more meaningful within future development.

Lastly, user testing was successful in generating limited but valuable feedback on the functionality required in future development to realise opportunities for the tool to be used in a wide range of conservation activities. Inherent in realising these opportunities will be a decision on how best to utilise and promote the tools unique selling point as an application for identifying and tracking habitat and land cover change over various temporal and spatial scales.

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## Appendix 1 – Script used for user testing

### 1. Document Purpose

The purpose of the document is to structure the session for user testing of the Landscape Monitoring tool. The test cases in this document are examples designed to allow the users to familiarise themselves with the tool. We invite testers to use their expertise in NNR management, habitat surveying and landscape monitoring to:

- a) Explore the tools ability to identify change on the ground; and
- b) To consider if the tool would (or could with further development) be useful in their line of work

Testers should carry out the tests as follows:

- a) Familiarise themselves with the background information provided about the tool (section 2).
- b) With the help of the session organiser, work through the tests described in Sections 3 and 4 by carrying out the steps in the order in which they appear. Use the 'Actual Results' column to make any notes about your findings.
- c) Once the session is complete, feel free to go back and explore other features in the tool.
- d) As is explained in section 5, complete the feedback questionnaire with your findings within two weeks of the initial session.

### 2. Background

In a collaboration with NatureScot and other partners, JNCC have developed a [proof-of-concept web-delivered service](#) which uses satellite data to identify and track habitat and land use change over time at a selection of sites and highlight changed areas on a map. The satellite data used by the tool come from Sentinel-1 and 2 satellites and are a mixture of radar and multispectral imagery from the years 2015 to 2021. Thanks to JNCC and the Simple Analysis Ready Data (ARD) service, these satellite data have been used to create seven different indices, each of which give us an insight into different environmental conditions on the ground:

Index Name	What does it measure	Values	Use in landscape monitoring examples
Normalised Difference Vegetation Index (NDVI)	Plant productivity	-1 to +1	Increases in response to plant growth Decreases in response to management activities and damage like erosion, drought, wildfire, etc
Normalised Difference Water Index (NDWI)	Surface Water	-1 to +1	Increase in response to water body expansion, flooding or re-wetting Decrease in response to drought or draining wetlands.

Index Name	What does it measure	Values	Use in landscape monitoring examples
Normalised Difference Moisture Index (NDMI):	Plant water content	-1 to +1	Increase in response to rain, irrigation, deciduous woodland coming into leaf or a change in habitat type Decrease in response to drought or management activities that reduce vegetation cover
Enhanced Vegetation Index (EVI)	Plant productivity	-1 to +1	Same as NDVI but less sensitive to background noise
Normalised Burn Ratio (NBR)	Burned vegetation	-1 to +1	Increase in response to vegetation recovery after burn Decrease in response to burning of vegetation
Radar Vegetation Index (RVIv)	Vegetation Structural Complexity	-2.2 to +2.6	Increase in response to increased structural complexity of vegetation, e.g. spring growth, tree planting or scrub encroachment on grassland Decrease in response to vegetation degradation and decreasing water content
Radar Vegetation Index (RVI)	Vegetation Structural Complexity	-1.50 to +1.55	Same as RVIv above but better at differentiating between urban and bare ground from vegetation

For a full description of how these indices have been created, what they measure and what they can be used for in landscape monitoring, [see this helpful document](#).

### 3. How the app works

- The app, accessible online through your web browser, is map based and includes 9 nature reserves: Abernethy, Beinn Eighe, Ben Lawers, Craigellachie, Forsinard Flows, The Great Trossachs Forest, Insh Marshes and Mar Lodge Estate.
- Within each site habitat maps have been provided from the Habitat Map of Scotland polygons. At some sites an additional EUNIS level 2 habitat map is provided which has been segmented into 20 x 20 m polygons.
- Using the drop-down menus in the tool, users are able to select the site and habitat they are interested in. Then by selecting one of the different indices as outlined above, users are able to examine the different results for each individual polygon in their chosen site.
- The results for each polygon within each index are reported in terms of change over a chosen period of time, for example for the year 2019, or for a given month for a given time period (e.g. 2016 to 2019).
- This change is measured as the amount a given polygon deviates from the mean index value of all the polygons of that habitat at that site in that given time period. Polygons that deviate by more than 1 standard deviation from that mean value are highlighted and can be clicked upon to reveal more information on how its index value varies throughout each year.

