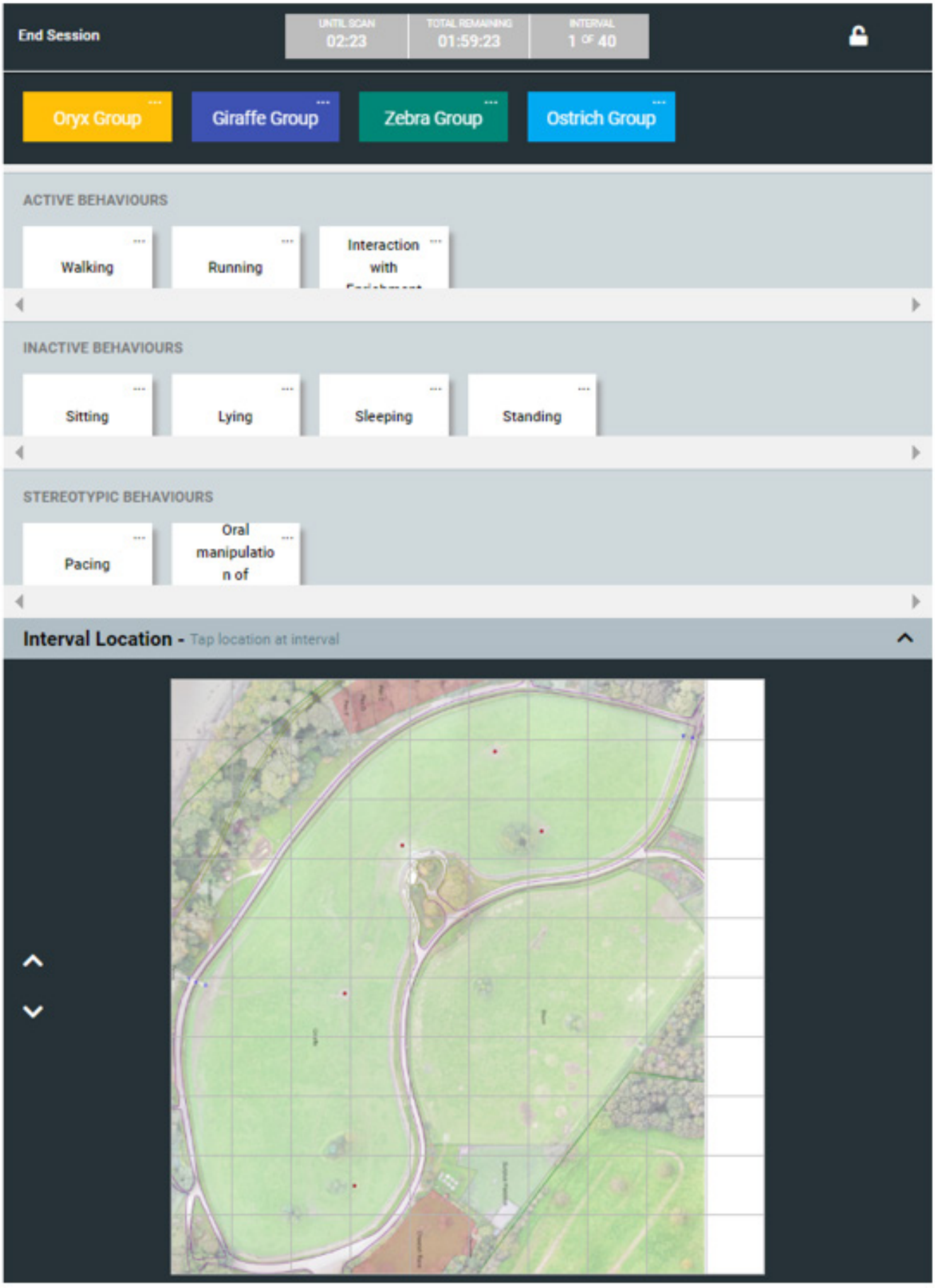

Supplementary Figure 1. Screenshot of the ZooMonitor software used for collecting data displaying some of the behaviours of the ethogram and the map of Fota paddock used for data collection. Map images were provided by Fota Wildlife Park for this purpose.

