

# ExActR: A Shiny app for creating ecosystem extent accounts

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## Abstract

Ecosystem accounting is a structured way to integrate nature into sustainable decision-making. The System of Environmental Economic Accounting-Ecosystem Accounting (SEEA-EA) was adopted by the United Nations as a set of international standards for the collection of habitat data and compiling ecosystem accounts. The ecosystem extent account is one of the four pillars of the SEEA-EA framework, where the spatial composition of an ecosystem accounting area is grouped by habitat types, and the land cover change over time is quantified. Here, we present *ExActR* (Extent Accounts in R), an open-source application for generating extent accounts using shapefiles, a geospatial vector data format. The app is built in R and the associated Shiny framework, which automatically updates as the user interacts with it. The application supports multiple timepoints, where extent accounts (tables) are generated for consecutive pairs of timepoints, accommodating users' needs for dynamic ecosystem assessments across several periods. Data visualisations are generated in the form of both interactive (leaflet) and static maps of each timepoint, and barplots to illustrate land type composition and change. A version of the app has been deployed (available at [https://gibbona1.shinyapps.io/extent\\_app/](https://gibbona1.shinyapps.io/extent_app/)), offering a space for interactive exploration of ecosystems. Shiny's reactivity, combined with JavaScript plugins for copying tables into multiple formats, including LaTeX and plots, make the application results suitable to insert directly into reports. The app is suitable for using with any spatial grouping variable. We test its functionality on small and large study sites on CORINE land cover data, as well as land cover maps generated using very-high resolution satellite imagery of a wind farm site in Ireland, during and post construction, demonstrating its ability to adapt to various land cover classification systems. The tool can be used to understand, visualise and track changes in ecosystem assets, aiding interpretation by both scientists and stakeholders.

**Keywords**— SEEA, Ecosystem Accounts, Ecosystem Extent, Land cover Change, Shiny App, R, Shapefiles, Geospatial Data, Data Visualization

## Introduction

Land cover maps document the area, configuration and category of what is physically present on the Earth's surface in an area of interest. They are useful for environmental monitoring, particularly as comparing two land cover maps of the same location over a period of time allows detection, quantification and monitoring of land cover change, a key driver of

biodiversity loss [13, 14, 16]. Loss of natural habitats due to anthropogenic land use change creates cascading effects that ultimately impact humans [4]. Climatic changes can also contribute to habitat degradation and loss, exacerbating its effects [15].

Studies documenting changes in land cover and land use are not new, but until recently there was no agreed standard framework to report them. In 2021, the United Nations (UN) approved the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA), the first step in providing an agreed and standardized methodology to report the extent, condition, and delivery of ecosystem services at the national, regional, and local scales [29]. A number of studies have since been published that use the system and many governments are starting to produce the accounts required [2, 10, 25]. The EU’s Corporate Sustainability Reporting Directive (CSRD) is another case study where ecosystem accounts are going to need to be produced quite rapidly, and often by non-experts, to measure organisations impact on ecosystems. The CSRD will require organisations, as soon as Jan 1<sup>st</sup> 2025, to disclose the risks climate change will have on them and the impacts their business can cause to both the climate and ecosystems.<sup>1</sup> The intended aim is that the accounts produced following the SEEA-EA will become a global standard for monitoring environmental change, including any effects upon the economy and, with regular updates, offer continuous insight into the the status and trends of ecosystems, as captured by their extent, condition, and provision of ecosystem services.

The first step in the SEEA-EA, upon which all subsequent steps are based, is the Extent Account. This account quantifies the extent (usually in hectares or km<sup>2</sup>) of each ecosystem type in a study area—called Ecosystem Accounting Area—at one point in time. When multiple time points are available, the SEEA-EA provides a consistent framework to present any changes, represented by tables and maps. The extent account of the SEEA-EA can serve as a template to follow, not only by studies producing accounts, but by any researcher interested in documenting changes in land cover over time. Several tools are available to measure land cover changes, such as GIS, EnSym, ARIES, and R/Python as well as Microsoft Excel for preparing tables and calculating changes in extent. However, each of those tools comes with specific limitations, notably that most software requires advanced technical expertise and that preparing the extent accounts can necessitate significant amounts of time. Further, most tools fail to make the operations repeatable, limiting reproducibility (we expand on this key point in the Discussion).

We introduce *ExActR*, an interactive shiny app to facilitate the generation of extent accounts and accompanying visualisations to streamline this process for spatial datasets. The app allows users to upload two or more sets of vectorised spatial data and calculate the increases and decreases in area according to a grouping variable of interest, e.g., habitat type. Some of the key features of the app are:

- The grouping variable is selected dynamically from the data loaded from each shapefile. These names can be different in each timepoint to help with situations where naming conventions change or the column names of interest are indexed in some way.
- While the majority of extent accounts are expected to just have two timepoints (an opening and closing map), it is possible to include multiple timepoints. With  $n$  time points, this generates  $n - 1$  extent accounts, with extent account  $i$  showing the difference from timepoint  $i - 1$  to  $i$ , for  $i \in 2, \dots, n$ . Note that the timepoints are assumed to be in chronological order.
- As well as the leaflet maps on the main page, the app provides a tab with an array of plot outputs to visualise changes in extent.
- Using both Shiny’s existing functionality and some JavaScript extensions, users can easily copy the table and plot outputs to their clipboard, or bulk export all outputs for the session.