- Finally, by selecting a specific year and a specific polygon, thumbnails can be generated either in true colour or the chosen index, which can be downloaded.
- This may all sound a bit confusing and therefore, it's best to have a play around and get familiar with the tool yourself. For more assistance a 'Getting started' and 'About the project' icons are also available at the top of the tool.

#### 4. Testing the tool

This section of the test script is designed to get users familiar with the tool.

ID	Step	Expected Result	Notes
0.1	<p>Navigate to the online tool at <a href="https://jncc.shinyapps.io/SASLandscapeMonitoring/">https://jncc.shinyapps.io/SASLandscapeMonitoring/</a></p> <p>*Remember to disconnect from NetExtender *</p>	<ul style="list-style-type: none"> <li>• I can navigate to the tool without any issue.</li> <li>• The web page loads and I see information about the project.</li> </ul>	
0.2	<p>Close the information notice using the [dismiss] button at the bottom right of the window (scroll down)</p> <p>Select a site you are interested in.</p> <p>Select a spatial framework; either HabMoS or if available the Habitat and Land Cover Map 2020.</p> <p>View the imagery generated in the map and try to zoom in and out. Drag the map around using your cursor and change the data displayed using the layers icon.</p>	<ul style="list-style-type: none"> <li>• I can select the site I am interested in and a spatial framework.</li> <li>• A habitat map of the site loads in the central window.</li> <li>• I am able to zoom in and out, drag and change the data displayed on the map using the layers icon.</li> </ul>	
0.3	<p>Hover over a given polygon on the map.</p> <p>View the information displayed beside each polygon in the hover box that appears.</p>	<ul style="list-style-type: none"> <li>• When hovering over a given polygon a small box appears displaying information about the polygon.</li> <li>• For the HabMos polygon this</li> </ul>	

ID	Step	Expected Result	Notes
		<p>includes the EUNIS and Annex 1 code, a polygon ID, the survey data and the habitat proportion.</p> <ul style="list-style-type: none"> <li>For the Habitat and Land cover map this includes a EUNIS code, classification name and a polygon ID.</li> </ul>	

This section of the test script focuses on the testing of the indices.

ID	Step	Expected Result	Actual Result
0.4	<p>Select an index. For example, choose NDVI (plant productivity).</p> <p>Selected a statistic. For example, choose 'Mean'</p> <p>Find a polygon in the map and click on it.</p>	<ul style="list-style-type: none"> <li>The map should reload</li> <li>When clicking on a polygon, data in the two right hand windows should be generated, charting the mean NDVI results for that polygon across different years and months.</li> </ul>	
0.5	<p>Rather than viewing all the polygons of a site on the map, filter the polygons by selecting a given habitat type using the drop-down menu.</p> <p>Select a given year, a given month or both, and click on a polygon.</p>	<ul style="list-style-type: none"> <li>When selecting a given habitat type, the map reloads and only show the habitat type selected</li> <li>When clicking on a given polygon new data are loaded</li> </ul>	
0.6	<p>For the polygon you have chosen, selected an individual year and a single month</p> <p>Select a thumbnail type at the bottom, either true color or the index type you have selected previously</p>	<ul style="list-style-type: none"> <li>In the bottom window, a series of thumbnail images are generated for the given polygon and month I have selected.</li> </ul>	

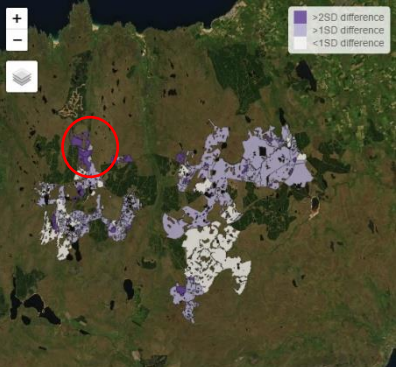
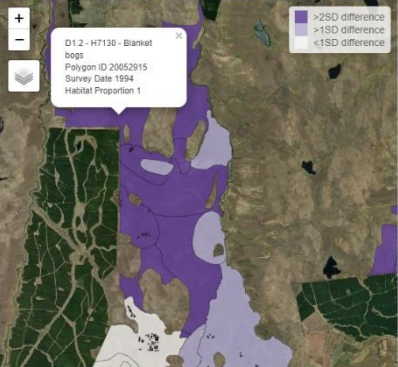