Supplementary information: Step-by-step translation process

The first step to translating this dataset is to estimate the coverage of the ZooMonitor 600 x 600 grid that is relevant to the image used. Each image takes up a different coverage depending on its size and shape. In this case, the estimated coverage was 540 x 600 pixels as the final column is not covered by the image (Appendix 1). Depending on the level of accuracy required for a project, this estimate can be calculated to a much more accurate degree by overlaying a grid of 600 x 600 to count exactly how many pixels are left uncovered by the map image. Another option is to upload the chosen image into image editing software such as Microsoft paint and editing the background to be exactly 600 x 600 pixels. This will place your chosen image on a white background with the exact scale that ZooMonitor uses. This image can then be saved and uploaded to ZooMonitor, removing the uncertainty of what coverage the chosen image has.

Next, in the QGIS software, load a new project and open your preferred satellite map layer. For this project the layer used was Google Maps. All projections were carried out in WCS84 EPSG2157 as this is the projection of the Irish Transverse Mercator, potentially leading it to be more accurate at a finer scale than a worldwide projection. Choose a projection that suits your data best, simply ensure to use the same projections throughout the translation process for all steps. Projection systems are calculated alterations to allow two-dimensional mapping processes to a three-dimensional base such as the globe. Using an appropriate projection system allows GIS software to correct for the curvature of the Earth and ensure more accurate analyses (Kumar et al. 2023).

The third step to translating the coordinates is to georeference the exact same image used in ZooMonitor onto the satellite map layer. To do this, open the "Georeferencer" tool under the "Layers" menu. By opening the chosen image in QGIS, it can be georeferenced to its known location in the real world by selecting points on the image and giving QGIS the location of the exact same location on the satellite layer. This step overlays the image used for data collection on a layer with known coordinates.

From here, the length and width of the image must be measured. This can be done using the measuring tool in the toolbar ribbon at the top of the screen. Measure the length and width as accurately as possible. The measuring tool provides options for measuring in both linear and cartesian formats, the difference between these two options relate to the curvature of the Earth and the necessary adjustments that must be made when measuring large distances (Holloway 2023; Kumar et al. 2023). For the purposes of this study and the majority of studies focusing on standard enclosure size ranges in zoos, measuring with the linear option is sufficiently accurate.

Take the measurements of the length and width and divide them by the number of pixels estimated for each respectively. This provides an important value for the next step which is creating a point grid over the georeferenced image using the create grid tool. For example, the values for the Fota Wildlife Park grid were 0.643 m for the horizontal spacing and 0.649 m for vertical spacing. The Dublin Zoo grid used 0.373 m for the horizontal spacing and 0.372 m for vertical spacing.

Search for the "Create Grid" tool in the lower left search bar. In the options for the tool, ensure grid type is set as point. For grid extent, go to the other options and select draw on map canvas, this will open a window allowing you to draw a rectangle on the project you are working on currently (Appendix 3). Draw a large rectangle over the image of the enclosure, allow plenty of extra space on all sides since this grid will be cut to size in the following steps. For horizontal spacing, enter the value calculated when dividing the measured length of the enclosure by the number of estimated pixels in the ZooMonitor grid. Make sure to pay attention to units to ensure the calculated value entered is in the same units as the settings of the tool. Fill in the vertical value similarly for the measurements of the enclosure width.

With a grid created that overlays the enclosure image, return to the measuring tool. Right click and select the measure angle option. Measure the angle between the edge of the enclosure and the edge of the grid, this will be used to rotate the grid to match the same orientation as the image. When measuring the angle, consider that the next tool will rotate the grid clockwise. Ensure that the angle entered into QGIS will align the lengths of both the new grid and the georeferenced image. Avoid aligning the length of the grid to the width of the image as this will result in a grid with incorrect point distances. An easy way to visually assure this is to make the grid very clearly rectangular and therefore easily recognisable if over or under rotated.

