Hillforts Primer

An Analysis of the Atlas of Hillforts of Britain and Ireland

Appendix 1

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Part 1: Name, Admin & Location Data

Colab Notebook: Live code (Must be logged into Google. Select Google Colaboratory, at the top of the screen, if page opens as raw code)
HTML: Read only
HTML: Read only topographic

Part 2: Management & Landscape

Colab Notebook: Live code
HTML: Read only
HTML: Read only topographic

Part 3: Boundary & Dating

Colab Notebook: Live code
HTML: Read only
HTML: Read only topographic

Part 4: Investigations & Interior

Colab Notebook: Live code
HTML: Read only
HTML: Read only topographic

Part 5: Entrance, Enclosing & Annex

Colab Notebook: Live code
HTML: Read only
HTML: Read only topographic

Appendix 1: Hypotheses Testing the Alignment of Hillforts with an Area of 21 Hectares or More

Colab Notebook: Live code
HTML: Read only
HTML: Read only topographic

User Settings

Pre-processed data and images are available for download (without the need to run the code in these files) here:
https://github.com/MikeDairsie/Hillforts-Primer.

To download, save images or to change the background image to show the topography, first save a copy of this document into your Google Drive folder. Once saved, change download_data, save_images and/or show_topography to **True**, in the code blocks below, **Save** and then select **Runtime>Run all**, in the main menu above, to rerun the code. If selected, running the code will initiate the download and saving of files. Each document will download a number of data packages and you may be prompted to **allow** multiple downloads. Be patient, downloads may take a little time after the document has finish running. Note that each part of the Hillforts Primer is independent and the download, save_image and show_topography variables will need to be enabled in each document, if this functionality is required. Also note that saving images will activate the Google Drive folder and this will request the user to **allow** access. Selecting show_topography will change the background image to a colour topographic map. It should also be noted that, if set to True, this view will only show the distribution of the data selected. It will not show the overall distribution as a grey background layer as is seen when using the simple coastal outlines.

In [ ]:
```
download_data = False
```

In [ ]:
```
save_images = False
```

In [ ]:
```
show_topography = False
```

Bypass Code Setup

The initial sections of all the Hillforts Primer documents set up the coding environment and define functions used to plot, reprocess and save the data. If you would like to bypass the setup, please use the following link:

Go to Appendix 1.

Reload Data and Python Functions

This study is split over multiple documents. Each file needs to be configured and have the source data imported. As this section does not focus on the assessment of the data it is minimised to facilitate the documents readability.

Python Modules and Code Setup

The Python imports enable the Hillforts Atlas data to be analysed and mapped within this document. The Python code can be run on demand, (see: User Settings). This means that as new research becomes available, the source for this document can be updated to a revised copy of the Atlas data and the impact of that research can be reviewed using the same code and graphic output. The Hillforts Atlas is a baseline and this document is a tool that can be used to assess the impact new research is making in this area.

In [ ]:
```
import sys
print(f'Python: {sys.version}')

import sklearn
print(f'Scikit-Learn: {sklearn.__version__}')

import pandas as pd
print(f'pandas: {pd.__version__}')

import numpy as np
print(f'numpy: {np.__version__}')

%matplotlib inline
import matplotlib
print(f'matplotlib: {matplotlib.__version__}')
import matplotlib.pyplot as plt
import matplotlib.cm as cm
import matplotlib.patches as mpatches
import matplotlib.patches as patches
from matplotlib.cbook import boxplot_stats
from matplotlib.lines import Line2D
import matplotlib.cm as cm

import seaborn as sns
print(f'seaborn: {sns.__version__}')
sns.set(style="whitegrid")

import scipy
print(f'scipy: {scipy.__version__}')
from scipy import stats
from scipy.stats import gaussian_kde

import os
import collections
import math
import random
import PIL
import urllib
random.seed(42) # A random seed is used to ensure that the random numbers created c

from slugify import slugify
```

```
# Import Google colab tools to access Drive
from google.colab import drive
```

```
Python: 3.10.11 (main, Apr  5 2023, 14:15:10) [GCC 9.4.0]
Scikit-Learn: 1.2.2
pandas: 1.5.3
numpy: 1.22.4
matplotlib: 3.7.1
seaborn: 0.12.2
scipy: 1.10.1
```

Ref: https://www.python.org/

Ref: https://scikit-learn.org/stable/

Ref: https://pandas.pydata.org/docs/

Ref: https://numpy.org/doc/stable/

Ref: https://matplotlib.org/

Ref: https://seaborn.pydata.org/

Ref: https://docs.scipy.org/doc/scipy/index.html

Ref: https://pypi.org/project/python-slugify/

Plot Figures and Maps functions

The following functions will be used to plot data later in the document.

In [ ]:
```
def show_records(plt, plot_data):
    text_colour = 'k'
    if show_topography == True:
        text_colour = 'w'
    plt.annotate(str(len(plot_data))+' records', xy=(-1180000, 6420000), xycoords=
```

In [ ]:
```
def get_backgrounds():
    if show_topography == True:
        backgrounds = ["hillforts-topo-01.png",
                       "hillforts-topo-north.png",
                       "hillforts-topo-northwest-plus.png",
                       "hillforts-topo-northwest-minus.png",
                       "hillforts-topo-northeast.png",
                       "hillforts-topo-south.png",
                       "hillforts-topo-south-plus.png",
                       "hillforts-topo-ireland.png",
                       "hillforts-topo-ireland-north.png",
                       "hillforts-topo-ireland-south.png"]
    else:
        backgrounds = ["hillforts-outline-01.png",
                       "hillforts-outline-north.png",
                       "hillforts-outline-northwest-plus.png",
                       "hillforts-outline-northwest-minus.png",
                       "hillforts-outline-northeast.png",
                       "hillforts-outline-south.png",
                       "hillforts-outline-south-plus.png",
                       "hillforts-outline-ireland.png",
                       "hillforts-outline-ireland-north.png",
                       "hillforts-outline-ireland-south.png"]
    return backgrounds
```

In [ ]:
```
def get_bounds():
    bounds = [[-1200000,220000,6400000,8700000],
    [-1200000,220000,7000000,8700000],
```

```
    [-1200000,-480000,7000000,8200000],
    [-900000,-480000,7100000,8200000],
    [-520000, 0,7000000,8700000],
    [-800000,220000,6400000,7100000],
    [-1200000,220000,6400000,7100000],
    [-1200000,-600000,6650000,7450000],
    [-1200000,-600000,7050000,7450000],
    [-1200000,-600000,6650000,7080000]]
    return bounds
```

In [ ]:
```
def show_background(plt, ax, location=""):
    backgrounds = get_backgrounds()
    bounds = get_bounds()
    folder = "https://raw.githubusercontent.com/MikeDairsie/Hillforts-Primer/main/h

    if location == "n":
        background = os.path.join(folder, backgrounds[1])
        bounds = bounds[1]
    elif location == "nw+":
        background = os.path.join(folder, backgrounds[2])
        bounds = bounds[2]
    elif location == "nw-":
        background = os.path.join(folder, backgrounds[3])
        bounds = bounds[3]
    elif location == "ne":
        background = os.path.join(folder, backgrounds[4])
        bounds = bounds[4]
    elif location == "s":
        background = os.path.join(folder, backgrounds[5])
        bounds = bounds[5]
    elif location == "s+":
        background = os.path.join(folder, backgrounds[6])
        bounds = bounds[6]
    elif location == "i":
        background = os.path.join(folder, backgrounds[7])
        bounds = bounds[7]
    elif location == "in":
        background = os.path.join(folder, backgrounds[8])
        bounds = bounds[8]
    elif location == "is":
        background = os.path.join(folder, backgrounds[9])
        bounds = bounds[9]
    else:
        background = os.path.join(folder, backgrounds[0])
        bounds = bounds[0]

    img = np.array(PIL.Image.open(urllib.request.urlopen(background)))
    ax.imshow(img, extent=bounds)
```

In [ ]:
```
def get_counts(data):
    data_counts = []
    for col in data.columns:
        count = len(data[data[col] == 'Yes'])
        data_counts.append(count)
    return data_counts
```

In [ ]:
```
def add_annotation_plot(ax):
    ax.annotate("Middleton, M. 2022, Hillforts Primer", size='small', color='grey'
    ax.annotate("Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk", size
```

In [ ]:
```
def add_annotation_l_xy(ax):
    ax.annotate("Middleton, M. 2022, Hillforts Primer", size='small', color='grey'
```

```
    ax.annotate("Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk", size
```

In [ ]:
```
def plot_bar_chart(data, split_pos, x_label, y_label, title, clip=False):
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])
    x_data = data.columns
    x_data = [x.split("_")[split_pos:] for x in x_data]
    x_data_new = []
    for l in x_data :
        txt =  ""
        for part in l:
            txt += "_" + part
        x_data_new.append(txt[1:])
    if clip:
        x_data_new = x_data_new[:-1]
        new_data = data.copy()
        data = new_data.drop(['Dating_Date_Unknown'], axis=1)
    y_data = get_counts(data)
    ax.bar(x_data_new,y_data)
    ax.set_xlabel(x_label)
    ax.set_ylabel(y_label)
    add_annotation_plot(ax)
    plt.title(get_print_title(title))
    save_fig(title)
    plt.show()
```

In [ ]:
```
def plot_bar_chart_using_two_tables(x_data, y_data, x_label, y_label, title):
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])
    ax.bar(x_data,y_data)
    ax.set_xlabel(x_label)
    ax.set_ylabel(y_label)
    add_annotation_plot(ax)
    plt.title(get_print_title(title))
    save_fig(title)
    plt.show()
```

In [ ]:
```
def plot_bar_chart_numeric(data, split_pos, x_label, y_label, title, n_bins, extra
    new_data = data.copy()
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])
    data[x_label].plot(kind='hist', bins = n_bins)
    ax.set_xlabel(x_label)
    ax.set_ylabel(y_label)
    add_annotation_plot(ax)
    title = f'{title} {extra}'
    plt.title(get_print_title(title))
    save_fig(title)
    plt.show()
```

In [ ]:
```
def plot_continuous(data, x_lable, title):
    fig = plt.figure(figsize=(12,8))
    ax = fig.add_axes([0,0,1,1])
    ax.set_xlabel(x_lable)
    plt.plot(data, linewidth=4)
    plt.ticklabel_format(style='plain')
    plt.title(get_print_title(title))
    add_annotation_plot(ax)
    save_fig(title)
    plt.show()
```

In [ ]:
```
def plot_data_range(data, feature, o="v"):
    fig = plt.figure(figsize=(12,2))
    ax = fig.add_axes([0,0,1,1])
    ax.set_xlabel(feature)
    add_annotation_plot(ax)
    plt.title(get_print_title(feature + " Range"))
    plt.ticklabel_format(style='plain')
    if o == "v":
        sns.boxplot(data=data, orient="v", whis=[2.2, 97.8])
    else:
        sns.boxplot(data=data, orient="h", whis=[2.2, 97.8])
    save_fig(feature + " Range")
    plt.show()

    bp = boxplot_stats(data, whis=[2.2, 97.8])

    low = bp[0].get('whislo')
    q1 = bp[0].get('q1')
    median =  bp[0].get('med')
    q3 = bp[0].get('q3')
    high = bp[0].get('whishi')

    return [low, q1, median, q3, high]
```