## 5. Specific use cases

This section focuses on the testing some specific use cases, which may give inspiration as to how the tool and its indexes can be used for identifying what may be meaningful

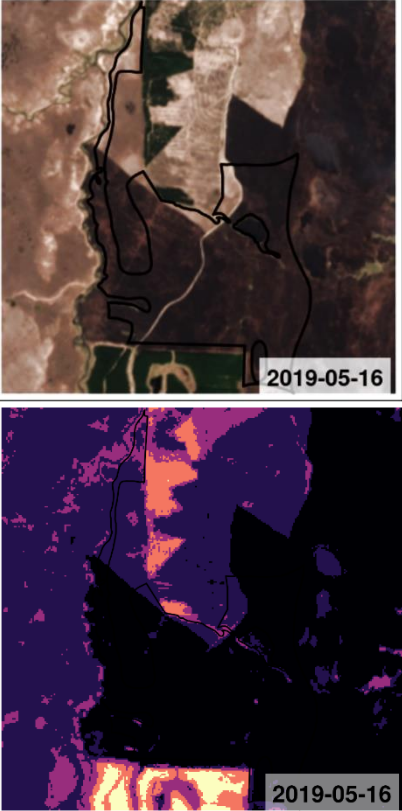
environmental change. The use cases given here are examples and we hope that users are willing to use their expertise and knowledge to explore the tools ability to identify change more widely.

### Use case 1: wildfire at Forsinard Flows – May 2019

Context: a large wildfire affected the Halladale area on 12 May 2019. The southern part of the fire extended into Forsinard Flows so should be detectable within some of the habitat polygons for the site.

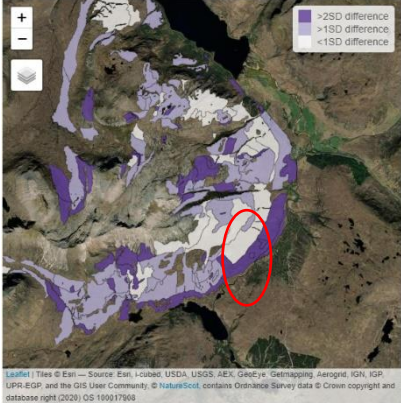
ID	Step	Expected Result	Notes
1.1	Select the following parameters: Site: Forsinard Flows Spatial framework: HabMoS Index: NBR Statistic: Mean Filter map polygons... By habitat: D1.2 – H7130 – Blanket Bogs By year: 2019	<ul style="list-style-type: none"> <li>Map window should look like this:</li> </ul> 	
1.2	Zoom into the dark purple polygons at the north and west of the site as ringed in red above. Highlight the polygon above the forestry block shown (ID 20052915)		
1.3	Explore the graphs produced for the polygon, especially that for 2019.	<ul style="list-style-type: none"> <li>Graph window for 2019 should look like this:</li> </ul>  <ul style="list-style-type: none"> <li>Note the sudden drop in the green line in May and the fact this is the only month over 6 years where the value goes below zero.</li> <li>Unfortunately there is no clear imagery again until September.</li> </ul>	
1.4	Check out the thumbnails for the polygon by first clicking on True colour and then on NBR. Note this may take a couple of minutes to generate 7 thumbnails.	<ul style="list-style-type: none"> <li>True colour thumbnail for May clearly shows evidence of burning.</li> </ul>	

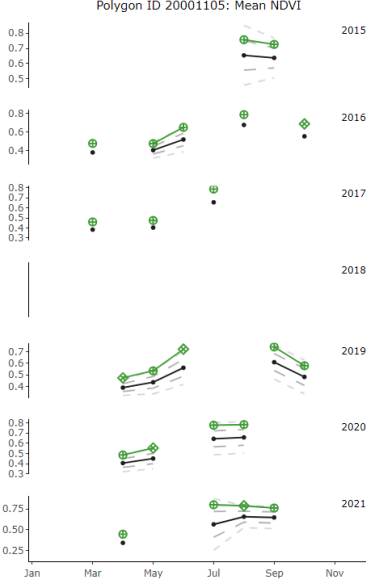




ID	Step	Expected Result	Notes
	Find the thumbnails for May 2019.	 <ul style="list-style-type: none"> <li data-bbox="683 1048 1254 1151">• NBR thumbnail for May 2019 shows extreme negative values for the polygon consistent with burning.</li> </ul>	

### Use case 2: woodland regeneration at Beinn Eighe

Context: woodland has been regenerating at Beinn Eighe over many years, the stretch along Glen Torridon has seen some planting, fencing and now more natural regeneration of young trees. The area is still classed as wet heath in HabMoS so is interesting to compare the satellite index results with surrounding wet heath polygons.