The structure of our paper is as follows. We first provide the overall layout of the Shiny application, as well as a brief overview of the libraries used. We then demonstrate a step-by-step workflow of how the app is utilised for generating extent accounts and give more detail on the computational back-end. We provide three examples of extent accounts to

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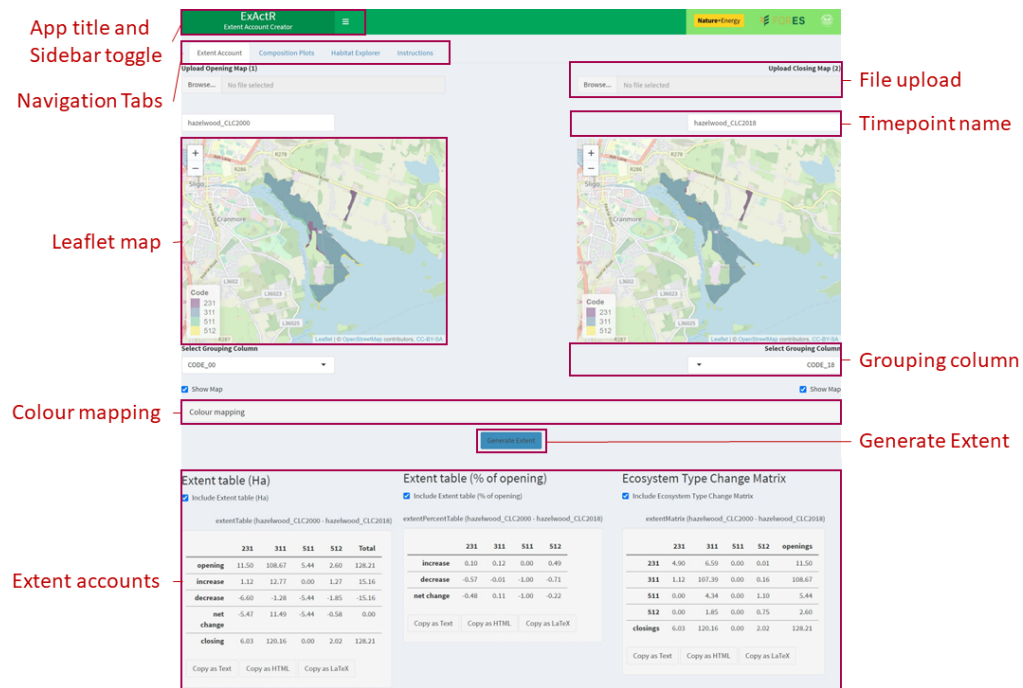
<sup>1</sup><https://seea.un.org/content/how-natural-capital-accounting-can-help-accelerate-finance-nature>

demonstrate features of the app and to show its flexibility when it comes to handling vectorised spatial data. We conclude with a discussion of how the app compares with other methods and plans for future work. Source code for the *ExActR* app, as well as a link to a working demo on an RStudio server, is available on GitHub at <https://github.com/gibbona1/ExActR>.

## Methods

### User Interface (UI)

The *ExActR* app (Fig. 1) was built in R [23,24] using the Shiny [6] framework. Shiny is itself a package in R. No knowledge of HTML, CSS, or JavaScript is necessary to build a simple application in Shiny, but small amounts were used here to enhance certain features. One of the many benefits of the Shiny framework is that end-users do not need any knowledge of R programming to interact with the data and produce accounts. Shiny has already been used in developing ecology-related apps and decision-support tools, such as in acoustic annotation of wildlife [12], species-habitat modeling [34], conservation management [21], forest structure assessment [27] and visualising macroalgal canopy photosynthesis levels [16].



**Fig 1. Main components of the *ExActR* App User Interface.** Each timepoint has a **File Upload** widget and a **Leaflet Map** displaying the spatial data. The **Timepoint Name** can be edited (the default is the shapefile name) and carried down to all outputs. The polygons in the data for each timepoint are coloured by a **Grouping Column**, which will later be used to generate extent. The **Extent accounts** (Main extent table, extent as a percent of opening area and ecosystem type change matrix) are a set of tables and the main desired output of the app. The tables in the diagram are placed side by side to save space but these are stacked vertically in the app, with different timepoints of each table type on the same horizontal if there are multiple. Most settings are contained in the **Sidebar** such as choosing the coordinate reference system, adding/deleting timepoints as well as downloading all outputs in bulk. Users can navigate to other **Tabs** to access other plots, tables and instructions.

