FPT_analysis.py User Guide

User Guide for First Passage Time (FPT) Analysis and Diagnostic Output

Purpose. This script performs First Passage Time (FPT) analysis on GPS trajectories to identify locations and spatial scales at which movement becomes concentrated. It calculates the variance of log-transformed FPT across a range of radii, then visualizes FPT values as a time series, a histogram, and a map of the movement path. These outputs help users evaluate where and at what spatial scale area-restricted search (ARS) or other concentrated movement patterns may occur.

1. Overview

- The script is intended for biologging datasets containing at least time, latitude, and longitude columns.
- It is particularly useful for exploratory analysis of GPS movement paths when the aim is to identify candidate zones of prolonged residence or concentrated search behaviour.
- The recommended workflow is: inspect the variance of log(FPT) across radii, select a biologically reasonable radius, and then interpret the resulting FPT map, time series, and histogram together.

2. Expected Input

Required columns: time, latitude, longitude

Optional column: number_of_satellites

3. Input Parameters

Prompt	Default	Use in most cases	Adjust when…
Enter the file name (without .csv)	—	Enter the target CSV file. The .csv extension may be omitted.	Only if the file is stored under a different name or path.
Enter the UTM zone	54	Use the zone appropriate for the study area.	Change when the track lies in a different UTM zone.
Minimum number_of_satellites	4 when the column is present	Use the default to reduce obviously poor-quality fixes.	Lower or skip the filter only when the dataset lacks this column or when GPS density would otherwise become too sparse.
Enter minimum radius (km)	User defined	Choose a lower bound small enough to detect local concentration.	Increase when very small radii are dominated by noise.
Enter maximum radius (km)	User defined	Choose an upper bound that covers the broad scale of movement.	Decrease when large radii smooth over the behavioural contrasts of interest.

Enter step radius (km)	User defined	Use a step small enough to describe the variance curve smoothly.	Increase when computation time is excessive or decrease when the curve needs finer resolution.
Enter the selected radius for DisplayFPT (km)	User defined	Select a radius after inspecting the variance plot.	Adjust when the chosen value does not match the biologically meaningful scale suggested by the variance curve.
Enter the file name (without .csv)	—	Enter the target CSV file. The .csv extension may be omitted.	Only if the file is stored under a different name or path.
Enter the UTM zone	54	Use the zone appropriate for the study area.	Change when the track lies in a different UTM zone.
Minimum number_of_satellites	4 when the column is present	Use the default to reduce obviously poor-quality fixes.	Lower or skip the filter only when the dataset lacks this column or when GPS density would otherwise become too sparse.
Enter minimum radius (km)	User defined	Choose a lower bound small enough to detect local concentration.	Increase when very small radii are dominated by noise.
Enter maximum radius (km)	User defined	Choose an upper bound that covers the broad scale of movement.	Decrease when large radii smooth over the behavioural contrasts of interest.

4. Example Run

```
python FPT_analysis.py
Enter the file name (without .csv): 9B41870_TS-AxyTrek_Movebank_YNo.6_release20210824
Enter the UTM zone (e.g., 54 for Zone 54N): 54
Minimum number_of_satellites (press Enter to use all) [4]:
Enter minimum radius (km): 0.05
Enter maximum radius (km): 1
Enter step radius (km): 0.05
Enter the selected radius for DisplayFPT (km): 0.3
```

5. Output Files

`variance_log_fpt_vs_spatial_scale.png` Plot of spatial scale versus variance of log(FPT).

`*_FPT_<radius>km_timeseries.png` Time-series plot of FPT values at the selected radius.

`*_FPT_<radius>km_histogram.png` Histogram of FPT values at the selected radius.

`*_FPT_<radius>km_FPT_on_MovementPath.png` Map of the movement path with FPT values encoded by symbol size and colour.

`*_FPT_<radius>km.csv` CSV file containing the extracted rows and FPT values for the selected radius.

6. Choosing the Radius

FPT analysis is strongly influenced by spatial scale. Small radii emphasize fine-scale changes in movement but may be noisy, whereas large radii smooth over local concentration and emphasize broader residence patterns. A practical approach is to examine the variance of log (FPT) across radii and choose a radius near the scale at which movement concentration becomes most clearly expressed.