In [ ]:
```
def plot_data_range_plus(data, feature, o="v"):
    fig = plt.figure(figsize=(12,8))
    ax = fig.add_axes([0,0,1,1])
    ax.set_xlabel(feature)
    add_annotation_plot(ax)
    plt.title(get_print_title(feature + " Range (Outlier Steps)"))
    plt.ticklabel_format(style='plain')
    if o == "v":
        sns.boxplot(data=data, orient="v", whis=[2.2, 97.8])
    else:
        sns.boxplot(data=data, orient="h", whis=[2.2, 97.8])

    # Add annotation lines
    x = [24, 24, 54, 54]
    y = [-0.05, -0.075, -0.075, -0.05]
    x1 = [54, 54, 84, 84]
    y1 = [-0.1, -0.125, -0.125, -0.1]
    x2 = [84, 84, 114, 114]
    y2 = [-0.05, -0.075, -0.075, -0.05]

    line_1 = plt.plot(x,y)
    line_2 = plt.plot(x1,y1)
    line_3 = plt.plot(x2,y2)

    # Add annotation text
    text_kwargs = dict(ha='center', va='center', fontsize=16, color='k')
    plt.text(39, -0.1, '30 Ha', **text_kwargs)
    plt.text(69, -0.1, '30 Ha', **text_kwargs)
    plt.text(99, -0.1, '30 Ha', **text_kwargs)

    save_fig(feature + " Range")
    plt.show()

    return
```

In [ ]:
```
def location_XY_plot():
    plt.ticklabel_format(style='plain')
    plt.xlim(-1200000,220000)
```

```
    plt.ylim(6400000,8700000)
    add_annotation_1_xy(plt)
```

In [ ]:
```
def add_grey(region=''):
    if show_topography == False:
        # plots all the hillforts as a grey background
        loc = location_data.copy()
        if region == 's':
            loc = loc[loc['Location_Y'] < 8000000].copy()
            loc = loc[loc['Location_X'] > -710000].copy()
        elif region == 'ne':
            loc = loc[loc['Location_Y'] < 8000000].copy()
            loc = loc[loc['Location_X'] > -800000].copy()

        plt.scatter(loc['Location_X'], loc['Location_Y'], c='Silver')
```

In [ ]:
```
def plot_over_grey_numeric(merged_data, a_type, title, extra="", inner=False, fring
    plot_data = merged_data
    fig, ax = plt.subplots(figsize=(14.2 * 0.66, 23.0 * 0.66))
    show_background(plt, ax)
    location_XY_plot()
    add_grey()
    patches = add_oxford_swindon(oxford,swindon)
    plt.scatter(plot_data['Location_X'], plot_data['Location_Y'], c='Red')
    if fringe:
        f_for_legend = add_21Ha_fringe()
        patches.append(f_for_legend)
    if inner:
        i_for_legend = add_21Ha_line()
        patches.append(i_for_legend)
    show_records(plt, plot_data)
    plt.legend(loc='upper left', handles= patches)
    plt.title(get_print_title(title))
    save_fig(title)
    plt.show()
    print(f'{round(((len(plot_data)/4147)*100), 2)}%')
```

In [ ]:
```
def plot_over_grey_boundary(merged_data, a_type, boundary_type):
    plot_data = merged_data[merged_data[a_type] == boundary_type]
    fig, ax = plt.subplots(figsize=(9.47, 15.33))
    show_background(plt, ax)
    location_XY_plot()
    add_grey(region='')
    plt.scatter(plot_data['Location_X'], plot_data['Location_Y'], c='Red')
    show_records(plt, plot_data)
    plt.title(get_print_title('Boundary_Type: ' + boundary_type))
    save_fig('Boundary_Type_' + boundary_type)
    plt.show()
```

In [ ]:
```
def add_21Ha_line():
    x_values = [-367969, -344171, -263690, -194654, -130542, -119597, -162994, -26
    y_values = [7019842, 6944572, 6850593, 6779602, 6735058, 6710127, 6684152, 666
    plt.plot(x_values, y_values, 'k', ls='-', lw=15, alpha=0.25, label = '≥ 21 Ha
    add_to_legend = Line2D([0], [0], color='k', lw=15, alpha=0.25, label = '≥ 21 Ha
    return add_to_legend
```

In [ ]:
```
def add_21Ha_fringe():
    x_values = [-367969,-126771,29679,-42657,-248650,-304545,-423647,-584307,-3679
    y_values = [7019842,6847138,6671658,6596650,6554366,6611780,6662041,6752378,70
    plt.plot(x_values, y_values, 'k', ls=':', lw=5, alpha=0.45, label = '≥ 21 Ha F
    add_to_legend = Line2D([0], [0], color='k', ls=':', lw=5, alpha=0.45, label =
    return add_to_legend
```

In [ ]:
```
def plot_density_over_grey(data, data_type, extra='', inner=False, fringe=False):
    new_data = data.copy()
    new_data = new_data.drop(['Density'], axis=1)
    new_data = add_density(new_data)
    fig, ax = plt.subplots(figsize=((14.2 * 0.66)+2.4, 23.0 * 0.66))
    show_background(plt, ax)
    location_XY_plot()
    add_grey()
    plt.scatter(new_data['Location_X'], new_data['Location_Y'], c=new_data['Densit
    if fringe:
        add_21Ha_fringe()
    if inner:
        add_21Ha_line()
        plt.legend(loc='lower left')
    plt.colorbar(label='Density')
    title = f'Density - {data_type} {extra}'
    plt.title(get_print_title(title))
    save_fig(title)
    plt.show()
```

In [ ]:
```
def plot_density_over_grey_three(data_low, data_iqr, data_high, title, extra='', i
    new_data_low = data_low.copy()
    new_data_low = new_data_low.drop(['Density'], axis=1)
    new_data_low = add_density(new_data_low)

    new_data_iqr = data_iqr.copy()
    new_data_iqr = new_data_iqr.drop(['Density'], axis=1)
    new_data_iqr = add_density(new_data_iqr)

    new_data_high = data_high.copy()
    new_data_high = new_data_high.drop(['Density'], axis=1)
    new_data_high = add_density(new_data_high)

    fig, ax = plt.subplots(1, 3)
    fig.set_figheight(7)
    fig.set_figwidth(15)

    bounds = get_bounds()
    folder = "https://raw.githubusercontent.com/MikeDairsie/Hillforts-Primer/main/h
    background = os.path.join(folder, "hillforts-bw-02.png")
    bounds = bounds[0]
    img = plt.imread(background)
    ax[0].imshow(img, extent=bounds)
    ax[1].imshow(img, extent=bounds)
    ax[2].imshow(img, extent=bounds)

    ax[0].scatter(new_data_low['Location_X'], new_data_low['Location_Y'], c=new_da
    ax[1].scatter(new_data_iqr['Location_X'], new_data_iqr['Location_Y'], c=new_da
    ax[2].scatter(new_data_high['Location_X'], new_data_high['Location_Y'], c=new_

    ax[0].get_yaxis().set_visible(False)
    ax[1].get_yaxis().set_visible(False)
    ax[2].get_yaxis().set_visible(False)

    ax[0].get_xaxis().set_visible(False)
```

```
    ax[1].get_xaxis().set_visible(False)
    ax[2].get_xaxis().set_visible(False)

    ax[0].set_title("1st Quarter (Tiny Hillforts)")
    ax[1].set_title("IQR (Small to Medium Hillforts)")
    ax[2].set_title("4th Quarter (Large Hillforts)")

    fig.suptitle(get_print_title(title), y=1.08)
    ax[0].annotate("Middleton, M. 2022, Hillforts Primer", size='small', color='gr
    ax[2].annotate("Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk", s
    save_fig(title)
    plt.show()
```

In [ ]:

```
def plot_density_over_grey_four(data_1, data_2, data_3, data_4, title, extra='', i
    new_data_1 = data_1.copy()
    new_data_1 = new_data_1.drop(['Density'], axis=1)
    new_data_1 = add_density(new_data_1)

    new_data_2 = data_2.copy()
    new_data_2 = new_data_2.drop(['Density'], axis=1)
    new_data_2 = add_density(new_data_2)

    new_data_3 = data_3.copy()
    new_data_3 = new_data_3.drop(['Density'], axis=1)
    new_data_3 = add_density(new_data_3)

    new_data_4 = data_4.copy()
    new_data_4 = new_data_4.drop(['Density'], axis=1)
    new_data_4 = add_density(new_data_4)

    fig, ax = plt.subplots(1, 4)
    fig.set_figheight(7)
    fig.set_figwidth(20)

    bounds = get_bounds()
    folder = "https://raw.githubusercontent.com/MikeDairsie/Hillforts-Primer/main/h
    background = os.path.join(folder, "hillforts-bw-02.png")
    bounds = bounds[0]
    img = plt.imread(background)
    ax[0].imshow(img, extent=bounds)
    ax[1].imshow(img, extent=bounds)
    ax[2].imshow(img, extent=bounds)
    ax[3].imshow(img, extent=bounds)

    ax[0].scatter(new_data_1['Location_X'], new_data_1['Location_Y'], c=new_data_1
    ax[1].scatter(new_data_2['Location_X'], new_data_2['Location_Y'], c=new_data_2
    ax[2].scatter(new_data_3['Location_X'], new_data_3['Location_Y'], c=new_data_3
    ax[3].scatter(new_data_4['Location_X'], new_data_4['Location_Y'], c=new_data_4

    ax[0].get_yaxis().set_visible(False)
    ax[1].get_yaxis().set_visible(False)
    ax[2].get_yaxis().set_visible(False)
    ax[3].get_yaxis().set_visible(False)

    ax[0].get_xaxis().set_visible(False)
    ax[1].get_xaxis().set_visible(False)
    ax[2].get_xaxis().set_visible(False)
    ax[3].get_xaxis().set_visible(False)

    ax[0].set_title("NE")
    ax[1].set_title("SE")
    ax[2].set_title("SW")
    ax[3].set_title("NW")
```

```
    fig.suptitle(get_print_title(title), y=1.08)
    ax[0].annotate("Middleton, M. 2022, Hillforts Primer", size='small', color='gr
    ax[3].annotate("Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk", s
    save_fig(title)
    plt.show()
```

In [ ]:

```
def plot_density_over_grey_five(data_1, data_2, data_3, data_4, data_5, title, ext
    new_data_1 = data_1.copy()
    new_data_1 = new_data_1.drop(['Density'], axis=1)
    new_data_1 = add_density(new_data_1)

    new_data_2 = data_2.copy()
    new_data_2 = new_data_2.drop(['Density'], axis=1)
    new_data_2 = add_density(new_data_2)

    new_data_3 = data_3.copy()
    new_data_3 = new_data_3.drop(['Density'], axis=1)
    new_data_3 = add_density(new_data_3)

    new_data_4 = data_4.copy()
    new_data_4 = new_data_4.drop(['Density'], axis=1)
    new_data_4 = add_density(new_data_4)

    new_data_5 = data_5.copy()
    new_data_5 = new_data_5.drop(['Density'], axis=1)
    new_data_5 = add_density(new_data_5)

    fig, ax = plt.subplots(1, 5)
    fig.set_figheight(7)
    fig.set_figwidth(24)

    bounds = get_bounds()
    folder = "https://raw.githubusercontent.com/MikeDairsie/Hillforts-Primer/main/
    background = os.path.join(folder, "hillforts-bw-02.png")
    bounds = bounds[0]
    img = plt.imread(background)
    ax[0].imshow(img, extent=bounds)
    ax[1].imshow(img, extent=bounds)
    ax[2].imshow(img, extent=bounds)
    ax[3].imshow(img, extent=bounds)
    ax[4].imshow(img, extent=bounds)

    ax[0].scatter(new_data_1['Location_X'], new_data_1['Location_Y'], c=new_data_1
    ax[1].scatter(new_data_2['Location_X'], new_data_2['Location_Y'], c=new_data_2
    ax[2].scatter(new_data_3['Location_X'], new_data_3['Location_Y'], c=new_data_3
    ax[3].scatter(new_data_4['Location_X'], new_data_4['Location_Y'], c=new_data_4
    ax[4].scatter(new_data_5['Location_X'], new_data_5['Location_Y'], c=new_data_5

    ax[0].get_yaxis().set_visible(False)
    ax[1].get_yaxis().set_visible(False)
    ax[2].get_yaxis().set_visible(False)
    ax[3].get_yaxis().set_visible(False)
    ax[4].get_yaxis().set_visible(False)

    ax[0].get_xaxis().set_visible(False)
    ax[1].get_xaxis().set_visible(False)
    ax[2].get_xaxis().set_visible(False)
    ax[3].get_xaxis().set_visible(False)
    ax[4].get_xaxis().set_visible(False)

    ax[0].set_title("0")
    ax[1].set_title("1")
```

```
    ax[2].set_title("2")
    ax[3].set_title("3")
    ax[4].set_title("4")

    fig.suptitle(get_print_title(title), y=1.08)
    ax[0].annotate("Middleton, M. 2022, Hillforts Primer", size='small', color='gr
    ax[4].annotate("Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk", s
    save_fig(title)
    plt.show()
```