ID	Step	Expected Result	Notes
2.1	Select the following parameters: Site: Beinn Eighe Spatial framework: HabMoS Index: NDVI Statistic: Mean Filter map polygons... By habitat: F4.11 – H4010 wet heaths	<ul style="list-style-type: none"> <li data-bbox="517 1496 826 1527">• Map output like this:</li> </ul> 	

ID	Step	Expected Result	Notes
2.2	Zoom into the large dark purple polygon along Glen Torridon circled above. Click on it (polygon ID 438) and examine the graphs.	<ul style="list-style-type: none"> <li>Consistently higher NDVI values than the mean of surrounding wet heath polygons owing to the greater productivity of the young trees.</li> </ul> 	
2.3	Change the index to NDMI – Normalised Difference Moisture Index.	<ul style="list-style-type: none"> <li>Results similar to NDVI which is consistent with the predicted response to scrub encroachment on heathland</li> </ul>	
2.4	Change the index to RVI – vegetation structure and examine the graphs.	<ul style="list-style-type: none"> <li>The values are lower than the average for wet heath. For example, the graph for 2020 below. This is not what is predicted as increased vegetation structure should increase the values of this index. This needs further investigation but is exactly the type of information we are looking for in the testing.</li> </ul> 	

ID	Step	Expected Result	Notes
2.5	<p>Zoom into the boundary between this polygon and the adjacent light purple polygon. Click on the layers icon in the top left.</p> <p>Deselect the three checkboxes to clear the polygons. You can then view the underlying imagery and clearly see the difference in vegetation structure between the two polygons.</p>		

## 6. Further exploration

We now encourage you to play around with the tool in your own time, exploring areas and indices that are of particular interest to your area of expertise

The final step of user testing is to submit your feedback on the tool through the online survey form. If you have any questions about the survey form, please contact NatureScot.

## Appendix 2 – Results of user feedback survey

### Q1. What is your role / job title?

- Data Manager
- Environmental Data and Innovative Technologies Officer
- Landscape and Climate Change Officer
- GIS & Data Analyst, Peatland ACTION
- Operations/Area Officer
- Biodiversity adviser
- Peatland Action Monitoring Officer
- Monitoring Officer - Peatland Action
- Research Engineer
- Property Manager/Senior Ranger

### Q2. Approximately how many hours did you spend testing the landscape monitoring app?

- 1 to 2 h (7)

### Q3. Which site(s) did you look at?

- Ben Lawers (6)
- Beinn Eighe (5)
- Forsinard Flow (3)
- Creag Meagaidh (3)
- Abernethy (2)
- The Great Trossachs Forest (2)
- Craigellachie (1)
- Insh Marshes (1)
- Mar Lodge Estate (0)

### Q4. Which indices did you look at?

- NDVI - plant productivity (10)
- NDWI - surface water (8)
- NDMI - plant water content (6)
- EVI - plant productivity (5)
- NBR - burnt vegetation (6)
- RVI - vegetation structure (9)
- RVlv - vegetation structure (2)

### Q5. Which statistics did you look at?

- Mean (10)
- Median (3)
- Q1 - first quartile (0)
- Q3 - third quartile (1)
- Min (2)
- Max (2)

### Q6. Which spatial framework did you use? If you used both, how did they compare?

- HabMos (3)
- Habitat and Landcover 2020 (1)
- Both (6)

- Habitat and Land Cover Map 2020 displays greater resolution of SD differences observed across an area broken down with small grid, HabMoS however makes the end product map more generalised, with what appears to be an averaged SD result across a larger given area, which is maybe easier to interpret. Both useful.
- Needs a definition / description of both, i.e. why the Habitat and Land Cover map is pixelated. Therefore, prefer HabMoS.
- I preferred habmos as it makes more sense to me ecologically.
- Habitat and Land Cover Map had smaller polygons, which I think is useful for looking for finer scale change. HabMoS has quite larger polygons and I think I would be interested in detecting change within these polygons, relative to other areas within the polygon. For example, in response to spatially explicit management activities like ditch-blocking to raise the water table.
- HabMoS is perhaps easier to explore, but less spatially accurate in places, and exhibits temporal decorrelation for older polygons.
- HabMos seemed easier to understand for my limited trial.