*ExActR* makes use of several open-source R packages [1, 3, 5–7, 11, 17, 20, 22, 26, 28, 30–32, 35], of which the most notable are:

- *sf* - Simple features, standardised way to read and manipulate spatial vector data.
- *shinyBS* - This contains extra user-interface (UI) objects such as collapsible panels.
- *shinyjq* - Allows jQuery UI functionality, primarily used here for resizable plots.
- *shinydashboard* - Dashboard layout. Moving the less-used options to the sidebar reduces clutter in the Shiny app’s main body.
- *shinycssloaders* - Illustrates loading for some of the slower plot and table outputs.
- *leaflet* - Interactive visualisation of spatial datasets on maps.
- *viridis* - default colour palette for plots.
- *colourpicker* - choosing colours for the map and plot outputs.
- *ggplot2* - Graphics library for bar charts (`geom_bar`) and sf objects (`geom_sf`).
- *magick* and *xfun* - keep these dimensions of resized images on exporting.
- *dplyr* - data and string manipulation, respectively. Part of tidyverse.
- *xtable* - formatting tables as L<sup>A</sup>T<sub>E</sub>X and HTML when exported.

## Workflow and computation details

Upon opening the app, users are presented with two upload widgets for map data, with a blank map window under each. Once the spatial data are uploaded, the interactive leaflet maps will be rendered for each. The extent tables below this are similarly hidden until they have data to work on. The **Composition Plots** and **Habitat Explorer** tabs remain blank until data are uploaded and accounts are generated.

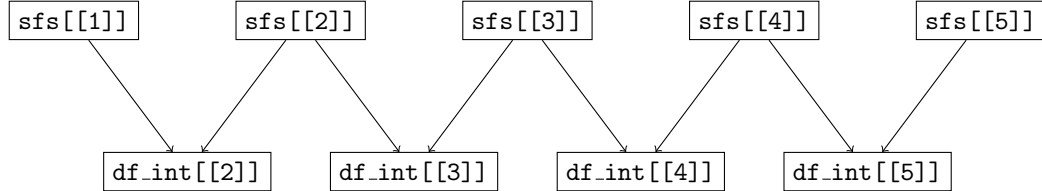
The standard use of the app to generate extent accounts is as follows:

1. Upload opening files (requires `.shp`, `.dbf`, `.shx` and `.prj` files uploaded together or in a `.zip` file, or a `.geojson` file). Repeat with closing files. For multiple timepoints, use the sidebar button to add more and upload them in chronological order.
2. Select grouping variable, e.g. habitat classification system, for each time point. These do not have to be the the same name, but should be some ecosystem type to compare areas between time points.
3. The colours for each unique value in the list of combined grouping variable values can be (optionally) edited using the colour pickers in the Colour Mapping Panel.
4. Click **Generate Extent**. This is included to stop the accounts from generating for some overly large grouping variables before the user is ready.
5. Wait for and inspect extent table and plot outputs, then copy or export as desired.

The Shiny framework employs reactive programming, allowing user changes in the interface inputs to automatically impact related outputs. This creates a seamless experience for users, as the app updates without the need for manual refreshes when settings are modified. Specifically, generating the Ecosystem Type Change Matrix represents the app’s most demanding computational task as it involves intersecting two (possibly large) spatial objects and investigating changed and unchanged regions. Ensuring that this matrix does not refresh with every unrelated input change is crucial for a fluid user experience. The app’s back-end features modular code to separate dependencies (user inputs) that influence the interface’s outputs. Further details on generating this Ecosystem Type Change Matrix are provided below.

1. Uploaded `sf` objects are read in to `sfs[[i]]` for each timepoint  $i$ . `sfs` itself is a list.
2. Each timepoint  $i$  uses a grouping variable  $G_i$  (a column of `sfs[[i]]`) which is used for comparison across timepoints. Their unique values form a list  $G$  for a consistent plot colour map.

3. The spatial dataframes `sfs[[i-1]]` and `sfs[[i]]` are intersected using `sf::st_intersection` to create `df_int[[i]]`, for  $2 \leq i \leq n$  (see Fig. 2).
4. The opening-closing pairs  $(g, g')$  of all combinations of values from  $G$  are then analysed. `df_int[[i]]` is filtered to just those polygons where  $G_{i-1} = g$  and  $G_i = g'$ . The  $(g, g')$  entry of the matrix is the total area of these polygons (see Fig. 3).



**Fig 2. Creating sf intersection object.** The intersection of maps from two consecutive timepoints takes the same index as the later timepoint,  $i$ .

	$g_1$	$g_2$	$\dots$	$g_n$	Openings
$g_1$	$A[g_1, g_1]$	$A[g_1, g_2]$	$\dots$	$A[g_1, g_n]$	$A[g_1, \cdot]$
$g_2$	$A[g_2, g_1]$	$A[g_2, g_2]$	$\dots$	$A[g_2, g_n]$	$A[g_2, \cdot]$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
$g_n$	$A[g_n, g_1]$	$A[g_n, g_2]$	$\dots$	$A[g_n, g_n]$	$A[g_n, \cdot]$
Closings	$A[\cdot, g_1]$	$A[\cdot, g_2]$	$\dots$	$A[\cdot, g_n]$	Total Area

**Fig 3. Ecosystem Type Change (Extent) Matrix diagram.** For each pair  $(g, g')$  of opening and closing group values respectively the entry  $A[g, g']$  in row  $g$  and column  $g'$  is the change in area from  $g$  in opening to  $g'$  in closing. The diagonal values  $A[g, g]$  are the amounts unchanged for that group. Each row is the unchanged areas plus the reduction in area in that group. Each column is the unchanged areas plus the additions in area to that group. The sum of a row  $g$ ,  $A[g, \cdot]$  will equal the opening extent for that group. Similarly, the sum of a column  $g$ ,  $A[\cdot, g]$  will equal its closing extent. The sum of all openings should equal the sum of all closings, i.e. the total area of the site common to both timepoints.