In [ ]:

```
def plot_density_over_grey_six(data_1, data_2, data_3, data_4, data_5, data_6, tit
    new_data_1 = data_1.copy()
    new_data_1 = new_data_1.drop(['Density'], axis=1)
    new_data_1 = add_density(new_data_1)

    new_data_2 = data_2.copy()
    new_data_2 = new_data_2.drop(['Density'], axis=1)
    new_data_2 = add_density(new_data_2)

    new_data_3 = data_3.copy()
    new_data_3 = new_data_3.drop(['Density'], axis=1)
    new_data_3 = add_density(new_data_3)

    new_data_4 = data_4.copy()
    new_data_4 = new_data_4.drop(['Density'], axis=1)
    new_data_4 = add_density(new_data_4)

    new_data_5 = data_5.copy()
    new_data_5 = new_data_5.drop(['Density'], axis=1)
    new_data_5 = add_density(new_data_5)

    new_data_6 = data_6.copy()
    new_data_6 = new_data_6.drop(['Density'], axis=1)
    new_data_6 = add_density(new_data_6)

    fig, ax = plt.subplots(1, 6)
    fig.set_figheight(6)
    fig.set_figwidth(24)

    bounds = get_bounds()
    folder = "https://raw.githubusercontent.com/MikeDairsie/Hillforts-Primer/main/
    background = os.path.join(folder, "hillforts-bw-02.png")
    bounds = bounds[0]
    img = plt.imread(background)
    ax[0].imshow(img, extent=bounds)
    ax[1].imshow(img, extent=bounds)
    ax[2].imshow(img, extent=bounds)
    ax[3].imshow(img, extent=bounds)
    ax[4].imshow(img, extent=bounds)
    ax[5].imshow(img, extent=bounds)

    ax[0].scatter(new_data_1['Location_X'], new_data_1['Location_Y'], c=new_data_1
    ax[1].scatter(new_data_2['Location_X'], new_data_2['Location_Y'], c=new_data_2
    ax[2].scatter(new_data_3['Location_X'], new_data_3['Location_Y'], c=new_data_3
    ax[3].scatter(new_data_4['Location_X'], new_data_4['Location_Y'], c=new_data_4
    ax[4].scatter(new_data_5['Location_X'], new_data_5['Location_Y'], c=new_data_5
    ax[5].scatter(new_data_5['Location_X'], new_data_5['Location_Y'], c=new_data_5

    ax[0].get_yaxis().set_visible(False)
    ax[1].get_yaxis().set_visible(False)
    ax[2].get_yaxis().set_visible(False)
    ax[3].get_yaxis().set_visible(False)
    ax[4].get_yaxis().set_visible(False)
```

```
    ax[5].get_yaxis().set_visible(False)

    ax[0].get_xaxis().set_visible(False)
    ax[1].get_xaxis().set_visible(False)
    ax[2].get_xaxis().set_visible(False)
    ax[3].get_xaxis().set_visible(False)
    ax[4].get_xaxis().set_visible(False)
    ax[5].get_xaxis().set_visible(False)

    ax[0].set_title("Part Univallate")
    ax[1].set_title("Univallate")
    ax[2].set_title("Part Bivallate")
    ax[3].set_title("Bivallate")
    ax[4].set_title("Part Multivallate")
    ax[5].set_title("Multivallate")

    fig.suptitle(get_print_title(title), y=1.08)
    ax[0].annotate("Middleton, M. 2022, Hillforts Primer", size='small', color='gr
    ax[5].annotate("Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk", s
    save_fig(title)
    plt.show()
```

In [ ]:
```
def add_oxford_swindon(oxford=False,swindon=False):
    # plots a circle over Swindon & Oxford
    radius = 50
    marker_size = (2*radius)**2
    patches = []
    if oxford:
        plt.scatter(-144362,6758380, c='dodgerblue', s=marker_size, alpha=0.50)
        b_patch = mpatches.Patch(color='dodgerblue', label='Oxford orbit')
        patches.append(b_patch)
    if swindon:
        plt.scatter(-197416, 6721977, c='yellow', s=marker_size, alpha=0.50)
        y_patch = mpatches.Patch(color='yellow', label='Swindon orbit')
        patches.append(y_patch)
    return patches
```

In [ ]:
```
def plot_over_grey(merged_data, a_type, yes_no, extra="", inner=False, fringe=Fals
    # plots selected data over the grey dots. yes_no controlls filtering the data
    plot_data = merged_data[merged_data[a_type] == yes_no]
    fig, ax = plt.subplots(figsize=(14.2 * 0.66, 23.0 * 0.66))
    show_background(plt, ax)
    location_XY_plot()
    add_grey()
    patches = add_oxford_swindon(oxford,swindon)
    plt.scatter(plot_data['Location_X'], plot_data['Location_Y'], c='Red')
    if fringe:
        f_for_legend = add_21Ha_fringe()
        patches.append(f_for_legend)
    if inner:
        i_for_legend = add_21Ha_line()
        patches.append(i_for_legend)
    show_records(plt, plot_data)
    plt.legend(loc='upper left', handles= patches)
    plt.title(get_print_title(f'{a_type} {extra}'))
    save_fig(f'{a_type}_{extra}')
    plt.show()
    print(f'{round(((len(plot_data)/4147)*100), 2)}%')
    return plot_data
```

In [ ]:
```
def plot_type_values(data, data_type, title,extra=''):
    new_data = data.copy()
    fig, ax = plt.subplots(figsize=((14.2 * 0.66)+2.4, 23.0 * 0.66))
```

```
    show_background(plt, ax)
    location_XY_plot()
    add_grey()
    plt.scatter(new_data['Location_X'], new_data['Location_Y'], c=new_data[data_ty
    plt.colorbar(label=data_type)
    title = f'{data_type} {extra}'
    plt.title(get_print_title(title))
    save_fig(title)
    plt.show()
```

In [ ]:
```
def bespoke_plot(plt, title):
    add_annotation_plot(plt)
    plt.ticklabel_format(style='plain')
    plt.title(get_print_title(title))
    save_fig(title)
    plt.show()
```

In [ ]:
```
def add_cluster_split_lines(plt, ax, extra=None):
    x_min = -550000
    if extra == 'ireland':
        x_min = -1200000
    plt.vlines(x=[-500000], ymin=7070000, ymax=9000000, colors='r', ls='-', lw=3)
    plt.hlines(y=[7070000], xmin=x_min, xmax=200000, colors='r', ls='-', lw=3)
    ax.annotate("N/S split", color='k', xy=(50000, 7090000), xycoords='data')
    ax.annotate("E/W split", color='k', xy=(-480000, 8660000), xycoords='data')
    ax.annotate("Irish Sea split", color='k', xy=(-1150000, 7510000), xycoords='da
    plot_line((-800000,6400000), (-550000,7070000))
    plot_line((-550000,7070000), (-666000,7440000))
    plot_line((-666000,7440000),(-900000,7500000))
```

In [ ]:
```
def plot_values(data, feature, title, extra=''):
    fig, ax = plt.subplots(figsize=((14.2 * 0.66)+2.4, 23.0 * 0.66))
    show_background(plt, ax)
    location_XY_plot()
    plt.scatter(data['Location_X'], data['Location_Y'], c=data[feature], cmap=cm.r
    plt.colorbar(label=feature)
    title = f'{title} {extra}'
    plt.title(title)
    save_fig(title)
    plt.show()
```

In [ ]:
```
def plot_line(point1, point2):
    x_values = [point1[0], point2[0]]
    y_values = [point1[1], point2[1]]
    plt.plot(x_values, y_values, 'r', ls='0', lw=2, alpha=1)
```

In [ ]:
```
def density_scatter_lines(location_data, scatter_data, plot_title, inner=False, fr
    fig, ax = plt.subplots(figsize=((14.2 * 0.66)+2.0, 23.0 * 0.66))
    show_background(plt, ax)
    location_XY_plot()
    plt.scatter(location_data['Location_X'], location_data['Location_Y'], c=locati
    plt.colorbar(label='Density Transformed')
    if inner:
        add_21Ha_line()
    if fringe:
        add_21Ha_fringe()
    plt.scatter(scatter_data['Location_X'], scatter_data['Location_Y'], c='Red')
    plt.legend(loc='lower left')
    plt.title(get_print_title(plot_title))
    save_fig(plot_title)
    plt.show()
```

In [ ]:
```
# def south_density_scatter_lines(location_data, scatter_data, plot_title, inner=Fa
#     fig, ax = plt.subplots(figsize=((6.73*1.5)+2.0, (4.62*1.5)))
#     show_background(plt, ax, 's')
#     plt.ticklabel_format(style='plain')
#     plt.xlim(-800000,220000)
#     plt.ylim(6400000,7100000)
#     plt.scatter(location_data['Location_X'], location_data['Location_Y'], c=locat
#     plt.colorbar(label='Density Transformed')
#     if inner:
#         add_21Ha_line()
#     if fringe:
#         add_21Ha_fringe()
#     if h1:
#         add_h1_line()
#     if limits:
#         add_limits()
#     plt.scatter(scatter_data['Location_X'], scatter_data['Location_Y'], c='red',
#     add_annotation_plot(plt)
#     plt.legend(loc='lower right')
#     plt.title(get_print_title(plot_title))
#     save_fig(plot_title)
#     plt.show()
```

In [ ]:
```
# def add_h1_line():
#     x_values = [-376969,-119597]
#     y_values = [7019842,6710127]

#     plt.plot(x_values, y_values, 'b', ls='-', lw=8, alpha=0.6, label = 'H1')
```

In [ ]:
```
def add_limits():
    x_values = [-584307,115292]
    y_values = [7019842,7019842]
    xx_values = [115292,115292]
    yy_values = [7019842,6485285]
    xxx_values = [-584307,115292]
    yyy_values = [6485285,6485285]
    x4_values = [-584307, -584307]
    y4_values = [7019842,6485285]


    plt.plot(x_values, y_values, 'g', ls='-', lw=8, alpha=0.6, label = 'Bounds of
    plt.plot(xx_values, yy_values, 'g', ls='-', lw=8, alpha=0.6)
    plt.plot(xxx_values, yyy_values, 'g', ls='-', lw=8, alpha=0.6)
    plt.plot(x4_values, y4_values, 'g', ls='-', lw=8, alpha=0.6)
```

In [ ]:
```
def add_linear_south():
    x_values = [-115637,-286900]
    y_values = [6678188,6585812]
    xx_values = [-244249,-363049]
    yy_values = [6555133,6589612]
    xxx_values = [-392213,-363146]
    yyy_values = [6577365,6647256]
    x4_values = [-169664, -207084]
    y4_values = [6599254, 6615290]
    x5_values = [-238560,-200891]
    y5_values = [6668083,6637826]


    plt.plot(x_values, y_values, 'g', ls='-', lw=8, alpha=0.6, label = 'Poss. corr
    plt.plot(xx_values, yy_values, 'g', ls='-', lw=8, alpha=0.6)
    plt.plot(xxx_values, yyy_values, 'g', ls='-', lw=8, alpha=0.6)
```

```
    plt.plot(x4_values, y4_values, 'g', ls='-', lw=8, alpha=0.6)
    plt.plot(x5_values, y5_values, 'g', ls='-', lw=8, alpha=0.6)
```