**Q7. Can you give one or more examples of where the app correctly detected change?**

- Forsinard Flows (e.g. polygon 261): Mainly focussed on the 2019 fire extent at Forsinard, as it gives a nice opportunity to check the tool (hence it was included in the script). From experience on site, the rate of recovery (i.e., re-establishment of vegetation) was quite quick across the Forsinard-Strathy transect. Burning was not as severe as thought and a lot of vegetation started to grow later in the summer: reflected by the change in indices (NBR, RVI, etc.) and vegetation indices for example.
- Beinn Eighe (e.g. polygon 86): Monthly changes in plant productivity (NDVI) of *P. sylvestris* woodland as expected. But hard to compare this for same month over successive years.

**Q9. From looking at the change identified within one or more indices at a site you are familiar with, are there any instances of change that are identified that you find surprising? This could be a location where you yourself would have expected to see change, or where change is highlighted by the tool yet you are unaware of any physical change that has occurred on the site**

- Ben Lawers (HabMos, polygon 20249590): In 2021, water levels/NDMI different to what was expected. Thumbnails showed little useful detail and in some cases just showed an outline. Some of the habitats I tried to look up were not shown, eg sub-arctic willow scrub and tall herbs in HabMos, but maybe need to experiment some more.
- Beinn Eighe (HabMos, polygon 20001239): NBR in May 2021 showed change in burnt vegetation. To knowledge no burnt vegetation here.

**Q10. Which designated sites or geographic areas would you most like to see included in future iterations of the app, and why?**

- Creag Meagaidh is a great example due to the known success of high deer cull pressure and very visible tree regrowth on site, I think the resulting change is apparent in these maps. I think it would therefore be useful to include other sites which are currently adversely affected by deer and lack of tree regen, like Loch Lomond Woods SAC and SSSIs, or Flanders Moss which has active cull efforts, to examine if there are likewise changes to those sites over time (hopefully) as a result of management.
- Somewhere on the west coast such as Lochaber or Argyll.
- National Scenic Areas to help detect land cover change.
- From our perspective, all Scottish peatlands would be awesome to include as they will open up a vast amount of comparable sites to be assessed. We need to monitor our

sites pre- and post-restoration, and this could be an effective (additional) tool for achieving this.

- Ardlair - Letterewe SSSI, Fannich Hills SSSI & SAC. App should be useful to check for change for over any large site in Highland with upland features.
- Larger montane sites as time consuming and expensive to survey and riparian habitats - even in urban areas to pick up INNS
- Areas of peatland that have been restored in Scotland so we can see if we can detect change as a result of rewetting management activities. Peatland Action could help identify some suitable areas.
- Some of the larger peatland restoration sites, can the change in NDVI and/or NDWI on peatland restoration site be detected? Can the indices be used as to flag up restoration sites that need further investigation in the years post-restoration (i.e. the indices are changing in a way unexpected post restoration).
- wall-to-wall, with the ability to provide a custom area for computing statistics would be ideal for all possible users.
- Ben Lawers

**Q11. We aim to integrate data from field surveys into future iterations of the app. For example, this could consist of point data with attributes of survey date, survey method, habitat type, habitat condition and perhaps key species. What information would you like to see included?**

- Deer Count, Deer Cull, Woodland and Upland HIA, Weather data
- Link to NBN data? Grazing impact data? Protected area feature condition?
- none
- Peat depth and condition surveys (available)
- Herbivore Impact Assessments
- INNS spread
- Peatland Action peat depth and condition data (<https://cagmap.snh.gov.uk/natural-spaces/dataset.jsp?code=PEATACT-DEPTH>)
- Peatland ACTION database WMS
- all of the above. Perhaps paired with remote sensing interpretation on change through time?
- SCM

