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Trajectory Analysis of Griffon Vulture in Kvarner Bay

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Abstract: Advancements in technology have allowed for detailed tracking of animal movements, revealing the complexity of their behaviour, and aiding in conservation efforts. The study of Griffon Vultures in the Kvarner Bay is a prime example of the importance of trajectory analysis in understanding habitat requirements, migration patterns, and disease surveillance of endangered species. This study helps in analysing their trajectories for better understanding of their behaviour. The results suggest that Griffon Vultures soar in trajectories with low straightness and low velocity which confirms the hypothesis based on their natural movement, mostly for searching for food. Every day approximately 12 hours of data were recorded, and the average distance crossed in one day was 600 meters. The calculated fractal dimension is close to 1, which suggests directed movement towards a clear target.

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1. Introduction

Animal movement and the trajectories they follow have been a topic of interest for diverse scientific disciplines, such as physics, biology and ecology.

The analysis of trajectories, which are recorded tracks of individual animals' movements through space and time, has been used to answer questions about animal foraging, navigation, dispersal ecology, migration and behavioural mimicry. The obtained analysis results are then used for conservation efforts, forecasting and controlling the spread of diseases and thus preventing animal extinction from happening.

Animal trajectories are calculated as a series of specific discrete locations over time and are typically limited to two spatial dimensions. After calculations, each trajectory can be visualized and analysed as a series of steps, each one having a length and a direction. The steps represent the vector between each sampled location.

In recent years, advances in technology have enabled researchers to track and monitor the movements and trajectories of animals in exceptional detail and scale, revealing new insights into the complexity of their behaviour. The movement of animals is influenced by a variety of factors that include intrinsic factors, such as physiology, behaviour and genetics, and extrinsic factors, such as environmental conditions and resource availability. These factors interact in complex ways to shape the movement and trajectories of animals, which makes it challenging to study and understand it but on the other hand it makes it a very important task for scientists to investigate.

Our research is based on Griffon Vultures that are soaring over Kvarner Bay in Croatia. The Griffon Vulture is an endangered species that requires attention for preventing extinction. Tracking the movement of Griffon Vultures is important for better understanding their habitat requirements and migration patterns as well as disease surveillance. In addition, trajectories analysis can help with their interaction with other species.

The rest of the paper is structured as follows: In section Methods we describe the dataset and approaches for the trajectory analysis. In section Hypothesis the hypothesis is presented. In section Results we analyse the obtained results with several evaluation metrics. Finally, we conclude the paper in section Conclusion.

2. Hypothesis

The research presents a hypothesis that there is an exact methodology for a unique formal description of animals' movement, which renders different trajectories comparable in an unbiased manner. The hypothesis claims that griffon vultures soar with low velocity (under 2 m/s) and low straightness. Since griffon vultures search for food most of the time, the hypothesis is that the fractal dimension will be ~1 since their movement has little deviations from their desired path.

3. Materials and methods

The R programming environment for statistical computing is a suitable option for analysing animal trajectories due to its powerful statistical packages, ability to handle large datasets, and open-source nature with online resources available. In this paper, functions from the trajr library developed for working with trajectories in R were used to evaluate the hypothesis that was made regarding the features of trajectories depicting the movement of Griffon Vultures.

3.1. Dataset

The dataset consists of flight records of Griffon Vultures flying over Kvarner Bay, mostly over the islands Krk and Cres, from the MoveBank website. The file is part of the research done for the LifeTrack Griffon Vulture Croatia study. The goal of the study was to follow re-released Vultures from the care center in Beli, on the island of Cres, and measure their flight behaviour [1].

Of the many values recorded in one measurement, we only focused on UTM (Universal Transverse Mercator) easting and UTM northing coordinates as they are used for creating a trajectory, as well as the timestamp. The timestamp is optional, but it is necessary if an accurate calculation of speed and acceleration for the trajectory is needed. We used UTM easting and UTM northing coordinates instead of latitude and longitude, which were also available in the recorded measurements because the functions in the trajr library only work with UTM easting and UTM northing coordinates. Conversion of latitude and longitude into UTM easting and UTM northing coordinates is also possible, but it was not necessary since the recorded data already contained both values. We used latitude and longitude to draw a line on a map representing the movement of the Griffon Vulture to better illustrate the data we are working with.