The extent account with opening, additions, deletions and net change are calculated from the Ecosystem Type Change Matrix this way. The table with extent as a percentage of opening value is then calculated. The values default to zero when the opening value for a group is zero.

## Case Studies

### Hazelwood (2000-2018, 2 timepoints)

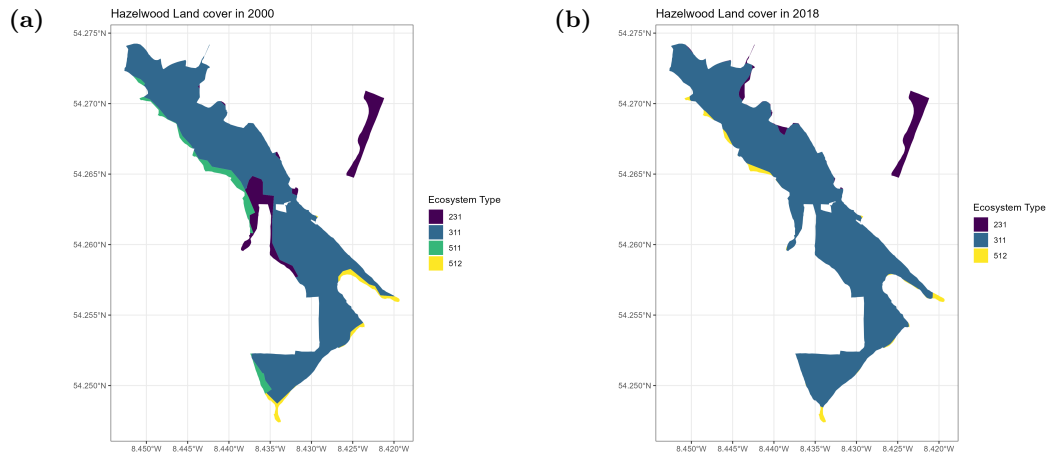
The Hazelwood Demesne is located along the western shore of Lough Gill, Co. Sligo, Ireland<sup>2</sup>. This is a small site with an area of 128 Ha, of which approximately 100 Ha is protected under the Natura 2000 framework<sup>3</sup>. A landcover summary, using CORINE land cover classification, is shown below in Table 1, with corresponding maps in Fig. 4. Table 2 shows the extent accounts for the period.

<sup>2</sup><https://www.coillte.ie/coillte-nature/ourprojects/restoringhazelwood/>

<sup>3</sup><https://www.eea.europa.eu/themes/biodiversity/natura-2000>

(a)	Code	Area (Ha)	% Coverage	(b)	Code	Area (Ha)	% Coverage
	231	11.50	0.09		231	6.03	0.05
	311	108.67	0.85		311	120.16	0.94
	511	5.44	0.04		511	0.00	0.00
	512	2.60	0.02		512	2.02	0.02

**Table 1. Hazelwood Land cover in (a) 2000 and (b) 2018.** This shows the broadest view of land cover change between the two timepoints. We can see that all land cover types changed somewhat from (a) to (b), with all types decreasing except for code 311 (*broad-leaved forest*) which increased during the period. The most notable change is code 511 (*water courses*) which has decreased from 5.44 Ha in 2000 (a) to zero Ha in 2018 (b). Without further analysis, we cannot conclude that all of this area converted to code 311 simply because it is the only land cover type with a (net) increase in area.



**Fig 4. Hazelwood Land Cover Maps.** The left (a) and right (b) plots show land cover at opening and closing respectively, coloured by CORINE Land Cover code. This smaller site has easily identifiable changes in habitat type of some polygons between opening and closing. A large portion of the habitat has remained unchanged. Code 511 (*water courses*) is present on the west side of the opening map is not present at all in the closing map. Both opening and closing are dominated by code 311 (*broad-leaved forest*). Code 231 (*pastures*), and code 512 (*water bodies*) are also present. A full collection of plot outputs for Hazelwood is available in Supplemental Information.

### Dargle (2000-2018, 4 timepoints)

The Dargle catchment area<sup>4</sup> is situated in the southern suburbs of Dublin City and northern County Wicklow in Ireland and is defined by the boundaries prescribed under the Water Framework Directive<sup>5</sup>. The Dargle catchment, covering 17,866 hectares, is ecologically rich, encompassing habitats listed under Annex I of the EU Habitats Directive which cover approximately 25% of the catchment area<sup>6</sup>. It also exhibits a significant presence of Natura 2000 sites. Extent accounts were built for Dargle in [10]. Fig. 5 shows some of the plot outputs generated by ExactR while generating the extent accounts. The table outputs themselves are not shown due to size limitations on what can be shown legibly, but are available in Supplemental Information.