In [ ]:
```
def plot_over_grey_south(merged_data, a_type, yes_no, extra=""):
    # plots selected data over the grey dots. yes_no controlls filtering the data j
    plot_data = merged_data[merged_data[a_type] == yes_no]
    fig, ax = plt.subplots(1,figsize=((6.73*1.5), (4.62*1.5)))
    show_background(plt, ax, 's')
    plt.ticklabel_format(style='plain')
    plt.xlim(-800000,220000)
    plt.ylim(6400000,7100000)
    add_annotation_1_xy(plt)
    add_grey('s')
    add_linear_south()
    plt.scatter(plot_data['Location_X'], plot_data['Location_Y'], c='Red')
    plt.legend(loc='lower right')
    plt.title(get_print_title(f'{a_type} {extra}'))
    save_fig(f'{a_type}_{extra}')
    plt.show()
    return plot_data
```

In [ ]:
```
def plot_over_grey_north(merged_data, a_type, yes_no, extra="", anno=False):
    # plots selected data over the grey dots. yes_no controlls filtering the data j
    plot_data = merged_data[merged_data[a_type] == yes_no]
    fig, ax = plt.subplots(1,figsize=((5.28*2), (5.28*2)))
    show_background(plt, ax, 'n')
    plt.ticklabel_format(style='plain')
    plt.xlim(-800000,0)
    plt.ylim(7200000,8000000)
    if anno == 'Stirling':
        plt.annotate('SC1514: Gillies Hill', xy=(-443187, 7578896), xycoords='data
        plt.annotate('SC3420: Morebattle Hill', xy=(-263209,7461125), xycoords='da
        plt.annotate('EN4374: Pike House Camp', xy=(-209365,7418590), xycoords='da
        plt.annotate('SC3900: Kilmurdie', xy=(-305133,7566913), xycoords='data', ha
    elif anno == 'Traprain':
        plt.annotate('SC3932: Traprain Law', xy=(-297708,7551155), xycoords='data'
        plt.annotate('SC3037: Law Hill', xy=(-372530,7642082), xycoords='data', ha
        plt.annotate("SC3571: Kerr's Knowe", xy=(-367362,7485652), xycoords='data'
        plt.annotate('SC3327: Eildon Hill North', xy=(-301491, 7476601), xycoords=
    elif anno == 'Kerr':
        plt.annotate("SC3571: Kerr's Knowe", xy=(-367362,7485652), xycoords='data'
    add_annotation_1_xy(plt)
    add_grey('ne')
    plt.scatter(plot_data['Location_X'], plot_data['Location_Y'], c='Red')
    plt.title(get_print_title(f'{a_type} {extra}'))
    save_fig(f'{a_type}_{extra}')
    plt.show()
    return plot_data
```

In [ ]:
```
def get_proportions(date_set):
    total = sum(date_set) - date_set[-1]
    newset = []
    for entry in date_set[:-1]:
        newset.append(round(entry/total,2))
    return newset
```

In [ ]:
```
def plot_dates_by_region(nw,ne,ni,si,s, features):
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])
    x_data = nw[features].columns
    x_data = [x.split("_")[2:] for x in x_data][:-1]
    x_data_new = []
```

```
    for l in x_data:
        txt =  ""
        for part in l:
            txt += "_" + part
        x_data_new.append(txt[1:])

    set1_name = 'NW'
    set2_name = 'NE'
    set3_name = 'N Ireland'
    set4_name = 'S Ireland'
    set5_name = 'South'
    set1 = get_proportions(get_counts(nw[features]))
    set2 = get_proportions(get_counts(ne[features]))
    set3 = get_proportions(get_counts(ni[features]))
    set4 = get_proportions(get_counts(si[features]))
    set5 = get_proportions(get_counts(s[features]))

    X_axis = np.arange(len(x_data_new))

    budge = 0.25

    plt.bar(X_axis - 0.55 + budge, set1, 0.3, label = set1_name)
    plt.bar(X_axis - 0.4 + budge, set2, 0.3, label = set2_name)
    plt.bar(X_axis - 0.25 + budge, set3, 0.3, label = set3_name)
    plt.bar(X_axis - 0.1 + budge, set4, 0.3, label = set4_name)
    plt.bar(X_axis + 0.05 + budge, set5, 0.3, label = set5_name)

    plt.xticks(X_axis, x_data_new)
    plt.xlabel('Dating')
    plt.ylabel('Proportion of Total Dated Hillforts in Region')
    title = 'Proportions of Dated Hillforts by Region'
    plt.title(title)
    plt.legend()
    add_annotation_plot(ax)
    save_fig(title)
    plt.show()
```

In [ ]:
```
def get_pcent_list(old_list):
    pcnt_list = []
    total = sum(old_list)
    for item in old_list:
        pcnt_list.append(round(item/total,2))
    return pcnt_list
```

In [ ]:
```
def order_set(set_list, x_data, pcnt=False):
    new_list = []
    set_values = set_list.index.tolist()
    for val in x_data:
        if val in set_values:
            new_list.append(set_list.loc[[val]].values[0])
        else:
            new_list.append(0)
    if pcnt:
        new_list = get_pcent_list(new_list)
    return new_list
```

In [ ]:
```
def plot_feature_by_region(nw,ne,ni,si,s, feature, title, clip):
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])
    max_val = int(max([nw[feature].max(),ne[feature].max(),ni[feature].max(),si[fe

    x_data = [x-1 for x in range(max_val+2)]
```

```
    set0_name = 'NW'
    set1_name = 'NE'
    set2_name = 'N Ireland'
    set3_name = 'S Ireland'
    set4_name = 'S'

    set0 = nw[feature].value_counts()
    set1 = ne[feature].value_counts()
    set2 = ni[feature].value_counts()
    set3 = si[feature].value_counts()
    set4 = s[feature].value_counts()

    set0 = order_set(set0,x_data, True)[:clip]
    set1 = order_set(set1,x_data, True)[:clip]
    set2 = order_set(set2,x_data, True)[:clip]
    set3 = order_set(set3,x_data, True)[:clip]
    set4 = order_set(set4,x_data, True)[:clip]

    X_axis = np.arange(len(x_data[:clip]))

    budge = 0.2

    plt.bar(X_axis - 0.6 + budge, set0, 0.3, label = set0_name)
    plt.bar(X_axis - 0.45 + budge, set1, 0.3, label = set1_name)
    plt.bar(X_axis - 0.3 + budge, set2, 0.3, label = set2_name)
    plt.bar(X_axis - 0.15 + budge, set3, 0.3, label = set3_name)
    plt.bar(X_axis + 0 + budge, set4, 0.3, label = set4_name)

    plt.xticks(X_axis, x_data)
    plt.xlabel('Number')
    plt.ylabel('Percentage of regional total')
    plt.title(title)
    plt.legend()
    add_annotation_plot(ax)
    save_fig(title)
    plt.show()
```

In [ ]:

```
def plot_quadrents(ramparts,ditches,ne,se,sw,nw):
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])
    x_data = [x for x in range(11)]

    set0_name = 'Ramparts'
    set00_name = 'Ditches'
    set1_name = 'NE'
    set2_name = 'SE'
    set3_name = 'SW'
    set4_name = 'NW'
    set0 = ramparts['Enclosing_Max_Ramparts'].value_counts()
    set0 = order_set(set0,x_data)[:8]
    set00 = ditches['Enclosing_Ditches_Number'].value_counts()
    set00 = order_set(set00,x_data)[:8]
    set1 = ne['Enclosing_NE_Quadrant'].value_counts()
    set1 = order_set(set1,x_data)[:8]
    set2 = se['Enclosing_SE_Quadrant'].value_counts()
    set2 = order_set(set2,x_data)[:8]
    set3 = sw['Enclosing_SW_Quadrant'].value_counts()
    set3 = order_set(set3,x_data)[:8]
    set4 = nw['Enclosing_NW_Quadrant'].value_counts()
    set4 = order_set(set4,x_data)[:8]

    X_axis = np.arange(len(x_data[:8]))
```

```
    budge = 0.2

    plt.bar(X_axis - 0.6 + budge, set0, 0.2, label = set0_name)
    plt.bar(X_axis - 0.46 + budge, set00, 0.2, label = set00_name)
    plt.bar(X_axis - 0.32 + budge, set1, 0.2, label = set1_name)
    plt.bar(X_axis - 0.18 + budge, set2, 0.2, label = set2_name)
    plt.bar(X_axis - 0.04 + budge, set3, 0.2, label = set3_name)
    plt.bar(X_axis + 0.1 + budge, set4, 0.2, label = set4_name)

    plt.xticks(X_axis, x_data)
    plt.xlabel('Number')
    plt.ylabel('Count')
    title = 'Ditches, Ramparts and Quadrant by Number'
    plt.title(title)
    plt.legend()
    add_annotation_plot(ax)
    save_fig(title)
    plt.show()
```

In [ ]:

```
def plot_regions(nw,ne,ni,si,s, features, xlabel, title, split_pos, yes_no, pcent=
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])

    x_data = features
    x_data = [x.split("_")[split_pos:] for x in x_data]
    x_data_new = []
    for l in x_data:
        txt =  ""
        for part in l:
            txt += "_" + part
        x_data_new.append(txt[1:])

    set0_name = 'NW'
    set1_name = 'NE'
    set2_name = 'N Ireland'
    set3_name = 'S Ireland'
    set4_name = 'S'

    set0_list = []
    set1_list = []
    set2_list = []
    set3_list = []
    set4_list = []

    for feature in features:
        set0_list.append((nw[feature].values == yes_no).sum())
        set1_list.append((ne[feature].values == yes_no).sum())
        set2_list.append((ni[feature].values == yes_no).sum())
        set3_list.append((si[feature].values == yes_no).sum())
        set4_list.append((s[feature].values == yes_no).sum())

    set0 = set0_list
    set1 = set1_list
    set2 = set2_list
    set3 = set3_list
    set4 = set4_list

    if pcent:
        set0 = get_pcent_list(set0)
        set1 = get_pcent_list(set1)
        set2 = get_pcent_list(set2)
        set3 = get_pcent_list(set3)
        set4 = get_pcent_list(set4)
```

```
    X_axis = np.arange(len(x_data))

    budge = 0.3

    plt.bar(X_axis - 0.6 + budge, set0, 0.13, label = set0_name)
    plt.bar(X_axis - 0.45 + budge, set1, 0.13, label = set1_name)
    plt.bar(X_axis - 0.3 + budge, set2, 0.13, label = set2_name)
    plt.bar(X_axis - 0.15 + budge, set3, 0.13, label = set3_name)
    plt.bar(X_axis + 0 + budge, set4, 0.13, label = set4_name)

    plt.xticks(X_axis, x_data_new)
    plt.xlabel(xlabel)
    if pcent:
        plt.ylabel('Percentage of Regional Total')
    else:
        plt.ylabel('Count')
    plt.title(get_print_title(f'{title}'))
    plt.legend()
    add_annotation_plot(ax)
    save_fig(title)
    plt.show()
```