We decided to group the measurements by date and consider them a single trajectory since our goal was to observe the daily habits and routines of Griffon Vultures. Records were sorted by date in ascending order, and then by time in ascending order.

Before a trajectory can be created from UTM easting and UTM northing coordinates, the timestamp that they are linked to must be converted from a date and time format into a single number that represents the elapsed time in seconds from the chosen starting point. This is necessary to correctly estimate speed and acceleration for the trajectory. Milliseconds were not recorded.

3.2. Trajectory features

For each trajectory, diffusion distance, straightness, duration of travel, mean travel velocity, and fractal dimension is calculated. These features of each trajectory were statistically analysed, as described in the rest of this document. The preprocessing of data, the calculation of the described trajectory features, and the subsequent division of the trajectory with the largest diffusion distance into hour-long trajectories to observe the habits of Griffon Vultures in a single day is described in Figure 1.

1) Velocity

Velocity can only be measured on a segment of the trajectory between two points. There are three ways to define velocity in a single point instead of a segment. If only the velocity of the segment preceding the point is considered, we need to specify this in the function TrajVelocity from the trajr library using "backward" as the value of the diff parameter. If only the velocity of the segment following the point is considered, we use "forward" as the value of the diff parameter. If the arithmetic average of the velocity of the segment preceding the point and the velocity of the segment following the point is calculated, we use "central" as the value of the diff parameter. Since the "forward" and "backward" method can produce misleading results in case of a sudden and large change in velocity, the "central" method is the default approach if the diff parameter of the function TrajVelocity from the trajr library is not specified. We decided to use the "central" method as well due to the uncharacteristically large values for the speed of the flight of the Griffon Vulture which the "forward" and "backward" methods produced. The large values are most likely due to wind gusts, calculation errors, or measurement errors.

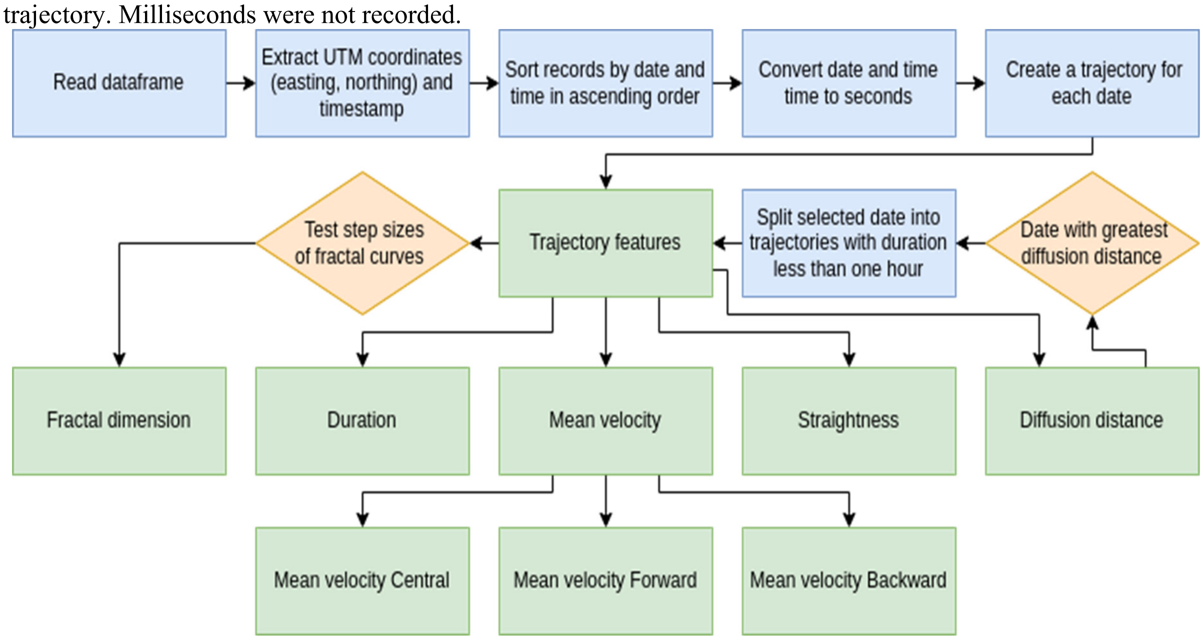


Fig. 1. Data preprocessing, calculation of trajectory features and division of the trajectory with the largest diffusion distance into hour-long trajectories.