<sup>4</sup><https://wicklowrivers.ie/rivers/dargle-catchment/>

<sup>5</sup><https://water.europa.eu/freshwater/europe-freshwater/water-framework-directive>

<sup>6</sup><https://www.npws.ie/legislation/eu-directives/habitats-directive>

(a) Ecosystem Type Change Matrix

	231	311	511	512	openings
231	4.90	6.59	0.00	0.01	11.50
311	1.12	107.39	0.00	0.16	108.67
511	0.00	4.34	0.00	1.10	5.44
512	0.00	1.85	0.00	0.75	2.60
closings	6.03	120.16	0.00	2.02	128.21

(b) Extent Table

	231	311	511	512	Total
opening	11.50	108.67	5.44	2.60	128.21
increase	1.12	12.77	0.00	1.27	15.16
decrease	-6.60	-1.28	-5.44	-1.85	-15.16
net change	-5.47	11.49	-5.44	-0.58	0.00
closing	6.03	120.16	0.00	2.02	128.21

(c) Extent Percent Table

	231	311	511	512
increase	0.10	0.12	0.00	0.49
decrease	-0.57	-0.01	-1.00	-0.71
net change	-0.48	0.11	-1.00	-0.22

**Table 2. Hazelwood Extent Account from 2000 to 2018.** This collection of tables make up the Ecosystem Extent Account itself. The codes in the margins of each table are CORINE Habitat Classifications. The Ecosystem Type Change Matrix (a) shows the changes in each habitat type from opening to closing. The Extent Table (b) is the main component of the account and provides more compact information on the changes in land cover for each ecosystem type. The Extent Percent Table (c) takes a selection of the rows from (b) and expresses them as a proportion of opening values for each ecosystem type. Values for (a) and (b) are in hectares. These tables correspond with the figures shown above in Fig. 4. Examining the change in code *511* (*water courses*), we can see from both the tables (b) and (c) that it has decreased completely to zero by closing (2018). As discussed in Table 1 however, we can see from looking at the *511* row of the matrix (a) that 4.34 Ha changed to *311* (*broad-leaved forest*) and 1.10 Ha changed to *512* (*water bodies*). The matrix therefore gives a more granular picture than the net change in each land cover type during the period.

## Meenadreen (2016-2022, 2 timepoints)

Meenadreen is an onshore wind farm located in Leghowney, South Donegal, Ireland. The wind farm consists of 38 Nordex N90 2.5 MW turbines with a total capacity of 95 MW. It was constructed in 2016 and has been operational since 2017. It is one of Ireland’s largest wind farms both in terms of energy production and size, having an area of over 800 Ha.

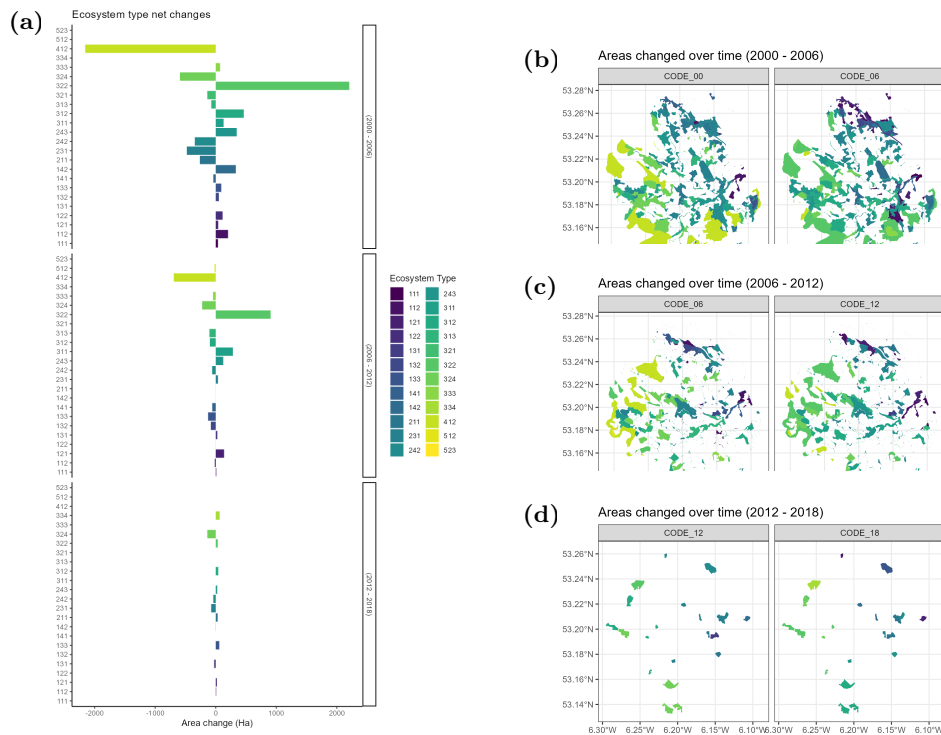
Data for this study came from the Nature+Energy [19] project, a collaboration between academic researchers and industry partners that aims to measure and enhance biodiversity at onshore wind farms throughout Ireland. Meenadreen was selected due to it being relatively young, meaning we could obtain satellite imagery for early (2016) and post (2022) construction of the wind farm. A segmentation model was used on the GeoTIFF images to classify areas into one of nine habitat types: Artificial (e.g., roads, buildings, turbine hardstands), Conifer, Heathland, Hedgerow, Pasture, Scrub, Semi-Natural Grassland, Shadow (unidentifiable areas) and Water.