In [ ]:
```
####################
####################
```

HERE

In [ ]:
```
def plot_data_range_95(data, feature, title, o="v"):
    fig = plt.figure(figsize=(12,2))
    ax = fig.add_axes([0,0,1,1])
    ax.set_xlabel(feature)
    add_annotation_plot(ax)
    plt.title(title)
    plt.ticklabel_format(style='plain')
    plt.axvline(x=mse_h1, color='r', lw=4)
    if o == "v":
        sns.boxplot(data=data, orient="v", whis=[2.5, 97.5])
    else:
        sns.boxplot(data=data, orient="h", whis=[2.5, 97.5])

    plot_title = get_print_title(title)
    save_fig(plot_title)
    plt.show()

    bp = boxplot_stats(data, whis=[2.5, 97.5])

    low = bp[0].get('whislo')
    q1 = bp[0].get('q1')
    median =  bp[0].get('med')
    q3 = bp[0].get('q3')
    high = bp[0].get('whishi')

    return [low, q1, median, q3, high]
```

In [ ]:
```
def plot_mse_hisogram(mse_list, mse_h1):
    fig = plt.figure(figsize=(12,5))
    ax = fig.add_axes([0,0,1,1])
    ax.set_xlabel('MSE')
    ax.set_ylabel('Count')
    plt.ticklabel_format(style='plain')
```

```
    plt.hist(mse_list, 100)
    plot_title = get_print_title('Mean Squared Error for hillforts offset from tes
    plt.title(plot_title)
    plt.axvline(x=mse_h1, color='r', lw=4)
    add_annotation_plot(ax)
    save_fig(plot_title)
    plt.show()
```

In [ ]:
```
def rotate_around_point(xy, radians, rotation_origin=(0, 0)):
    x, y = xy
    offset_x, offset_y = rotation_origin
    adjusted_x = (x - offset_x)
    adjusted_y = (y - offset_y)
    cos_rad = math.cos(radians)
    sin_rad = math.sin(radians)
    qx = offset_x + cos_rad * adjusted_x + sin_rad * adjusted_y
    qy = offset_y + -sin_rad * adjusted_x + cos_rad * adjusted_y

    return qx, qy
```

In [ ]:
```
def get_random_line(dist):
    test_bounds_x =[-584307, 115292]
    test_bounds_y =[6485285, 7019842]
    rand_point = (random.randrange(test_bounds_x[0],test_bounds_x[1]), random.randr
    new_second_point = (-10000000002, 1000000000)

    count = 0
    while (new_second_point[0] <= test_bounds_x[0]) or (new_second_point[0] >= tes
        rand_second_point = (rand_point[0]+dist, rand_point[1])
        rand_angle_rad = random.uniform(0.0,3.14)
        new_second_point = rotate_around_point(rand_second_point, rand_angle_rad, r
        count+=1
        if count == 10:
            rand_point = (random.randrange(test_bounds_x[0],test_bounds_x[1]), ran
            count = 0
    return [rand_point, new_second_point, math.degrees(rand_angle_rad)]
```

In [ ]:
```
def line_intersection(line1, line2):
    x = 1000000
    y = 1000000
    xdiff = (line1[0][0] - line1[1][0], line2[0][0] - line2[1][0])
    ydiff = (line1[0][1] - line1[1][1], line2[0][1] - line2[1][1])

    def det(a, b):
        return a[0] * b[1] - a[1] * b[0]

    div = det(xdiff, ydiff)
    if div == 0:
       pass
    else:
        d = (det(*line1), det(*line2))
        x = det(d, xdiff) / div
        y = det(d, ydiff) / div

    return x, y
```

In [ ]:
```
def show_perpendicular_lines(points, x_values, y_values, angle, scatter_data, show_

    length_divider = 4.85
    distance_list = []

    x_bounds = [-584307,115292]
```

```
    y_bounds = [6485285,7019842]
    max_len = math.sqrt( (x_bounds[0] - x_bounds[1])**2 + (y_bounds[0] - y_bounds[
    x0 = points[0][0]
    y0 = points[0][1]
    x1 = points[1][0]
    y1 = points[1][1]
    line_dist = math.sqrt( (x0 - x1)**2 + (y0 - y1)**2 )
    for index, row in scatter_data.iterrows():
        x2 = row['Location_X']
        y2 = row['Location_Y']
        if x2 >= x_bounds[0] and x2 <= x_bounds[1] and y2 >= y_bounds[0] and y2 <=
            p1 = (x2,y2)
            p2 = (x2+max_len,y2)
            new_p2 = p2
            value = ((x1 - x0)*(y2 - y0)) - ((x2 - x0)*(y1 - y0))
            if value < 0:
                pass
                new_p2 = rotate_around_point(p2, math.radians((angle-90)), p1)
            elif value > 0:
                new_p2 = rotate_around_point(p2, math.radians((angle+90)), p1)
            else:
                # on line
                new_p2 = p1
            line1 = ((x_values[0], y_values[0]), (x_values[1], y_values[1]))
            line2 = ((x2, y2), new_p2)
            x3, y3 = line_intersection(line1, line2)

            if x3 == 1000000:
                x3 = x2
                y3 = y2

            px_values = [x2, x3]
            py_values = [y2, y3]

            #set east/west
            west = x0
            east = x1
            if east < west:
                west = x1
                east = x0

            #set north/south
            north = y0
            south = y1
            if east < west:
                north = y1
                greater_than_21ha_south = y0

            if x3 >= west and x3 <= east and y3 >= south and y3 <= north:
                dist = abs(math.sqrt( (px_values[1] - px_values[0])**2 + (py_values
                if dist < line_dist/length_divider:
                    #print(row['Main_Atlas_Number'])
                    distance_list.append(dist)
                    if show_perpendicular:
                        plt.plot(px_values, py_values, 'magenta', ls='-', lw=3, al
    return distance_list
```

In [ ]:

```
def angle_between(p1, p2):
    ang1 = np.arctan2(*p1[::-1])
    ang2 = np.arctan2(*p2[::-1])
    return np.rad2deg((ang1 - ang2) % (2 * np.pi))
```

In [ ]:
```
def add_h1_line(scatter_data, show_perpendicular_from_main):
    penycloddiau_m = (312888, 367647)
    bozedown_m = (464350, 178250)
    x_values = [-376969,-119597]
    y_values = [7019842,6710127]
    angle_rad = math.atan((bozedown_m[1] - penycloddiau_m[1])/(bozedown_m[0] - peny
    angle = angle_between((x_values[0], y_values[0]), (x_values[1], y_values[1]))+

    plt.plot(x_values, y_values, 'b', ls='-', lw=8, alpha=0.6, label = 'H1')

    points = [(x_values[0], y_values[0]), (x_values[1], y_values[1]), angle]

    distance_list = []

    if show_perpendicular_from_main:
        distance_list = show_perpendicular_lines(points, x_values, y_values, angle
    return distance_list
```

In [ ]:
```
def add_random_lines(scatter_data, test_lines, dist, show_perpendicular):
    add_lines = test_lines

    distance_lists = []

    for i in range(add_lines):
        points = get_random_line(dist)
        x_values = [points[0][0], points[1][0]]
        y_values = [points[0][1], points[1][1]]
        angle = points[2]
        plt.plot(x_values, y_values, 'darkmagenta', ls='-', lw=3, alpha=0.6)
        distance_list = []

        distance_list = show_perpendicular_lines(points, x_values, y_values, angle
        distance_lists.append(distance_list)
    return distance_lists
```

In [ ]:
```
def south_density_scatter_lines(location_data, scatter_data, plot_title, inner=Fals
    penycloddiau = (-367969, 7019842)
    bozedown = (-119597, 6710127)
    dist = math.sqrt( (bozedown[0] - penycloddiau[0])**2 + (bozedown[1] - penyclod
    h1_distance_list = []
    distance_lists = []
    fig, ax = plt.subplots(figsize=((6.73*1.5)+2.0, (4.62*1.5)))
    show_background(plt, ax, 's')
    plt.ticklabel_format(style='plain')
    plt.xlim(-800000,220000)
    plt.ylim(6400000,7100000)
    plt.scatter(location_data['Location_X'], location_data['Location_Y'], c=locati
    plt.colorbar(label='Density Transformed')
    if inner:
        add_21Ha_line()
    if fringe:
        add_21Ha_fringe()
    if h1:
        h1_distance_list = add_h1_line(scatter_data, show_perpendicular_from_main)
    if limits:
        add_limits()
    if random_lines:
        distance_lists = add_random_lines(scatter_data, test_lines, dist, show_per
    plt.scatter(scatter_data['Location_X'], scatter_data['Location_Y'], c='red', s
    add_annotation_plot(plt)
    plt.legend(loc='lower right')
    plt.title(get_print_title(plot_title))
```

```
    save_fig(plot_title)
    plt.show()

    return h1_distance_list, distance_lists
```

Review Data Functions

The following functions will be used to confirm that features are not lost or forgotten when splitting the data.

In [ ]:
```
def test_numeric(data):
    temp_data = data.copy()
    columns = data.columns
    out_cols = ['Feature','Entries', 'Numeric', 'Non-Numeric', 'Null']
    feat, ent, num, non, nul = [],[],[],[],[]
    for col in columns:
        if temp_data[col].dtype == 'object':
            feat.append(col)
            temp_data[col+'_num'] = temp_data[col].str.isnumeric()
            entries = temp_data[col].notnull().sum()
            true_count = temp_data[col+'_num'][temp_data[col+'_num'] == True].sum(
            null_count = temp_data[col].isna().sum()
            ent.append(entries)
            num.append(true_count)
            non.append(entries-true_count)
            nul.append(null_count)
        else:
            print(f'{col} {temp_data[col].dtype}')
    summary = pd.DataFrame(list(zip(feat, ent, num, non, nul)))
    summary.columns = out_cols
    return summary
```

In [ ]:
```
def find_duplicated(numeric_data, text_data, encodeable_data):
    d = False
    all_columns = list(numeric_data.columns) + list(text_data.columns) + list(enco
    duplicate = [item for item, count in collections.Counter(all_columns).items() 
    if duplicate :
        print(f"There are duplicate features: {duplicate}")
        d = True
    return d
```

In [ ]:
```
def test_data_split(main_data, numeric_data, text_data, encodeable_data):
    m = False
    split_features = list(numeric_data.columns) + list(text_data.columns) + list(e
    missing = list(set(main_data)-set(split_features))
    if missing:
        print(f"There are missing features: {missing}")
        m = True
    return m
```

In [ ]:
```
def review_data_split(main_data, numeric_data, text_data, encodeable_data = pd.Data
    d = find_duplicated(numeric_data, text_data, encodeable_data)
    m = test_data_split(main_data, numeric_data, text_data, encodeable_data)
    if d != True and m != True:
        print("Data split good.")
```

In [ ]:
```
def find_duplicates(data):
    print(f'{data.count() - data.duplicated(keep=False).count()} duplicates.')
```

In [ ]:
```
def count_yes(data):
    total = 0
    for col in data.columns:
        count = len(data[data[col] == 'Yes'])
        total+= count
        print(f'{col}: {count}')
    print(f'Total yes count: {total}')
```

Null Value Functions

The following functions will be used to update null values.