2) Fractal dimension

The fractal dimension has been proposed as a valuable measure for straightness or tortuosity, with values ranging between 1 (representing straight line movement) and 2 (movement that frequently changes direction). However, research has shown that using fractal dimension as a measure for animal trajectories is problematic because animal trajectories are not fractal curves. Because of this their fractal dimension strongly depends on the variable range of step sizes used for the calculation [b2]. Despite these limitations, fractal dimension is still commonly calculated. The modified 'dividers' method [3] is used by default in the TrajFractalDimension function to adjust for truncation error and the corresponding equation for the 'dividers' method is contained in equation 1. By recommendation of Nams [4], this function compensates for the overestimation of D by default. This is done by walking the dividers backward and forward. After the final step, the length of the path that remains is estimated.

$$D_0 = \lim_{\varepsilon \to 0} \frac{\log N(\varepsilon)}{\log \frac{1}{\varepsilon}} \quad (1)$$

In order to calculate fractal dimension, a range of step sizes that will be used for all trajectories must be defined. The TrajLogSequence function from the library trajr was used to return a sequence of 10 points which are regularly spaced between 0.1 and 3 when plotted on a logarithmic axis. Only 10 points were used because computational complexity and execution time increases significantly with a larger number of points. A test must be conducted to ensure that the trajectory is a fractal curve for the given step sizes. This is done by using the function TrajFractalDimensionValues which returns path lengths for a given trajectory and a range of step sizes. If the relationship between step size and path length is linear, then the trajectory is a fractal curve for the given range of step size. With a process of trial and error, we settled on the range of step sizes between 0.1 and 3 because the relationship between step size and path length was linear for all tested trajectories in this range.

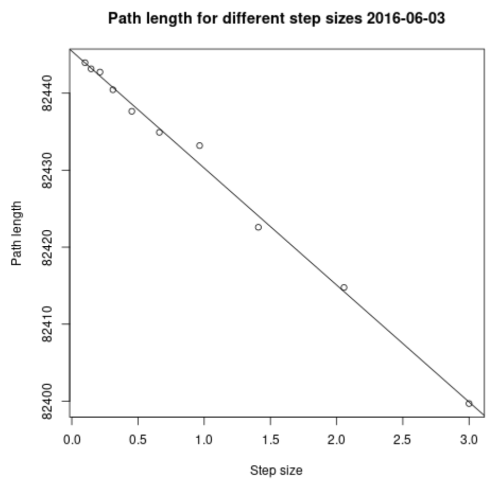


Fig. 2. Relationship between step size and path length.

In order to demonstrate this, one curve representing the relationship between step size and path length was plotted, as shown in Figure 2, along with a 45-degree reference line, for a trajectory that covers a whole day and has the largest diffusion distance. This can be seen in Figure 2. For larger step sizes, nonlinearity was observed. Additionally, some short trajectories could not support a step size larger or equal to 4.

3) Straightness

Trajr contains several built-in methods for measuring the straightness or tortuosity of trajectories. One of these methods uses the simple D/L formula, where D is the distance between the trajectory's start and end, while L is the trajectory's length. The TrajStraightness function calculates the straightness index in this manner. The straightness index obtained with this function ranges from 0 to 1, with 1 indicating a completely straight line. Some sources [5] consider this value to be a reliable indicator of efficiency if applied to a directed walk, even though it is not applicable to random trajectories. Others [6] approximate the straightness index with the length of the mean vector of turning angles (r) after rediscretization to a constant step length.

As animal movement trajectories are not random trajectories, but are usually directed walks towards some goal in the environment, the simpler straightness index defined by D/L and calculated by the function TrajStraightness, was used in this paper.

3.3. *Statistical* analysis

The minimum, first quartile, median, third quartile, maximum, standard deviation, and variance are calculated to help estimate a continuous distribution from the data in further processing. The statistical analysis of each trajectory feature with all the calculated parameters and estimated distributions is described in Figure 3.

3.4. Estimating a continuous distribution

Histograms are created for each feature of the trajectories. A line representing the estimated kernel density is drawn along with the histogram. Lines that represent the probability density of the estimated normal, log-normal, exponential, Gamma, and Weibull distributions are also drawn. Before a continuous distribution can be estimated, duplicate values must be removed from the data.