Due to the resolution of the image ( $0.5 \text{ m}^2$ ) being too high for the app to process for  $25 \text{ km}^2$ , we selected a  $500 \text{ m} \times 500 \text{ m}$  square at the centre of the site, representing  $\sim 1\%$  of the total area covered by the satellite image, as a sample. See Fig. 6 for the selected area at each timepoint and some of the visual results generated by the app. The extent account for Meenadreen is available in Supplemental Information.

## Discussion

The *ExActR* app allows users to upload two or more geospatial vector datasets and generate ecosystem extent accounts, quantifying land cover change over time. These accounts offer insights into the state and dynamics of focal environments, aligning with conservation efforts. They are the first step in many Ecosystem Accounting pipelines, including the SEEA-EA.

The app allows extent accounts to be easily implemented and reproduced, and the



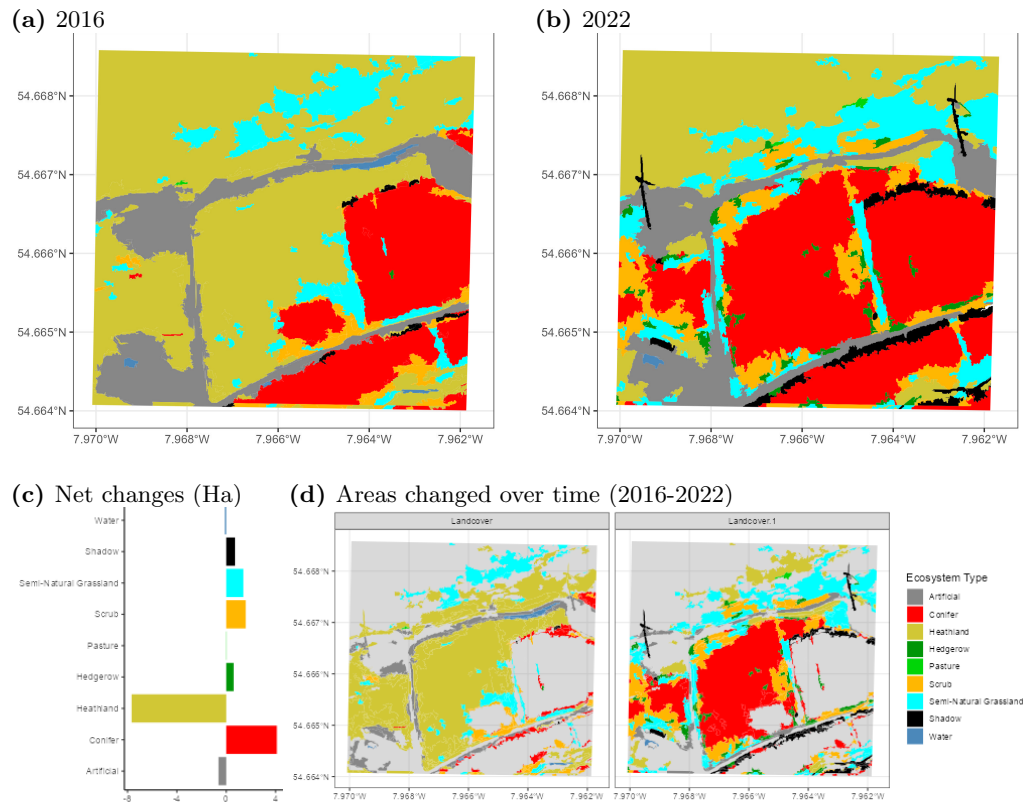
**Fig 5. Dargle plot outputs.** The polygons are coloured by CORINE Land Cover code. Some of the differences are more apparent than others, for example the reduction in code 412 (*Peat bogs*) between 2000 and 2006 is much more stark than any change present in code 111 (*Continuous urban fabric*) during the same period. The net changes in each ecosystem type can be clearly assessed using the bar charts in (a), where the overall magnitude of changes seems to reduce with each successive account. Given that the opening and closing maps have the same boundary, the sum of all increases and decreases for each account should be zero. The side-by-side plots (b)-(d) show the changed polygons each at opening and closing for each pair of consecutive timepoints. It agrees with (a) in that the magnitude of total area changed is much larger in the first account than the third. Additional outputs for Dargle are available in the supplemental material.

reactive elements in the Shiny framework make any changes made automatically carry down to the connected outputs. Results can be exported in bulk for use in reporting. Together, these features comprise a significant advance on existing tools. For example, GIS workflows offer little reproducibility and require a lot of repetitive manual work. Similarly, Microsoft Excel work is cumbersome and would require one of the other tools to work with spatial data. The EnSym tool, which was used previously for similar work [10], is now available at Data4Nature<sup>7</sup>. However it is not freely accessible. Using R or Python requires familiarity with programming and having a suitable Integrated Development Environment (IDE), an obstacle likely most common among practitioners that may lack the necessary skills [33]. ARIES<sup>8</sup> is perhaps the most valuable resource currently available that does not require other software and is aligned with the SEEA-EA. However, ARIES does not allow users to upload spatial data/polygons of specific boundaries, which is often needed to researchers or practitioners working on specific sites, mostly at small spatial scales. Furthermore, ARIES uses the IUCN Ecosystem Typology classification [18] and does not allow as much flexibility