On the list of layers on the left of the screen, select the created grid and right click, click on toggle editing to allow changes to be made to this layer. Search for the "Rotate" tool in the search bar. Enter the measured angle and rotate the grid. After this process is completed, the grid may have moved. Use the "Move Feature" tool in the "Advanced Digitizing Toolbar" to drag the grid back into position, covering the enclosure.

Then, clip the grid to match the size of the image used in ZooMonitor. For this, a new shapefile must be created. Go to the Layer menu, select "Create new shapefile" and set the type as polygon. Add the points to the shapefile that will create an outline of the georeferenced image.

Go to the "Raster" menu, then the "Extraction" sub-menu and select "Clip raster by extent". For this tool, the input layer will be the grid file, and the clipping extent will be the newly created shapefile. To select the shapefile, look under other options for the option to "Calculate from layer", which will allow the new polygon layer to be selected.

This will create a grid that is orientated correctly and matches the enclosure image exactly in size. To check the accuracy of this grid, go to the layer on the left of the screen, right click and ensure "Show feature count" is turned on. This will display the number of points that the grid layer contains. This can be compared to the estimated number of pixels from the first step. The maximum possible number of points should not exceed 360,000.

At this point, editing and restarting certain steps such as grid creation and rotation may be necessary to increase the accuracy of the final product depending on the required level of accuracy.

Once the to-size grid reaches satisfactory accuracy, the ZooMonitor data can be added matching the new grid coordinate system that has just been created. Open the layer properties by right clicking on the layer and go to the "Fields" sub-menu to show the attribute table. This provides the metadata for the grid. In the tool ribbon, select the "Field Calculator" This tool creates and edits new metadata on the attribute table. Create three new columns entitled, X-Coordinate, Y-Coordinate and ZooMonitor XY Reference. The first two columns can be automatically filled with the longitude and latitude of the respective points by the field calculator.

To fill the final column, select the top left corner point on the grid only. At the bottom left of the attribute table, filter to "Show Selected Features". This should filter out all, but one row. In the remaining row, fill in the ZooMonitor XY Reference as 1, 1. Do the same for the other three corner points with the respective point coordinates pertaining to the size of the current grid being worked on, in the example provided these are 1, 540; 600, 1; 600, 540.

This grid is now ready to be exported. Right click on the layer in the layer window and export the file as a .xlsx file. Open the new

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file. However, the first thing that may be required is saving this file in a different format so that changes to it are saved. Go to "Save as" and save the file again in a .csv format. In the new working file, create two new columns and label them as ZooMonitor X Reference and ZooMonitor Y Reference respectively. These columns will be filled using the four corner points as reference.

To do so can be done manually, or with a combination of Excel functions and shortcuts. A suggestion for filling in repeated lists of numbers is to use a combination of the Quotient and Sequence formulae as follows.

=QUOTIENT(SEQUENCE(A x D,1,0,1),A) x C + B

Repeat	Start
A	B
Step	Stop
C	D

Once these two columns are filled, merge their values into the column previously created in the attribute table "ZooMonitor XY Reference". To do so, use the formula, =A1&", "&B1, where A1 is the first value of ZooMonitor X Reference and B1 is the first value of ZooMonitor Y Reference.