Any missing and infinite values must be removed as well. We test if the data fits the estimated continuous distributions using the Shapiro-Wilk test for the normal distribution and the Kolmogorov-Smirnov test for the normal as well as all the other estimated distributions. If the p-value is less than the alpha value of 0.05, the initial hypothesis that the data fits the estimated continuous distribution is rejected.

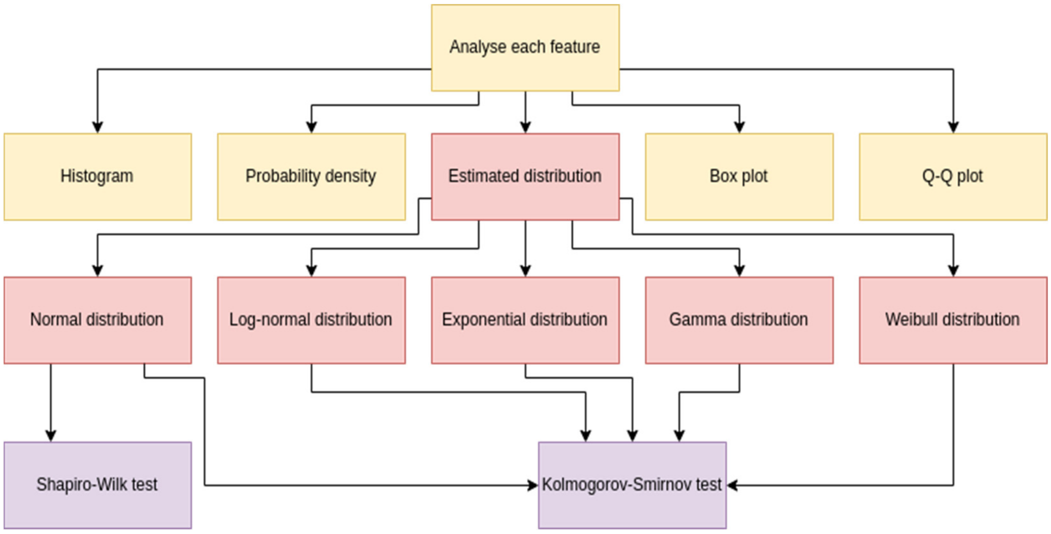


Fig. 3. Statistical analysis of trajectory features with calculated parameters and estimated distributions.

1) The log-normal distribution

In the log-normal distribution, the logarithm of the variable is normally distributed. Thus, $exp(\mu)$ equals the median of the data, and $exp(\mu + \frac{\sigma^2}{2})$ equals the mean of the data. We can calculate the median and the mean of the data and use these values to calculate μ and σ for the estimated log-normal distribution, as illustrated in the relations established in the previous sentence.

2) The exponential distribution

In the exponential distribution, the inverse value of the rate parameter is equal to the mean of the data. The inverse value of the rate parameter is equal to the scale parameter. We can use this knowledge to estimate the rate (λ) and the scale parameter for the estimated exponential distribution.

3) The Gamma distribution

In the Gamma distribution, the mean value of the data is equal to the product of the shape (k) and scale (θ) parameters, or $k\theta$. The variance of the Gamma distribution is equal to the product of the shape parameter and the square of the scale parameter, or $k\theta^2$. We can calculate the variance and the mean of the data and use these values to calculate the shape and scale parameters for the estimated Gamma distribution, as explained in the relations established in the previous sentence.

4) The Weibull distribution

Instead of a step-by-step calculation, the function eweibull from the EnvStats library was used to estimate the shape (k) and scale (λ) parameters for the Weibull distribution in order to simplify the code.

3.5. Analysis of hour-long trajectories

After the analysis was complete for all the trajectories that cover a full day, the trajectory which has the largest diffusion distance was identified. This trajectory, which covers a full day, was divided into smaller trajectories. The motivation for creating shorter trajectories was to determine whether there was any change in the activity of Griffon Vultures within a single day, and not exclusively over the course of several days. We chose the date with the largest diffusion distance because this would give us more data to analyse. This analysis was not repeated for each day because of time constraints. The goal was to choose smaller trajectories that have a duration of approximately one hour. Any larger duration would be too close to a full day. Any shorter duration would have a very small number of points and a very small diffusion distance, so calculated velocity and other values would not be accurate and would not reflect the data as a whole.