In theory, the peak of the variance curve often marks the representative scale of behavioural switching. In practice, however, peaks can be broad or multiple. In such cases, it can be useful to select the radius just after the main peak where the curve begins to decline, because this may better represent the upper scale at which concentrated behaviour is still maintained. This interpretation is consistent with common use of FPT analysis in movement ecology and with the practical guidance described in the accompanying article.

7. Interpretation of the Present Example

For this track, the variance plot suggests that a radius of approximately 0.3 km captures the spatial scale at which concentrated behaviour is most clearly expressed. At this radius, the FPT map highlights a limited number of areas with especially high values, and the time series shows corresponding temporal peaks.

These high-FPT segments should not be interpreted as direct proof of foraging itself. Rather, they indicate locations and times at which movement slowed or became concentrated. In seabirds, such segments may reflect searching, foraging, or other forms of localized activity, but ecological interpretation should ideally be supported by additional information such as dive data, acceleration data, or environmental context.

8. Practical Notes

- The quality of the result depends on the temporal resolution and regularity of the GPS track. Long gaps or noisy fixes can affect interpretation.
- FPT analysis is scale dependent. It is good practice to inspect the variance curve rather than selecting a radius arbitrarily.
- Visual interpretation should combine the variance plot, map, time series, and histogram. No single output is sufficient on its own.
- FPT identifies candidate zones of concentrated movement, not feeding events themselves. Biological conclusions should be strengthened with other data sources whenever possible.

Example Output Figures

These figures (Figs. 1–4) show an example of the FPT workflow applied to a GPS-tracked Streaked Shearwater dataset.

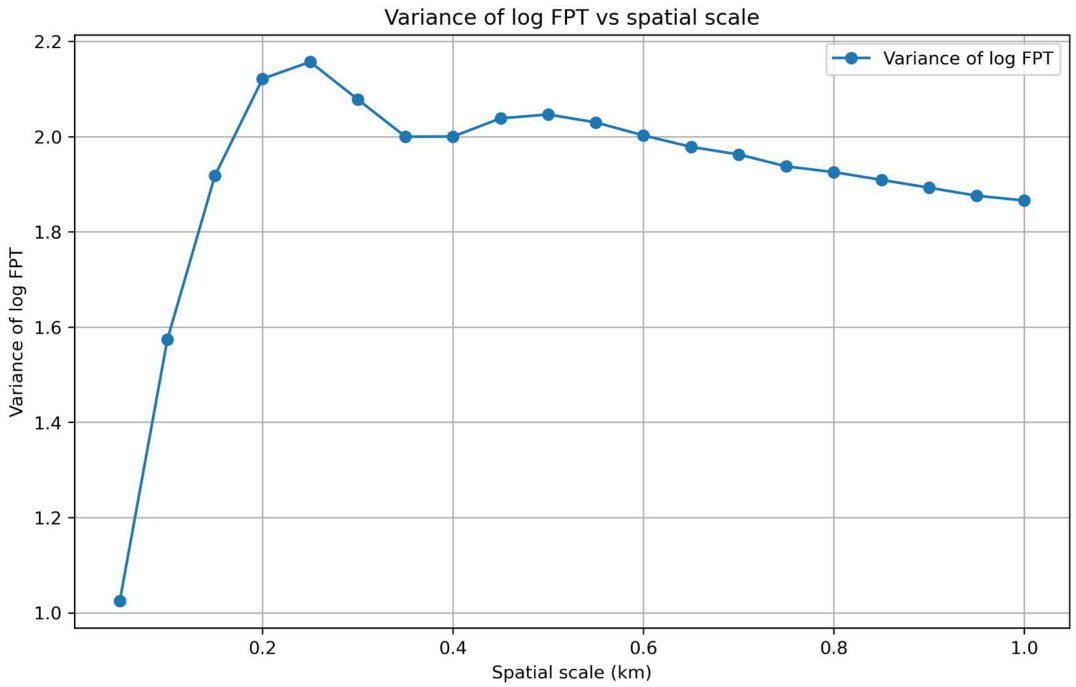

Fig. 1. Variance of log (FPT) plotted against spatial scale. In this example, the variance rises rapidly at small radii, reaches a broad maximum around 0.20–0.30 km, and then gradually declines. This pattern suggests that concentrated movement is expressed most clearly at an intermediate spatial scale, and a radius of 0.3 km is therefore a reasonable choice for subsequent visualization.