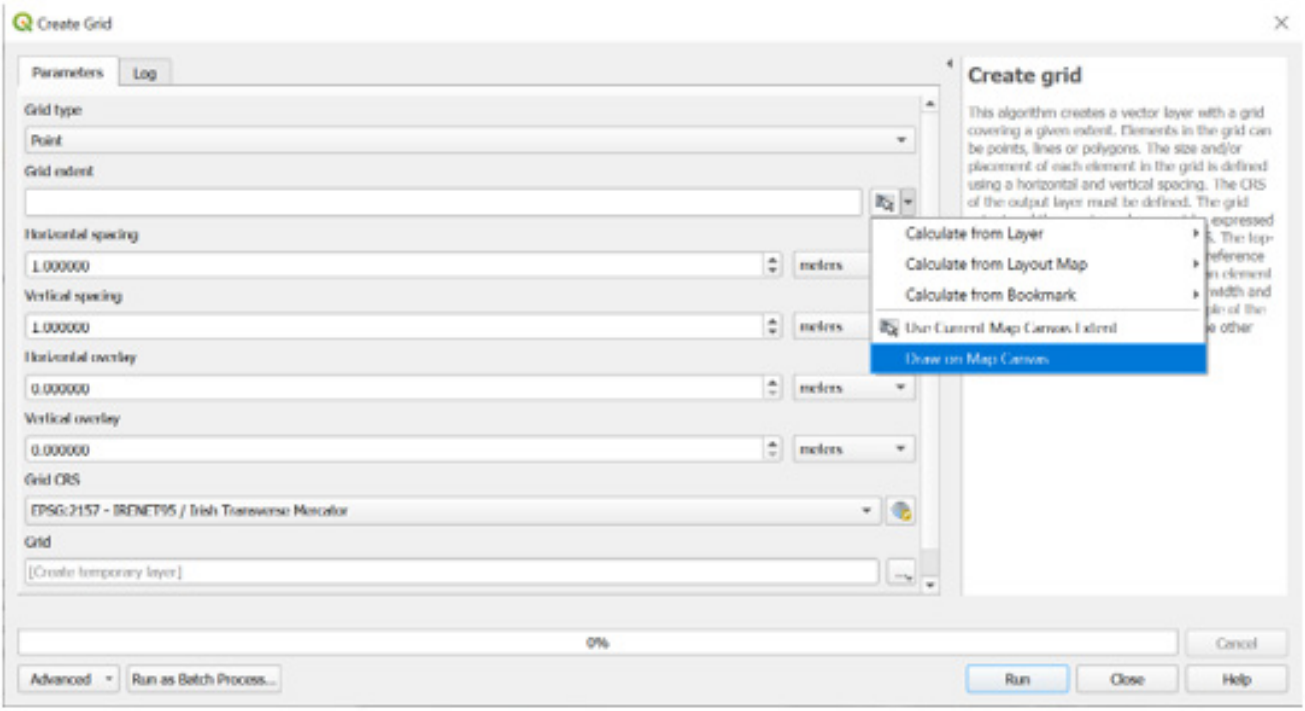
This excel file can now be used to extract latitude and longitude for any spatial data collected in ZooMonitor using this enclosure image. Be warned, if the image in use is changed and does not have the exact same coverage and dimensions, the created excel file will not produce accurate data and the process will need to be repeated to create a new reference file.

Finally, to extract the latitude and longitude from ZooMonitor data, export the data file from ZooMonitor. This file again, may need to be changed in format to allow any changes to be made, see previous instructions on this. Copy and paste the XY Coordinate column from the ZooMonitor file into your new reference file. Use the paste values option to avoid any issues with the formulae.