These small trajectories were created by adding points to a trajectory one by one until the duration of the trajectory became larger or equal to 3500 seconds, at which point the created trajectory was saved and a new one began. This was done in order to create trajectories that had a duration as close as possible to one hour. If we had chosen to terminate trajectories once the duration exceeded or became equal to exactly 3600 seconds, the duration of each trajectory would have been significantly larger than the desired hour. This happens because the average time between measurements is quite large when compared to an hour, usually several minutes. Once these new shorter trajectories are created, the same features are calculated and analysed in the same way it was done for the longer trajectories.

4. Results

The results obtained from the analysis of trajectories confirmed our thesis on the movement of griffon vultures. Griffon vultures move by soaring, and this is evident from the results that show a low speed of movement. The outliers in speed show that anomalies, such as strong wind, can increase the soaring velocity. It can also be seen that the movement trajectories of griffon vultures have low straightness which confirmed the thesis of circular soaring for finding food. The fractal dimension is ~1, which means that the griffon vultures movement did not deviate from their desired path very often. The duration of daily trips is measured for ~12 hours. The graphical representation of trajectories is shown in Figure 4 where the blue line shows the trajectory with the largest diffusion distance and the red line showing all trajectory points of all days.

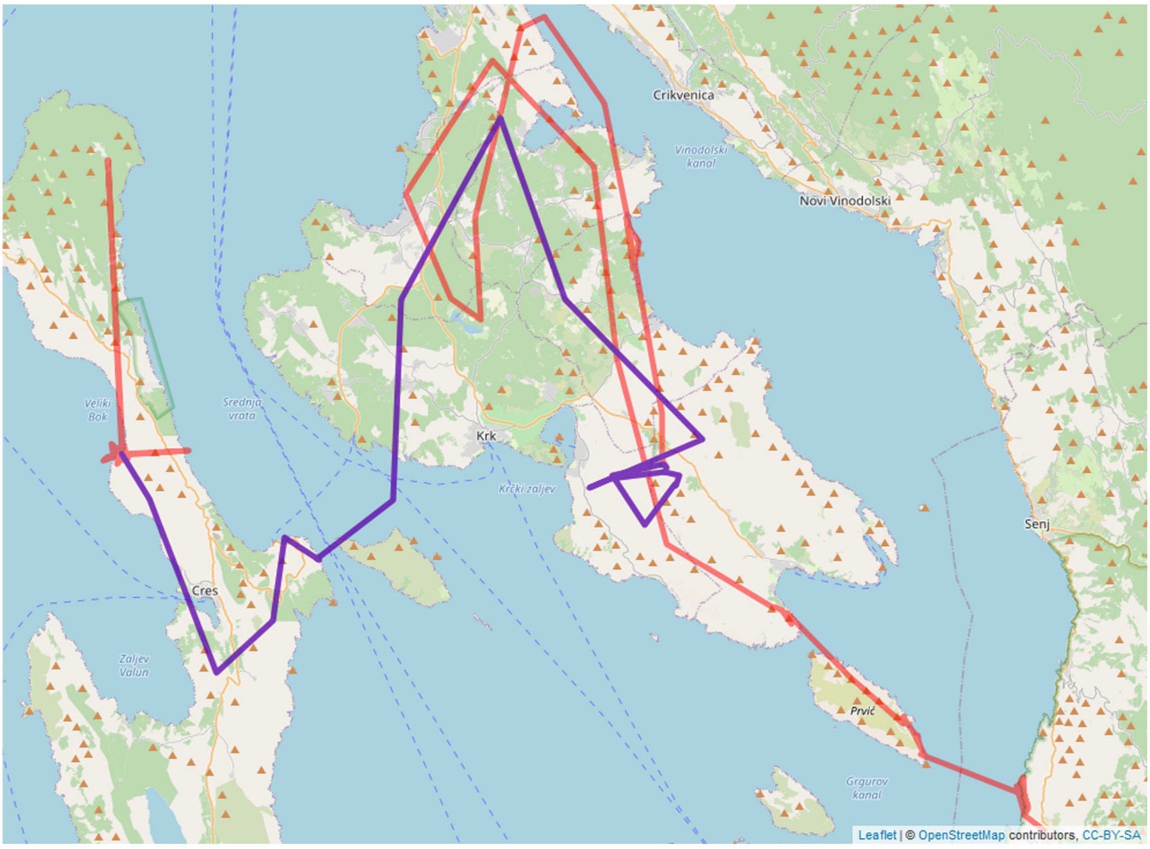


Fig. 3. Griffon Vultures trajectories. Blue showing the trajectory with the largest diffusion distance and red showing all trajectory points of all days.