**Q11.2. How would you use it?**

- It would allow us to examine data sets in conjunction and better understand the cause and direction of changes detected
- To see if grazing impact affects the Indices, and thus indicator species and protected area condition?
- To use as references across sites.
- to compare changes in herbivore impacts to changes in vegetation structure and community.
- Monitoring INNS spread and targeting management
- Peatland habitat condition data useful to interpret differences in the indices.
- compare restoration work with indices
- inform land management practices
- Not sure yet!
- I think being able to detect changes on site with these maps is already incredibly useful with many applications on its own. However, I think it would be great if we could build on this and examine many data sets in parallel to better understand the circumstances which have led to that change. It would be great if there was a simple statistic which would report if the variation observed in one variable was significantly

linked with another. For example, there might be an expected negative correlation between deer population (declining population count surveys) and a significant change/increase in vegetation structure. The more data sets added the better understood the change is. I think this would benefit deer management and woodland restoration efforts particularly as they are often difficult to survey at the landscape scale needed. I think MET weather data might also be good for context. Variation in ambient temperatures and rainfall etc between years, and things like extreme weather events, could maybe cause observed changes. Other factors like topography and resulting hillshade might also explain different and disproportionate changes to productivity etc in some areas than others. Including average cloud cover might also allow the observer to determine how trustworthy map outputs are if the survey method is adversely affected by clouds.

- many INNS grow rapidly and spread rapidly, e.g. knotweed/ hogweed balsam, need to start control at the top of the catchment so the survey is essential, huge changes in vegetation so a distinctive signature.
- Peatland ACTION Data & Evidence team are currently working to produce WMS of (a selection of) the data held on the PA database. This will allow access by project staff to much more detailed spatially explicate information. If the indices data were similarly available, it would make interpretation of notable change in relation to peatland restoration easier. Layering up your data products to start to build a picture of evidence and interpretation.

#### **Q12. Is there anything else you would change about the app?**

- Annual graphs being displayed on the same axis as the default - to quickly at a glance understand the extent of change relatively between months and across years.
- Highlighting the direction of change would be useful, whether above or below the mean. "
- Getting started guide is great but the box above the text for each section does not have anything in it if you click on the Get Started at the start. However, once you have selected the data and THEN click on the Get started it obviously has content in it. This is a bit circular.
- Thumb nails did not load, I cancelled out of them and then they wouldn't load at all. Then said disconnected from server and reloaded. This happened several times especially with those sites with more than 1 thumb nail.
- Would be good to have some place names in ESRI world imagery as per the grey baselayer Stamen toner Lite.
- When I tried to change site from Abernethy to Beinn Eighe it wouldn't change and kept the Abernethy map up?
- Ability to enlarge map pane.
- Separate scroll bar for left hand pane.
- Linked information on habitat types.
- Interpretation of second from right pane.
- Legend for right hand pane.
- More information on how to interpret images.
- Much quicker image creation.
- Satellite images for entire site not just for polygons.
- Ability to create more than one index map for entire site to visually interpret satellite images between maps.
- There are a couple of key options that would make it better to use for monitoring:
  - make sure the plotted indices across the years have the same y-axis range(!);
  - allow for not using a spatial framework, but perhaps a hectare BNG grid as an alternative. This to capture any variation within pre-defined polygons, as is currently the case with the frameworks;

- allow for comparison across all or a subset of sites: the strength of this tool lies in the ability to compare for example habitat types across the NNRs and see whether particular sites show very different temporal dynamics compared to similar habitats elsewhere. Currently, significant deviations from the 'statistics' are based on the variation within the site. With insufficient spatial coverage of particular classes across an NNR, one could end up not capturing sufficient variation to properly assess the 'deviations' from the patterns across the site. I would highly recommend implementing this, even if it comes at the cost of processing speed, as this would be a very novel thing to do(!);
  - apart from mapping 1SD / 2SD, perhaps use a gradient to map actual deviation values as plotted in the graphs. This helps the user to identify areas of high deviation from the 'statistic' to investigate.
- I find it difficult to compare annual changes, e.g. compare vegetation productivity in May 2022 to all previous Mays. Is this just the way the plots are layed out? Looking at changes within a single year is less useful, as they are most likely just related to season.
  - Fixed shape of habitat classification polygons makes it difficult to monitor changes to the extent of particular habitats, or very localised changes within each polygon.
  - It would be useful to compare polygons that are not in the same class as these are not always defined correctly. I feel differences in polygons may often be related to environmental conditions (e.g. altitude, aspect), so if there was more control to compare polygons that are better matched this could be useful to help identify meaningful change.
  - Graph lines hard to interpret quickly
  - Better graph titles and quick info boxes on each graph explaining
  - Tune lines on graphs on and off
  - Scale bar on map
  - analysis a selection of multiple polygons or ability to draw a line across an area (multiple polygons) and see the indices change in that area.
  - adding standard deviations to the indices plots.
  - Creating the thumbnails is a bit clunky. Perhaps having the images as layers directly could be more helpful.
  - Need to experiment a bit more to be able to comment properly.