<sup>7</sup><https://www.data4nature.com.au>

<sup>8</sup><https://aries.integratedmodelling.org/aries-for-seea-explorer/>





**Fig 6. Meenadreen plot outputs.** Artificial (roads) narrowed after construction, replaced with or returned to primarily heathland, scrub and semi-natural grassland. Hedgerow and Pasture which both had only 0.01 Ha in opening now had 0.61 and 0.03 Ha respectively in closing. Shadow also increased significantly, as evidenced by the shadows cast by the two wind turbines found in this site as well as shadows from conifer, and so the true habitat underneath is unclear. A large conifer plantation in centre of the closing map, replacing primarily heathland, is the most obvious change between the two timepoints. Artificial, Heathland and Water all experienced a net decrease.

with other typologies of ecosystem types. This last aspect is especially relevant to users who may be interested in using other classifications, such as the CORINE used here or others available for example at a national level. *ExActR* complements the options currently available by providing the following advantages: it can be used without any knowledge of R, GIS, or any other software or programming language; it accommodates different land cover classifications; the code is open-source and can be adapted or modified by skilled users who may be interested in adjusting some of the features to meet their specific goals.

*ExActR* has some size limitations in terms of the size of spatial data it can handle. The CORINE maps for the entire country of Ireland could be loaded in about a minute, but calculating the extent change (by intersecting the two maps) could not be computed in a reasonable amount of time. Likewise, it took 3 minutes to load 25 km<sup>2</sup> land cover maps derived from very-high resolution imagery (0.5 m<sup>2</sup> pixels) and timed out while calculating extent change, highlighting that the minimum mapping area and total area of the map are key factors in the performance of the app. More work needs to be done, using RCpp or similar, to speed up the process and allow extent accounts for entire countries or even larger areas like Europe to be computed feasibly. However, the use of ecosystem accounts is

expanding fast and it is expected to be adopted more also from private businesses [8], which typically operate at small spatial scales. Future development work could also involve expanding support for other file types such as KML, which was developed for Google Earth, as well GeoTIFF, which stores the data in raster format.

The *ExActR* app generates ecosystem extent accounts which, while useful by themselves, are only one part of Ecosystem Accounting. Future work involving the other three ecosystem accounts in the SEEA-EA framework—condition accounts, ecosystem services flow accounts, and monetary ecosystem asset accounts—will help to offer a complete Ecosystem Accounting package for a range of users—ecology practitioners, people working on building accounts at local scales, as well as researchers interested in land cover dynamics.

## Author Contributions

AG, FM, CW conceived the ideas and designed methodology; AG led the software development; FM, CW, EK tested the app; FM, CW, EK collected the data; AG, FM, CW analysed the data; AG, FM led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

## Acknowledgements

We extend our gratitude to Coillte, Ireland’s semi-state forestry company, for granting us access to their Hazelwood site via the Coillte Web Viewer App. This dataset was most often used in early development of the app.

We would also like to thank Energia for allowing us the use of data from Meenadreen. This publication is an output of the Nature+Energy Project, funded by Science Foundation Ireland (12/RC/2302.P2), industry partners and MaREI, the SFI Research Centre for Energy, Climate and Marine Research and Innovation.

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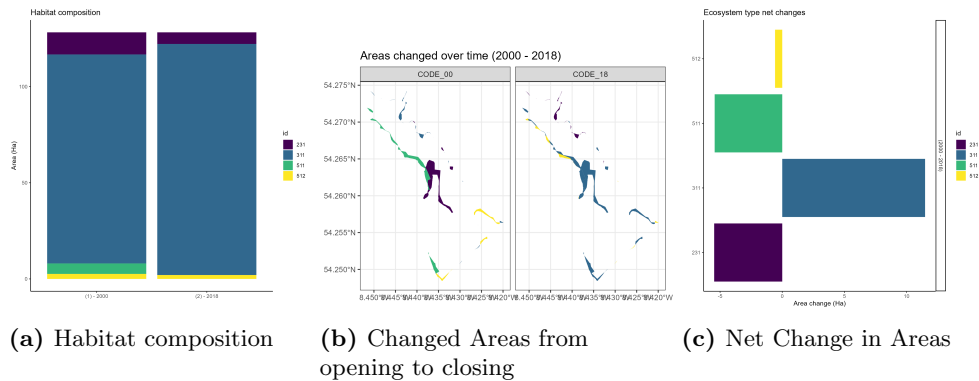
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## A Supplemental Information