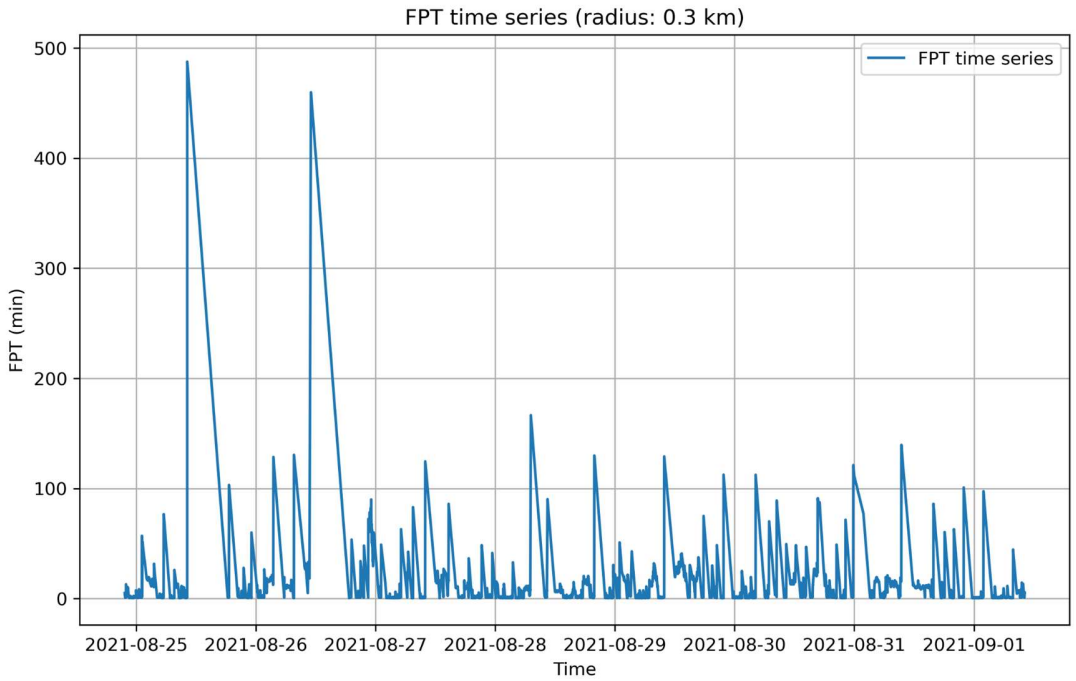

Fig. 2. FPT time series for a radius of 0.3 km. High peaks indicate periods during which the bird remained within the same spatial neighbourhood for a relatively long time, whereas low values indicate more direct and rapid movement. In this example, several pronounced peaks suggest repeated episodes of localized residence or search behaviour during the deployment.