**Q13. The following ideas are being considered for future development of the app. Please comment on if/how this would help you in your work, and whether it is a high, medium, or low priority**

App feature	High	Medium	Low
Improved cloud masking	1	8	1
Inclusion of Very High-Resolution data	5	4	1
Inclusion of field data	3	5	2
Provide interpretation of observed changes	7	2	1



**Additional comments:**

- Development of these kind of tools often focusses on the actual data-to-product conversion and I support that kind of approach over trying to combine all sorts of different data types into one (i.e., field data). Especially, if this data can be exported and used in a GIS, then people can add their own supplementary data for their reporting and analysis, thus, low priority for you to focus on.
- Cloud masking algorithms are available, so shouldn't be too hard to implement, but, with the wealth of data available for this already, I do not see it as a high priority.
- Including of VHR data would be very interesting, as it will allow to properly assess the added benefit of these products in the long run. We (PA) are trying to acquire VHR data from MAXAR which I can see lining up with this tool for sure in the near to distant future.
- Automatic reporting (i.e., a PDF with the outputs) would be helpful to have, but only after some of the suggested changes are made.

**Q14. How likely are you to use this app in your work?**

- Very likely (2)
- Likely (2)
- Somewhat likely (6)
- Unlikely (0)

**Q15. How would or could you use this app in your work?**

- To understand the influence of management and observe if there has been change on site as a result.
- I would like to see how protected area feature condition was reflected in the app indices and vice versa, on a landscape scale.
- To identify land cover change over time helps with monitoring landscape change.
- We need to add more information in our monitoring for peatland restoration and this app can help better describe what's happening on site, especially with the temporal component in there.
- Very likely if relevant sites are covered, and any annual changes to vegetation are easily identified.
- Would have to see how well it could integrate - good to have it available in conjunction with other service (e.g. geoview) rather than having to go to a different application
- In its current format I think it is unlikely I would use it at work. If coverage was much wider and the available polygons were smaller and accompanied with high-resolution imagery to allow more fine-scale interpretation of changes, I think it could be useful for monitoring response of peatlands to restoration management.
- I am thinking from a Peatland ACTION project officer POV as I am not sure there have been any testing this tool, I have tried to come up with an example of how the indices could be used but of course I haven't actually gone out to the project officers to discuss its just some initial thoughts. Potential to use it as way to check in on a site post restoration each year and highlight areas where additional field visit to check out unexpected change. Difficult to know if the indices can do this on the scale PA are working at and of course the type of work might affect if it is useful. For example, heavily eroded sites may show change in NDVI (bare peat to vegetated peat) but would a change be detected on drained sites where the response to restoration is likely to be more subtle (alteration in plant community).
- quick exploration and looking for change areas.
- Not entirely sure yet

**Q16. Does your proposed use of the app reflect your current work or are there new applications that you would use the app for?**

- It would be great to incorporate into the upcoming SCM development
- This would be a new application (above)
- App could reflect current work if developed further. Identification of habitat change within a site could influence a wide variety of subsequent activity, e.g. site management and tailored monitoring.
- I see this tool being able to be used for land use change analysis in the long run.
- Yes
- Increased INNS surveillance
- My current work does not involve using satellite-derived indices, but I could see this being a new application if the tool was sufficiently user-friendly. At this point, I found it quite difficult to interpret the data, but this could be due to the limited time I had available for testing.
- These indices are not currently used by the project officers, additional support and training to enable speedy interpretation would be required.
- mostly the proposed one.
- Current work

**Q17. What would stop you from using this app?**

- Lack of additional/context information. Great at detecting change, I would love for it to go further and help us better understand the reasons for change.
- The thumb nail loading time and subsequent crash of the app.
- Requires changes, as suggested previously, especially image creation time interrupts flow of analysis.
- If new data is not added to the app for example.
- A lack of ability to clearly compare annual changes at specific sites.
- Familiarity an extra step or new system to get to know = time!
- Poor coverage of areas on interest, lack of available imagery due to cloud cover, my own lack of understanding about how best to use it.
- One barrier to using the app is that it is not integrated with the existing methods of working for Project officers, they currently use QGIS with WMS this allows them to layer up their datasets and build a picture of a restoration area for (mostly) planning restoration works.
- For my use case (more technical, using remote sensing imagery) the reduction in flexibility is a bit of a deal-breaker. Could be good for screening, but not deeper analysis. Also, maybe some brief explanations on the caveats of different indices is needed for non-earth-observation experts. Since many of these saturate, are prone to noise from outside factors or are incomplete descriptors of the biophysical characteristics they're proxying."
- Lack of time (as for this trial).