The statistical analysis of all trajectories can be found in Table 1 and the statistical analysis of the specific date 2016-06-03 can be found in Table 3.

In Table I it can be seen that Griffon Vultures fly almost 600 meters on average with a trajectory that has an average straightness of 0.8125. The central velocity shows that the average speed of Griffon Vultures in the Kvarner Bay area is less than 1 m/s which confirms the hypothesis of them flying at low speed.

Table 1. Observed features of trajectories and p-values.

Name	Min	Q1	Median	Arithmetic mean	Q3	Max	Variance	St. dev.
Diffusion distance (m)	0.78358	4.35953	7.17817	587.2926	11.80907	25526.165	9896147	3141.52
Straightness	0.0001	0.00381	0.00965	0.08125	0.03241	0.98585	0.03444	0.18558
Duration	28782	41375.5	41375.5	41124.73	41391.25	53973	10895691	3300.862
Mean velocity (central) (m/s)	0.00013	0.01523	0.04085	0.53539	0.14121	52.96057	22.38886	4.73167
Mean velocity (forward/backward) (m/s)	0.00022	0.02106	0.07847	0.13891	0.16444	1.97052	0.06416	0.25330
Fractal dimension	1.00011	1.03526	1.04811	1.04811	1.06461	1.11115	0.00053	0.02312

Table 2. Observed features of trajectories and p-values.

Distribution	Normal	Normal	Log-normal	Exponential	Gamma	Weibull
Test	Shapiro-Wilk	Kolmogorov - Smirnov				
Diffusion distance (m)	< 2.2e-16	< 2.2e-16	4.848e-8	< 2.2e-16	< 2.2e-16	4.808e-11
Straightness	< 2.2e-16	< 2.2e-16	0.00197	< 2.2e-16	2.472e-11	0.00816
Duration	2.425e-10	1.579e-7	8.677e-9	< 2.2e-16	3.888e-7	1.09e-7
Mean velocity (central)	< 2.2e-16	< 2.2e-16	0.02924	< 2.2e-16	< 2.2e-16	0.00947
Mean velocity (forward/backward)	< 2.2e-16	1.103e-9	0.00301	0.00557	8.161e-10	0.6163
Fractal dimension	0.0214	0.5864	0.00558	< 2.2e-16	0.5525	0.6307