In [ ]:
```
def fill_nan_with_minus_one(data, feature):
    new_data = data.copy()
    new_data[feature] = data[feature].fillna(-1)
    return new_data
```

In [ ]:
```
def fill_nan_with_NA(data, feature):
    new_data = data.copy()
    new_data[feature] = data[feature].fillna("NA")
    return new_data
```

In [ ]:
```
def test_numeric_value_in_feature(feature, value):
    test = feature.isin([-1]).sum()
    return test
```

In [ ]:
```
def test_catagorical_value_in_feature(dataframe, feature, value):
    test = dataframe[feature][dataframe[feature] == value].count()
    return test
```

In [ ]:
```
def test_cat_list_for_NA(dataframe, cat_list):
    for val in cat_list:
        print(val, test_catagorical_value_in_feature(dataframe, val,'NA'))
```

In [ ]:
```
def test_num_list_for_minus_one(dataframe, num_list):
    for val in num_list:
        feature = dataframe[val]
        print(val, test_numeric_value_in_feature(feature, -1))
```

In [ ]:
```
def update_cat_list_for_NA(dataframe, cat_list):
    new_data = dataframe.copy()
    for val in cat_list:
        new_data = fill_nan_with_NA(new_data, val)
    return new_data
```

In [ ]:
```
def update_num_list_for_minus_one(dataframe, cat_list):
    new_data = dataframe.copy()
    for val in cat_list:
        new_data = fill_nan_with_minus_one(new_data, val)
    return new_data
```

Reprocessing Functions

In [ ]:
```
def add_density(data):
    new_data = data.copy()
    xy = np.vstack([new_data['Location_X'],new_data['Location_Y']])
```

```
    new_data['Density'] = gaussian_kde(xy)(xy)
    return new_data
```

In [ ]:

Save Image Functions

In [ ]:
```
# Set-up figure numbering
fig_no = 0
part = 'Appendix1'
IMAGES_PATH = r'/content/drive/My Drive/'
fig_list = pd.DataFrame(columns=['fig_no', 'file_name', 'title'])
topo_txt = ""
if show_topography:
    topo_txt = "-topo"
```

In [ ]:
```
# Remove unicode characters from file names
def get_file_name(title):
    file_name = slugify(title)
    return file_name
```

In [ ]:
```
# Remove underscore from figure titles
def get_print_title(title):
    title = title.replace("_", " ")
    title = title.replace("-", " ")
    title = title.replace(",", ";")
    return title
```

In [ ]:
```
# Format figure numbers to have three digits
def format_figno(no):
    length = len(str(no))
    fig_no = ''
    for i in range(3-length):
        fig_no = fig_no + '0'
    fig_no = fig_no + str(no)
    return fig_no
```

In [ ]:
```
# Mount Google Drive if figures to be saved
if save_images == True:
    drive.mount('/content/drive')
    os.getcwd()
else:
    pass
```

In [ ]:
```
def save_fig(fig_id, tight_layout=True, fig_extension="png", resolution=300):
    global fig_no
    global IMAGES_PATH
    if save_images:
        #IMAGES_PATH = r'/content/drive/My Drive/Colab Notebooks/Hillforts_Primer_
        fig_no+=1
        fig_no_txt = format_figno(fig_no)
        file_name = file_name = get_file_name(f'{part}_{fig_no_txt}')
        file_name = f'hillforts_primer_{file_name}{topo_txt}.{fig_extension}'
        fig_list.loc[len(fig_list)] = [fig_no, file_name, get_print_title(fig_id)]
        path = os.path.join(IMAGES_PATH, file_name)
        print("Saving figure", file_name)
        plt.tight_layout()
        plt.savefig(path, format=fig_extension, dpi=resolution,  bbox_inches='tigh
    else:
        pass
```

Load Data

The source csv file is loaded and the first two rows are displayed to confirm the load was successful. Note that, to the left, an index has been added automatically. This index will be used frequently when splitting and remerging data extracts.

In [ ]:
```
hillforts_csv = r"https://raw.githubusercontent.com/MikeDairsie/Hillforts-Primer/ma
hillforts_data = pd.read_csv(hillforts_csv, index_col=False)
pd.set_option('display.max_columns', None, 'display.max_rows', None)
hillforts_data.head(2)
```

```
<ipython-input-82-2b53084ab660>:2: DtypeWarning: Columns (10,12,68,83,84,85,86,16
5,183) have mixed types. Specify dtype option on import or set low_memory=False.
  hillforts_data = pd.read_csv(hillforts_csv, index_col=False)
```

Out[ ]:

	OBJECTID	Main_Atlas_Number	Main_Country_Code	Main_Country	Main_Title_Name	Main_Site
0	1	1	EN	England	EN0001 Aconbury Camp, Herefordshire	Aconbur
1	2	2	EN	England	EN0002 Bach Camp, Herefordshire	Bac

Load Date Data

In [ ]:
```
date_features = [
 'Dating_Date_Pre_1200BC',
 'Dating_Date_1200BC_800BC',
 'Dating_Date_800BC_400BC',
 'Dating_Date_400BC_AD50',
 'Dating_Date_AD50_AD400',
 'Dating_Date_AD400_AD800',
 'Dating_Date_Post_AD800',
 'Dating_Date_Unknown']

date_data = hillforts_data[date_features]
```

Download Function

In [ ]:
```
from google.colab import files
def download(data_list, filename, hf_data=hillforts_data):
    if download_data == True:
        name_and_number = hf_data[['Main_Atlas_Number','Main_Display_Name']].copy(
        dl = name_and_number.copy()
        for pkg in data_list:
            if filename not in ['england', 'wales','scotland','republic-of-ireland
                if pkg.shape[0] == hillforts_data.shape[0]:
                    dl = pd.merge(dl, pkg, left_index=True, right_index=True)
```

```
            else:
                dl = data_list[0]
        dl = dl.replace('\r',' ', regex=True)
        dl = dl.replace('\n',' ', regex=True)
        fn = 'hillforts_primer_' + filename
        fn = get_file_name(fn)
        dl.to_csv(fn+'.csv', index=False)
        files.download(fn+'.csv')
    else:
        pass
```

Reload Name and Number

The Main Atlas Number and the Main Display Name are the primary uninqe reference identiriers in the data. With these, users can identify any record numerically and by name. Throughout this document, the data will be clipped into a number of sub-data packages. Where needed, these data extracts will be combined with Name and Number features to ensure the data can be understood and can, if needed, be concorded.

In [ ]:
```
name_and_number_features = ['Main_Atlas_Number','Main_Display_Name']
name_and_number = hillforts_data[name_and_number_features].copy()
name_and_number.head()
```

Out[ ]:

	Main_Atlas_Number	Main_Display_Name
0	1	Aconbury Camp, Herefordshire (Aconbury Beacon)
1	2	Bach Camp, Herefordshire
2	3	Backbury Camp, Herefordshire (Ethelbert's Camp)
3	4	Brandon Camp, Herefordshire
4	5	British Camp, Herefordshire (Herefordshire Bea...

Reload Location

In [ ]:
```
location_numeric_data_short_features = ['Location_X','Location_Y', 'Main_X', 'Main_
location_numeric_data_short = hillforts_data[location_numeric_data_short_features]
location_numeric_data_short = add_density(location_numeric_data_short)
location_numeric_data_short.head()
location_data = location_numeric_data_short.copy()
location_data.head()
```

Out[ ]:

	Location_X	Location_Y	Main_X	Main_Y	Density
0	-303295	6798973	350350	233050	1.632859e-12
1	-296646	6843289	354700	260200	1.540172e-12
2	-289837	6808611	358700	238900	1.547729e-12
3	-320850	6862993	340000	272400	1.670548e-12
4	-261765	6810587	376000	240000	1.369981e-12

Reload Regional Data Packages

See Cluster Data Packages in Part 1: Name, Admin & Location Data
https://colab.research.google.com/drive/1C7HcuLuGGhG8o4EGciS-XTAhxVs3MhX3?usp=sharing

In [ ]:
```
cluster_data = hillforts_data[['Location_X','Location_Y', 'Main_Country_Code']].co
cluster_data['Cluster'] = 'NA'
cluster_data['Cluster'].where(cluster_data['Main_Country_Code'] != 'NI', 'I', inpl
cluster_data['Cluster'].where(cluster_data['Main_Country_Code'] != 'IR', 'I', inpl

cluster_data['Cluster'] = np.where(
   (cluster_data['Cluster'] == 'I') & (cluster_data['Location_Y'] >= 7060000) , 'N
   )
north_ireland = cluster_data[cluster_data['Cluster'] == 'North Ireland'].copy()

cluster_data['Cluster'] = np.where(
   (cluster_data['Cluster'] == 'I') & (cluster_data['Location_Y'] < 7060000) , 'So
   )
south_ireland = cluster_data[cluster_data['Cluster'] == 'South Ireland'].copy()

cluster_data['Cluster'] = np.where(
   (cluster_data['Cluster'] == 'NA') & (cluster_data['Location_Y'] < 7070000) , 'S
   )
south = cluster_data[cluster_data['Cluster'] == 'South'].copy()

cluster_data['Cluster'] = np.where(
   (cluster_data['Cluster'] == 'NA') & (cluster_data['Location_Y'] >= 7070000) & (
   )
north_east = cluster_data[cluster_data['Cluster'] == 'Northeast'].copy()

cluster_data['Cluster'] = np.where(
   (cluster_data['Cluster'] == 'NA') & (cluster_data['Location_Y'] >= 7070000) & (
   )
north_west = cluster_data[cluster_data['Cluster'] == 'Northwest'].copy()

temp_cluster_location_packages = [north_ireland, south_ireland, south, north_east,

cluster_packages = []
for pkg in temp_cluster_location_packages:
    pkg = pkg.drop(['Main_Country_Code'], axis=1)
    cluster_packages.append(pkg)

north_ireland, south_ireland, south, north_east, north_west = cluster_packages[0],
```

Reload Enclosing Area 1

In [ ]:
```
enclosing_data = hillforts_data.copy()
enclosing_numeric_features =  ['Enclosing_Area_1']
enclosing_numeric_data = enclosing_data[enclosing_numeric_features].copy()
```

Enclosing Numeric Data - Resolve Null Values

Test for -1.

In [ ]:
```
test_num_list_for_minus_one(enclosing_numeric_data, enclosing_numeric_features)
```

```
Enclosing_Area_1 0
```

Replace null with -1.

In [ ]:
```
enclosing_numeric_data = update_num_list_for_minus_one(enclosing_numeric_data, encl
enclosing_numeric_data.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 4147 entries, 0 to 4146
Data columns (total 1 columns):
 #   Column            Non-Null Count  Dtype  
---  ------            --------------  -----  
 0   Enclosing_Area_1  4147 non-null   float64
dtypes: float64(1)
memory usage: 32.5 KB
```

Appendix 1

Enclosing Area 1: Distribution of Outliers Over 21 Ha Mapped

After multiple tests to filter the data for forts over various sizes, a possible alignemnt of hillforts was isolated for forts over 21 Ha.

In [ ]:
```
enclosing_numeric_data = update_num_list_for_minus_one(enclosing_numeric_data, encl
location_enclosing_data = pd.merge(location_numeric_data_short, enclosing_numeric_
enclosing_area_1_21 = location_enclosing_data.copy()
enclosing_area_1_21 = enclosing_area_1_21[enclosing_area_1_21['Enclosing_Area_1']>
enclosing_area_1_21['Enclosing_Area_1'].describe()
```

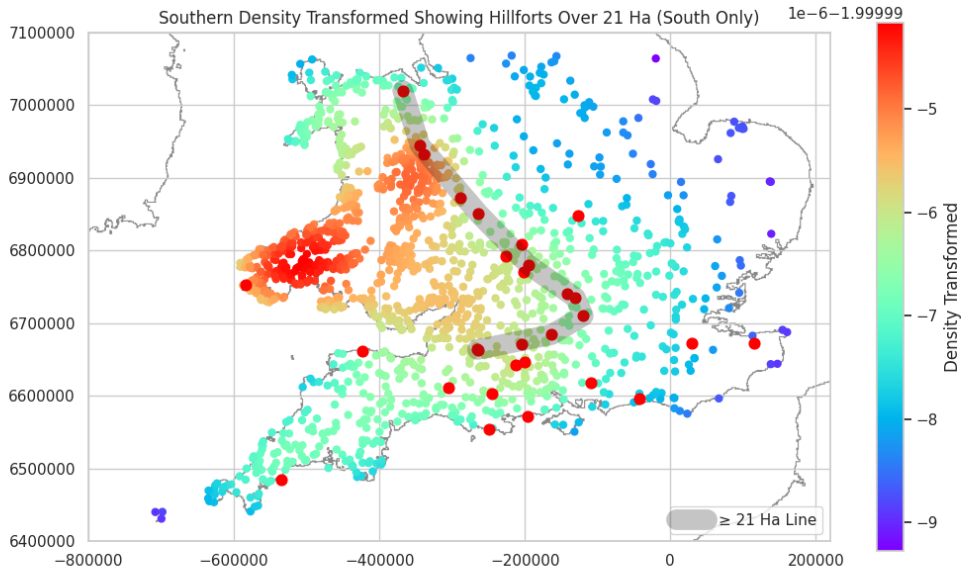
Out[ ]:
```
count     38.000000
mean      42.501053
std       26.680691
min       21.000000
25%       24.875000
50%       30.000000
75%       51.875000
max      130.000000
Name: Enclosing_Area_1, dtype: float64
```

Enclosing Area 1: Southern Hillfort Density Transformed overlayed by hillforts over 21 Ha

Map showing possible alignement of hillforts which are 21 hectars or larger.