**Q18. How likely are you to recommend this app to others?**

- Very likely (2)
- Likely (4)
- Somewhat likely (3)
- Unlikely (1)

**Q19. Who else do you think would benefit from using this app?**

- Staff of many organisations who intimately know the sites and the issues for those sites.

- Aggregated analysis of land cover changes should inform land use policy makers, nationally and regionally.
- Universities and research institutes could benefit. Also, the other way around: open up the app/code for optimisations and upscaling through MSc/PhD projects.
- Area Officers involved in SCM and AECS
- Landowners and people leading restoration projects
- NatureScot colleagues

**Q20. What was the best thing about the app?**

- Easy to follow, simple presentation of data
- Easy to use, excellent Get Started, nice intro information, and most importantly shows data in a format that we haven't seen before which could be really useful for site management and assessment.
- Visual identification of potential land cover change. Really excellent potential in this app if developed further.
- The interface is great, but you need to know how to query a map and read a plot. Also processing speed is impressive!
- to filter by habitat type.
- Can't comment
- Being able to engage with satellite-derived indices through a relatively user-friendly tool
- Great to have the satellite products and some analysis right to hand.
- Quick way of finding outliers and areas which may need monitoring.
- It did what I expected

**Q21. What was the worst thing about the app?**

- Not being able to overlay data sets? Don't really consider anything to be bad.
- Crashing with the thumb nails.
- Image creation time, highly technical in appearance and needs more definitions and interpretation explanations.
- I wouldn't go as negative as 'the worst', but the non-matching y-axes is really, really putting me off and makes the app unreadable from time to time.
- Suggestion: having the yearly data on the bottom, horizontally.
- Open up the webpage: there's much more space to be used in the interface, to have a bigger map viewer for example. Data availability 'calendar' is nice to have but does not need to be that large for example.
- still limited output. Lack of ability to look at changes between years.
- Can't comment
- Difficulty interpreting what I was seeing. I wasn't clear exactly what the app was doing when I selected different years and months. I also wasn't clear how to interpret the standard deviations. Most polygons seemed to be 1 or 2 SD from the mean, does this mean those that were closer to the mean were not displayed?
- I found the graphs hard to interpret quickly but this depends on your end user, for example a user might access regularly in which case they'd be familiar with the graphs and getting what they need from it. A user who accesses only very occasionally would struggle each time.
- Loading times for impatient users. Also, the second panel from the right could be placed differently, or collapsible to leave more space for the trends.
- Seems that resolution of some images isn't very good, but maybe I wasn't using the correct parameters.

**Q22. Please let us know what you thought of each element of the app?**

App feature	Excellent	Good	Fair	Poor
'Walkthrough' of features launched by the Information button	4	3	2	1
Filters	2	7	1	0
Interactive map	1	8	1	0
Graphs	0	2	8	0
Thumbnails	1	4	4	1
Data download	1	6	2	1

**Suggestions for improvement**

- Graphs all on same axis by default and option to toggle others on and off
- As described previously.
- Clearer description of how the filters work would be useful. More control over the graphs, including displaying multiple years on the same graph and having the same scale on the Y axis between years.

**Q23. Are there any further comments you would like to make about the app or this project?**

- I think it is great and much needed. Great for landscape scale work and management. I think it would be great if was automated for passive monitoring and alerted/flagged when standard deviation is above a certain threshold to allow us to detect drastic changes to sites.
- I really like this app – it's moved on so much and looks to be particularly useful for those that are working on a site on the ground. Thank you so much for sharing it with us, looking forward to seeing it used more widely.
- The tool should not really be titled 'Landscape' monitoring tool as it monitors land cover only. Landscape monitoring requires all three natural, cultural and perceptual aspects to be considered. Therefore, suggest renaming tool to 'Land Cover' or 'Habitat' monitoring tool.
- Would be very happy to stay in touch on this to provide peatland-related feedback on the app.