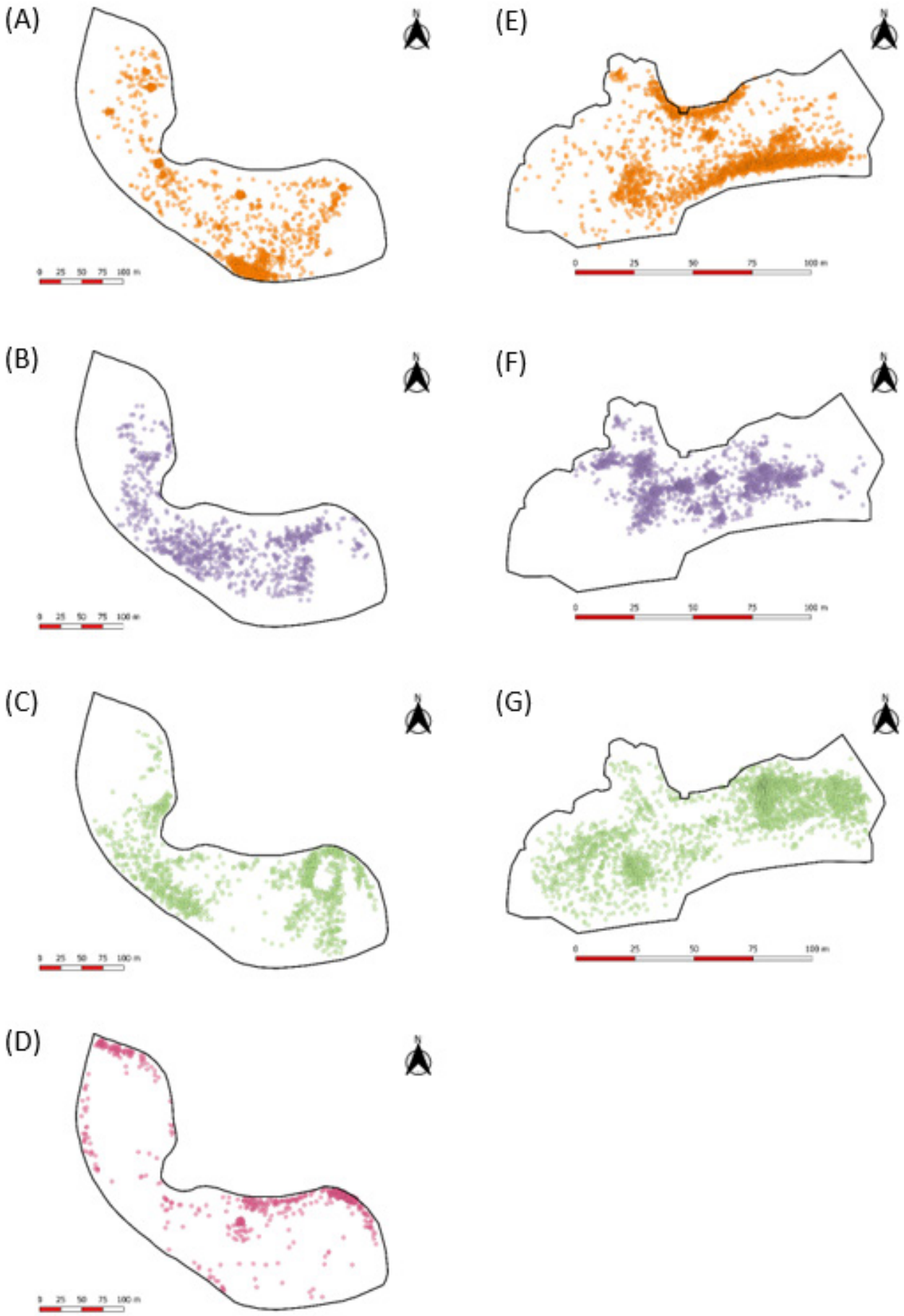
Once this is complete, the ZooMonitor data can be referenced against the list of points using the =VLOOKUP() function and all data points can be assigned a longitude and latitude.

To upload the data to QGIS, go the "Layer" menu, "Add layer" sub-menu and select "Add delimited text layer". Find and select the edited ZooMonitor data layer and upload it, ensuring that the X-Coordinate and Y-Coordinate columns are selected for longitude and latitude respectively.

After uploading, data can be manipulated with a number of tools to separate variables such as the "Split Vector Layer" tool which allows a variable to be selected to separate a file by. In figures 2(A) and 3(A), the data for this project has been split by species. By right clicking on a layer and opening the "Features" menu, the colour, size and shape of the symbols displayed can be edited through the "Symbology" tab.



Supplementary figure 2. Screenshot displaying the "Create Grid" tool necessary for the creation of a grid in QGIS to translate the data collected in the ZooMonitor application.



Supplementary figure 3. Raw datasets plotted as point files in QGIS with each individual species shown separately. (A)–(D) represent Fota Wildlife Park. (E)–(G) represent Dublin Zoo. Orange=Giraffe, Purple=Zebra, Green=Oryx and Pink=Ostrich.

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