In [ ]:
```
cluster_south = south.copy()
enclosing_area_1_21_s = enclosing_area_1_21[enclosing_area_1_21['Location_X']>-600
cluster_south = add_density(cluster_south)
cluster_south['Density_trans'] = stats.boxcox(cluster_south['Density'], 0.5)
```

In [ ]:
```
_ , _ = south_density_scatter_lines(cluster_south, enclosing_area_1_21_s, 'Southern
```



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Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk

Hillforts 21 Ha and over in the South

A full list of hillforts over 21 hectares in the southern data package.

In [ ]:
```
greater_than_21ha_south = pd.merge(name_and_number, enclosing_area_1_21_s, left_in
twenty_one_ha_and_over_south = greater_than_21ha_south[['Main_Atlas_Number', 'Main_
twenty_one_ha_and_over_south = twenty_one_ha_and_over_south.data
twenty_one_ha_and_over_south
```

```
<ipython-input-94-70982358cfd6>:2: FutureWarning: this method is deprecated in fav
our of `Styler.hide(axis="index")`
  twenty_one_ha_and_over_south = greater_than_21ha_south[['Main_Atlas_Number', 'Ma
in_Display_Name', 'Enclosing_Area_1', 'Location_X', 'Location_Y', 'Main_X', 'Main_
Y']].copy().sort_values(by='Enclosing_Area_1').style.hide_index()
```

Out[ ]:

	Main_Atlas_Number	Main_Display_Name	Enclosing_Area_1	Location_X	Location_Y	Main_X
1127	1155	Penycloddiau, Denbighshire (Pen y Cloddiau)	21.0	-367969	7019842	312888
621	643	Dodman Castle, Cornwall (Dodman Point; The Dod...	21.0	-534770	6485285	200100
731	753	Norbury Camp, Northleach, Gloucestershire	22.0	-202278	6770873	412700
1889	1997	Wooltack Point, Pembrokeshire (Deer Park Fort)	22.0	-584307	6752378	175770
3403	3595	Hod Hill, Dorset	22.0	-245476	6602754	385670
735	757	Salmonsbury Camp, Gloucestershire	23.0	-194654	6779602	417400
357	367	Woodbury, Great Witley, Worcestershire (Woodbu...	23.0	-263690	6850593	374939
136	139	Bozedown Camp, Oxfordshire (Binditch)	23.5	-119597	6710127	464350
3552	3749	Cissbury Ring, West Sussex (Cissbury Camp)	24.0	-42657	6596650	513886
1437	1504	Roulston Scar, North Yorkshire (Sutton Bank; C...	24.5	-134884	7213231	451490
388	404	Ogbury Camp, Wiltshire	26.0	-200007	6646748	414320
443	461	Tedbury Camp, Somerset	26.0	-263616	6663457	374400
373	389	Casterley Camp, Wiltshire (Catterley Banks)	27.5	-204306	6671153	411584
734	756	Willersey Camp, Gloucestershire (Willersey Hil...	28.0	-203808	6807893	411700
410	427	Ebsbury Hill, Wiltshire (Grovely Earthworks)	28.0	-212997	6642126	406160
1234	1276	y Breiddin, Powys (Breddin Hillfort; The Breid...	28.0	-338884	6931868	329570
89	91	Titterstone Clee, Shropshire	29.6	-289034	6872454	359516
3598	3795	Butser Hill, Hampshire	30.0	-109375	6617356	471527

	Main_Atlas_Number	Main_Display_Name	Enclosing_Area_1	Location_X	Location_Y	Main_X
446	464	Wadbury Camp, Somerset (Wadbury Hillfort)	30.0	-265052	6663609	373500
166	173	Abingdon, The Vineyard, Oxfordshire	33.0	-142388	6740992	449950
95	97	Walbury Camp, West Berkshire	33.0	-162994	6684152	437408
3271	3459	Countisbury Castle, Devon (Shoulsbury; Wind Hill)	35.0	-423647	6662041	274024
3625	3823	Homestall Wood, Kent	35.0	115292	6672762	611760
165	172	Dyke Hills, Oxfordshire (Dike Hills)	46.0	-130542	6735058	457350
738	760	Nottingham Hill Camp, Gloucestershire	48.6	-225551	6791821	398300
3577	3774	Oldbury Camp, Kent	51.5	29679	6671658	558165
751	773	Borough Hill 1, Northamptonshire (Borough Hill)	52.0	-126771	6847138	458877
194	201	Mull of Galloway, Dumfries & Galloway	54.0	-542988	7291829	214381
70	71	Llanymynech Hill, Powys	57.0	-344171	6944572	326479
3402	3594	Hengistbury Head, Dorset	80.0	-195572	6571275	417263
430	448	Ham Hill, Somerset (Hamdon Hill Camp)	84.0	-304545	6611780	348409
3390	3582	Bindon Hill, Dorset	114.0	-248650	6554366	383568

In [ ]:
```
download([twenty_one_ha_and_over_south], 'twenty_one_ha_and_over_south')
```

Hypothosis testing

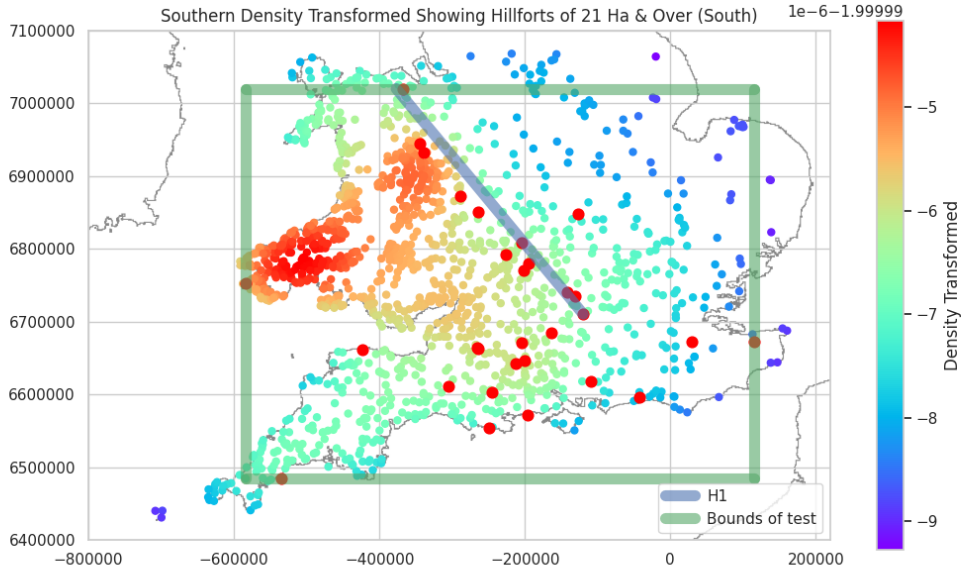
It is beyond the skills of the author to test the hypothosis of the curved line shown in the image above. This being so, the longer straight section from (1155) Penycloddiau, Denbighshire (Pen y Cloddiau) and (139) Bozedown Camp, Oxfordshire (Binditch) will be tested.

Hypothosis (H1): Hillforts of 21 ha and over are aligned between (1155) Penycloddiau, Denbighshire (Pen y Cloddiau) and (139) Bozedown Camp, Oxfordshire (Binditch).

Null Hypothosis (H0): Hillforts of 21 ha and over, between (1155) Penycloddiau,

Denbighshire (Pen y Cloddiau) and (139) Bozedown Camp, Oxfordshire (Binditch), are not aligned.

In [ ]:
```
_ , _ = south_density_scatter_lines(cluster_south, enclosing_area_1_21_s, 'Southern
```



Middleton, M. 2022, Hillforts Primer

Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk

The line is 242,511 m (242.5 Km) long.

In [ ]:
```
penycloddiau = (-367969, 7019842)
bozedown = (-119597, 6710127)
dist = math.sqrt( (bozedown[0] - penycloddiau[0])**2 + (bozedown[1] - penycloddiau
print(f"{round(dist)} units")
```

```
397004 units
```

In [ ]:
```
penycloddiau_m = (312888, 367647)
bozedown_m = (464350, 178250)
dist_m = math.sqrt( (bozedown_m[0] - penycloddiau_m[0])**2 + (bozedown_m[1] - peny
print(f"{round(dist_m)} m")
```

```
242512 m
```

In [ ]:
```
print(f"Line offset from line {round(dist_m/4.85)} m")
```

```
Line offset from line 50002 m
```

Random Alignments

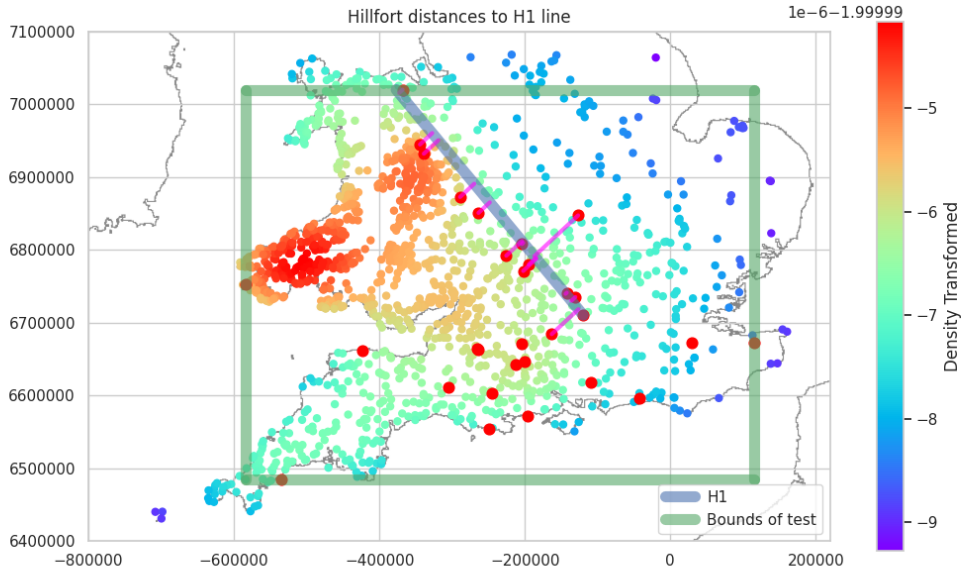
To test the hypothesis, 1500 random alignments will be created within the bounds of the forts in the South. The test will measure the perpendicular distance from each hillfort to the line, within a buffer of 50 Km. These distances will be used to calculate the Mean Squared Error (MSE) for all forts falling within the limits of each test alignment. The alignments will all be the same length as the hypothesis line (H1). The perpendicular distance from the line will be classified as the error. The error, for each fort of 21 Ha or above, will be squared and the sum of the squared values, for each line, will be divided by the number of forts that fall within the length of that line. 1500 random alignments will be created but only those with five or more hillforts, within the length of the line will be retained to ensure that the result of the MSE is based on a group of hillforts and not just a couple of individuals. 1500 was chosen to ensure that, at least, 1000 alignments remain after the lines with less than five

hillforts have been removed. A single example of a random line is shown below with the perpendicular distances to the line shown.