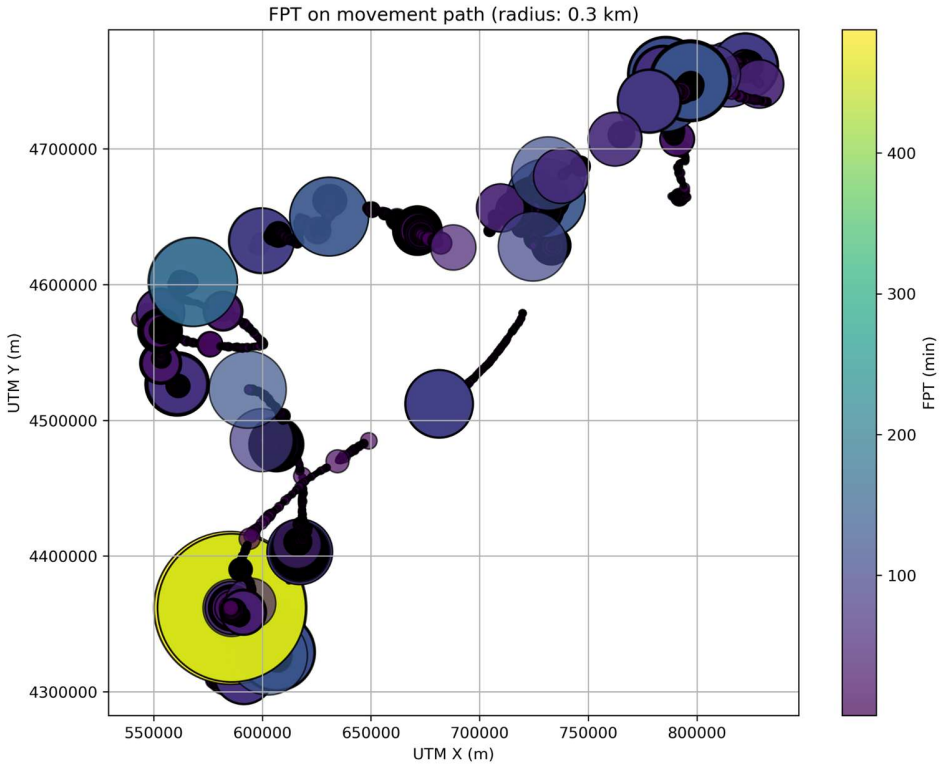

Fig. 3. FPT values projected onto the movement path for a radius of 0.3 km. Larger and lighter symbols indicate higher FPT values and therefore longer local residence. These points highlight candidate areas where exploratory or area-restricted search behaviour may have been concentrated.

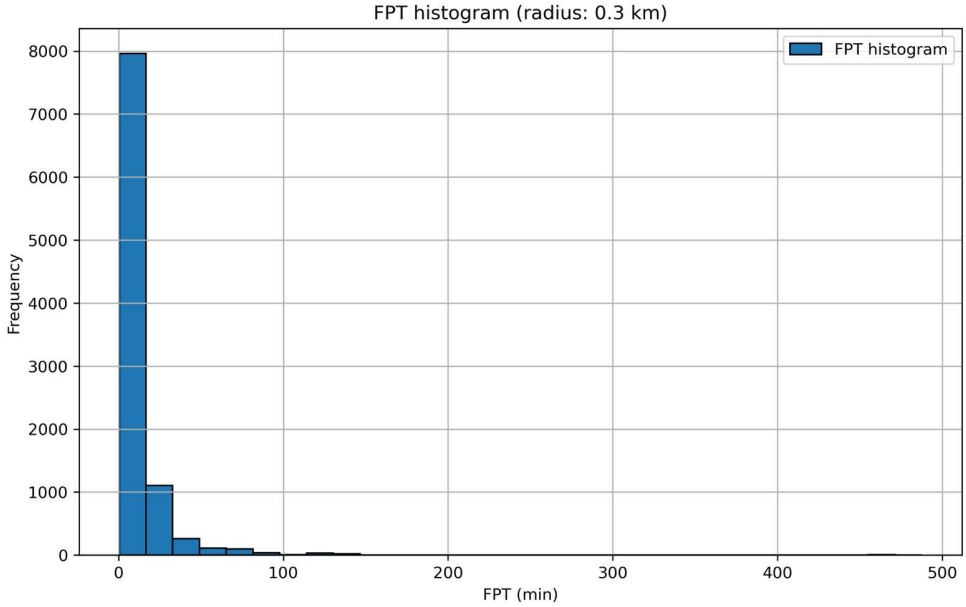

Fig. 4. Histogram of FPT values for a radius of 0.3 km. The strongly right-skewed distribution indicates that most locations were passed quickly, whereas a smaller number of locations were associated with long residence times. This contrast supports the interpretation that the track contains a mixture of transit segments and concentrated movement segments.