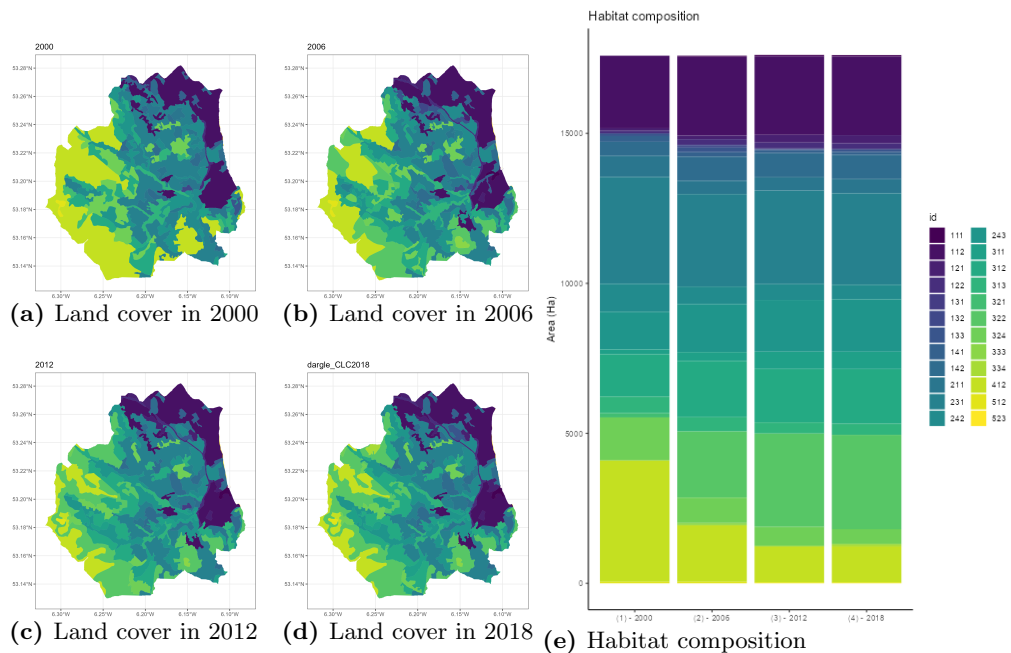
### Accessing Data

CORINE data are made available by the European Union through the Copernicus Service [9]. As for the boundaries of Hazelwood, the spatial data are available from Coillte<sup>9</sup>; however, you must have an ArcGis account to download the data. For the Dargle catchment, the boundaries can be accessed at the EPA Geoportal<sup>10</sup> by navigating to *Water / Water Framework Directive → General information → Catchments Data Package - June 2022*.

To view the collection of *ExActR* outputs for the sites used in the Case Studies, the comparison of Dargle's output with the previously-published accounts, and the spatial data for Meenadreen, these are all available at [https://github.com/gibbona1/extent\\_app\\_data](https://github.com/gibbona1/extent_app_data). Below is a selection of the plots and tables generated.



**Fig 7. Additional plot outputs for Hazelwood.**



**Fig 8. Additional Dargle plot outputs.**

<sup>9</sup><https://coillte.maps.arcgis.com/apps/webappviewer/index.html?id=7b05ec6a44a14bd8b523ea1fcb78b4e9>

<sup>10</sup><https://gis.epa.ie/GetData/Download>

(a) Ecosystem Type Change Matrix

	Artificial	Conifer	Heathland	Hedgerow	Pasture	Scrub	Semi-Natural Grassland	Shadow	Water	openings
Artificial	2.41	0.07	0.48	0.09	0.00	0.13	0.39	0.21	0.02	3.79
Conifer	0.02	4.49	0.02	0.06	0.00	0.10	0.10	0.24	0.00	5.03
Heathland	0.65	3.99	5.50	0.29	0.00	1.68	2.22	0.21	0.00	14.54
Hedgerow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Scrub	0.07	0.25	0.05	0.07	0.00	0.25	0.05	0.06	0.00	0.80
Semi-Natural Grassland	0.01	0.32	0.74	0.08	0.03	0.20	0.71	0.00	0.00	2.09
Shadow	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.09	0.00	0.11
Water	0.00	0.01	0.07	0.01	0.00	0.01	0.00	0.02	0.02	0.14
closings	3.17	9.13	6.86	0.61	0.03	2.38	3.48	0.82	0.03	26.51

(b) Extent Table

	Artificial	Conifer	Heathland	Hedgerow	Pasture	Scrub	Semi-Natural Grassland	Shadow	Water	Total
opening	3.79	5.03	14.54	0.01	0.01	0.80	2.09	0.11	0.14	26.51
increase	0.76	4.64	1.37	0.61	0.03	2.13	2.76	0.73	0.02	13.04
decrease	-1.38	-0.54	-9.04	-0.00	-0.01	-0.55	-1.37	-0.01	-0.13	-13.04
net change	-0.63	4.10	-7.67	0.60	0.02	1.58	1.39	0.71	-0.11	0.00
closing	3.17	9.13	6.86	0.61	0.03	2.38	3.48	0.82	0.03	26.51

(c) Extent Percent Table

	Artificial	Conifer	Heathland	Hedgerow	Pasture	Scrub	Semi-Natural Grassland	Shadow	Water
increase	0.20	0.92	0.09	119.78	5.03	2.65	1.32	6.83	0.12
decrease	-0.36	-0.11	-0.62	-0.65	-1.00	-0.69	-0.66	-0.13	-0.90
net change	-0.16	0.82	-0.53	119.13	4.03	1.96	0.66	6.69	-0.77

**Table 3. Meenadreen Extent Account from 2016 to 2022.**