The resulting histogram for all 1000+ alignments will be a normal curve with the most common MSE toward the centre and the least toward the edges. For the null hypothesis to be rejected, the test alignment (H1 - the blue line) would be expected to be to the far left of the curve with a probability of less than 5%.

Shown below are the hillforts perpendicular to the H1 line within an offset distance of 50 km.

In [ ]:
```
h1_distance_list, _ = south_density_scatter_lines(cluster_south, greater_than_21ha
```



Middleton, M. 2022, Hillforts Primer

Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk

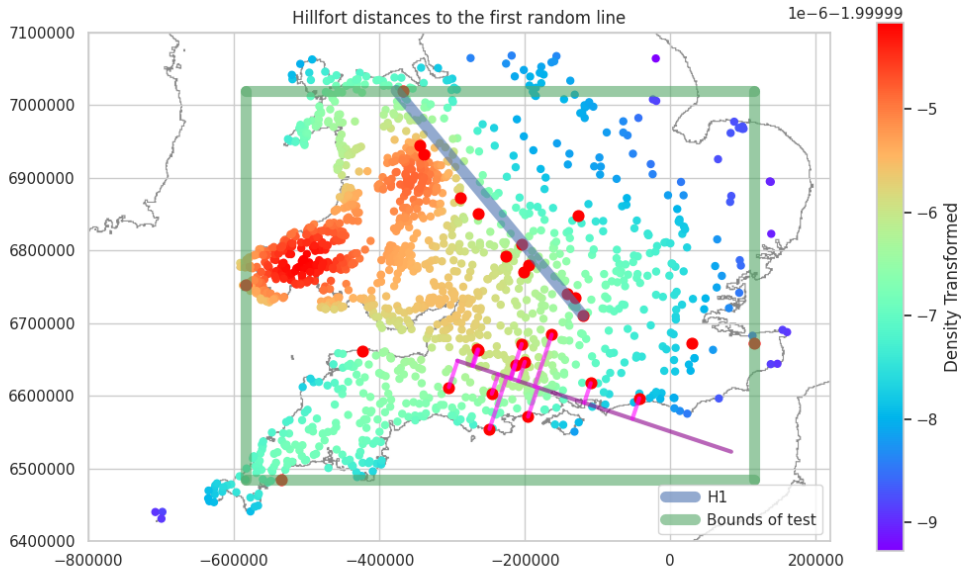
The H1 line has 14 hillforts, withing 50 km, along its lenth.

In [ ]:
```
len(h1_distance_list)
```

Out[ ]:
```
14
```

A random seed is used to ensure that the random numbers created are the same for each run of this document. Below, hillforts perpendicular to the first random alignment are shown.

In [ ]:
```
_ , _ = south_density_scatter_lines(cluster_south, enclosing_area_1_21_s, 'Hillfor
```



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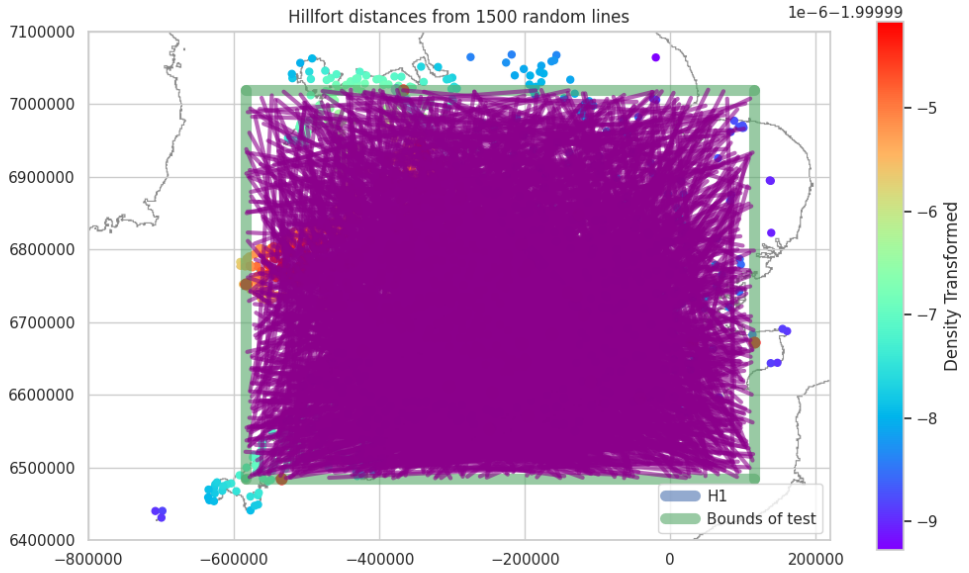
Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk

Next, 1500 random alignments area created within the bounds. The distance to hillforts perpendicular to each line are returned for analysis below.

In [ ]:
```
_, distance_lists = south_density_scatter_lines(cluster_south, enclosing_area_1_21
```



Middleton, M. 2022, Hillforts Primer

Source Data: Lock & Ralston, 2017. hillforts.arch.ox.ac.uk

A list of the number of hillforts in each list is created.

In [ ]:
```
length_list = pd.DataFrame([len(x) for x in distance_lists], columns=["count"])
length_list.head()
```

Out[ ]:

	count
0	6
1	9
2	15
3	13
4	9

There H1 alignment has 14 hillforts along its length. The 1,0000 alignments have alignments with between 0 and 19 hillfotrts along their lengths. For this analysis we will exclude alignments with less than 5 hillforts along their length to reduce the potential for low hillfort counts skewing the results. We want the mean values to be the mean of goups of hillforts not just isolated individuals. For instanse, a single hillfort laying close to the line will give a very low MSE while a alternative alignment with a single hillfort far from the line would give a very high MSE. The influence of individual values is reduced, the larger the sample.

In [ ]:
```
length_list.value_counts().sort_index()
```

Out[ ]:
```
count
0         22
1         62
2         75
3        101
4         91
5        100
6        104
7         85
8         92
9        107
10       116
11       114
12       139
13       132
14        69
15        45
16        28
17        10
18         4
19         4
dtype: int64
```

The filtered list contains 1149 alignments where there are at least 5 or more hillforts perpendicular to the line along the lengh of the line.

In [ ]:
```
filtered_length_list = [x for x in distance_lists if len(x) >= 5]
len(filtered_length_list)
```

Out[ ]:
```
1149
```

First we get the MSE for the H1 line.

In [ ]:
```
def get_mean_sum_of_squares(lst):
    sum_list = 0
    for i in lst:
        sum_list += i**2
    mse = sum_list/len(lst)
    return mse
```

In [ ]:
```
mse_h1 = int(get_mean_sum_of_squares(h1_distance_list))
mse_h1
```

Out[ ]:
```
959477730
```

Then we get the MSE for the filterd lines.

In [ ]:
```
mse_list = [int(get_mean_sum_of_squares(x)) for x in filtered_length_list]
mse_df = pd.DataFrame({'mse':mse_list})
mse_df.head()
```

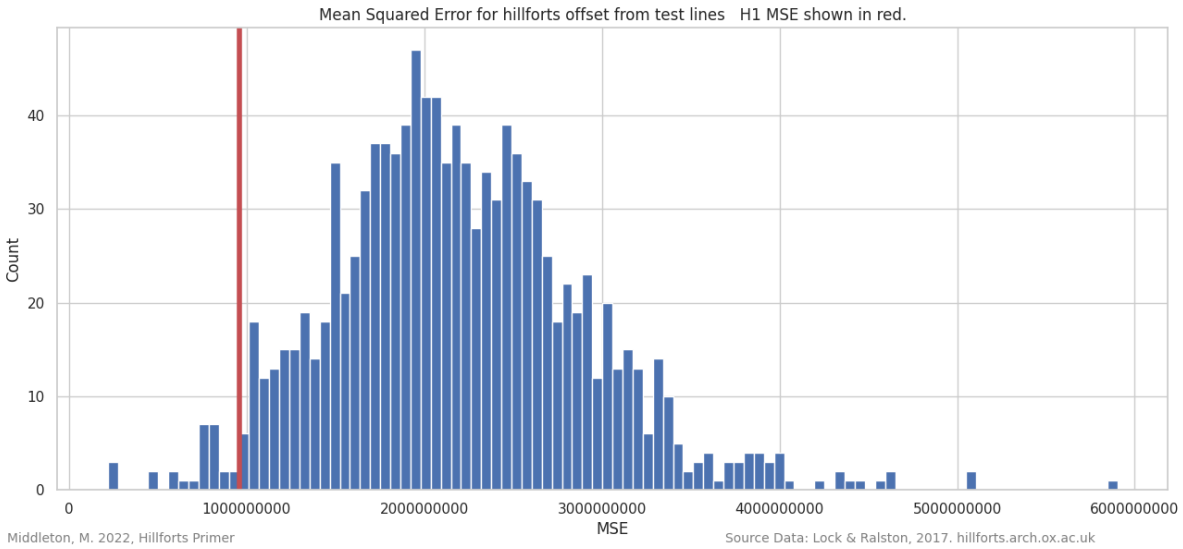
Out[ ]:

	mse
0	1329023715
1	1832084194
2	3014799598
3	2769225228
4	1299407983

Mean Squared Error (offset)

With these results we can plot a histogram of the MSE data. As anticipated the random alignemnts have produced (more-or-less) a normal curve. The H1 alignement is toward the far left of the curve.

In [ ]:
```
plot_mse_hisogram(mse_list, mse_h1)
```

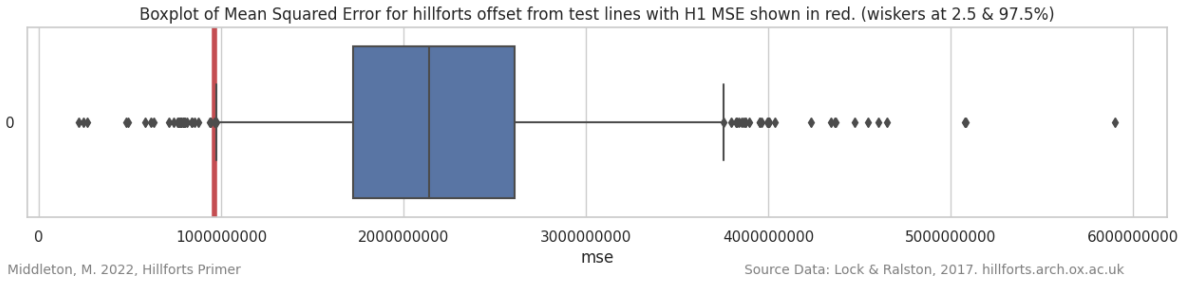


In [ ]:
```
mse_h1
```

Out[ ]:
```
959477730
```

A boxplot of the same data shows the interquartile range (IQR) (the blue box) and the first and fourth quarted bounded by the whiskers. The whiskers, on either side of the IQR are located at 2.5% and 97.5%.

In [ ]:
```
offset_range = plot_data_range_95(mse_list, "mse", "Boxplot of Mean Squared Error
```



In [ ]:
```
print(f"H1 MSE = {round(mse_h1/(offset_range[0]/2.5),2)}%")
```

```
H1 MSE = 2.46%
```

The H1 line (red) has a probabilty of 2.46%, just under 2.5%. Below 2.5% or over 97.5% are routeenly considered the values above and below which the null hypothesis can be rejected.

Hillforts of 21 Ha and over, falling within 50 km of a straight line between (1155) Penycloddiau, Denbighshire (Pen y Cloddiau) and (139) Bozedown Camp, Oxfordshire (Binditch), are aligned.

Save Figure List

In [ ]:
```
if save_images:
    path = os.path.join(IMAGES_PATH, f"fig_list_{part.lower()}.csv")
    fig_list.to_csv(path, index=False)
```