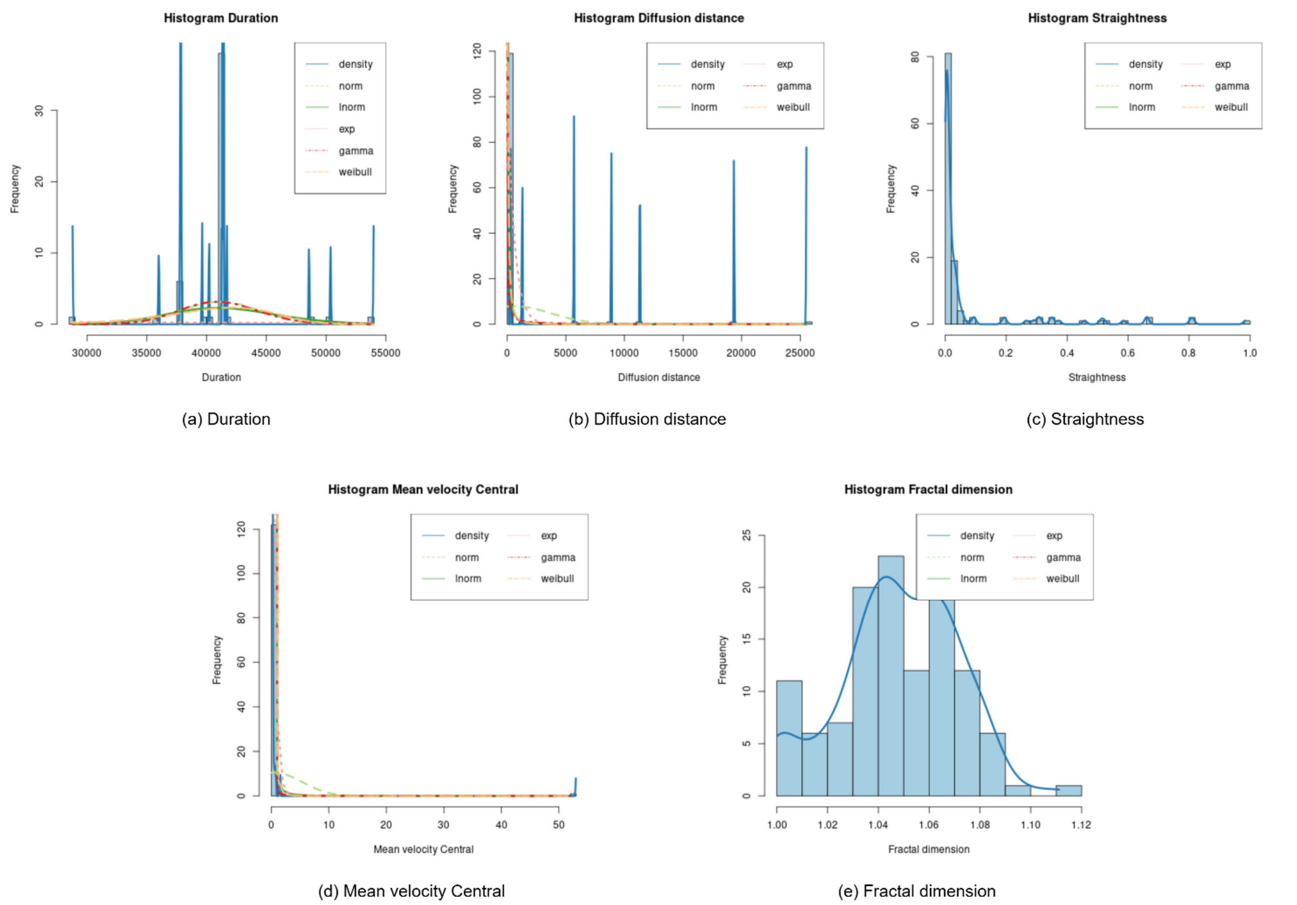
Table 3. Statistical analysis of trajectory features for 2016-06-03.

Name	Min	Q1	Median	Arithmetic mean	Q3	Max	Variance	St. dev.
Diffusion distance (m)	7.2619	35.61172	2434.5412	3021.966	2824.16292	12404.78795	16060629	4007.571
Straightness	0.24061	0.42038	0.68374	0.66793	0.98122	1.0000	0.09571	0.30937
Duration	1770.00	3590.50	3600.50	3417.2	3607.75	3622.00	335189.1	578.9552
Mean velocity (central) (m/s)	0.00487	0.01223	0.59749	1.21629	1.56179	5.521138	3.04297	1.74441
Mean velocity (forward/backward) (m/s)	0.00486	0.02431	0.72097	1.55584	2.1577	7.96301	6.08095	2.46595
Fractal dimension	1.00000	1.00007	1.00022	1.00781	1.00404	1.0443	0.00024	0.01542

Table 4. Observed features of trajectories and p-values for 2016-06-03.

Distribution	Normal	Normal	Log-normal	Exponential	Gamma	Weibull
Test	Shapiro-Wilk	Kolmogorov - Smirnov				
Diffusion distance (m)	0.004759	0.2324	0.05899	0.08191	0.2252	0.3083
Straightness	0.07501	0.6423	0.08154	0.2317	0.5789	0.5741
Duration	1.834e-7	0.00741	0.00919	0.00241	0.00459	0.00457
Mean velocity (central)	0.00324	0.5163	0.06521	0.0885	0.3868	0.6829
Mean velocity (forward/backward)	0.00047	0.212	0.08607	0.1104	0.8097	0.7359
Fractal dimension	4.57e-5	0.07513	0.00791	0.00023	0.07691	0.09094

For the fractal dimension, since the griffon vultures have an intended destination in mind and do not alter the direction of their movement, even the maximal value is near 1.



(a) Duration (b) Diffusion distance (c) Straightness

(d) Mean velocity Central (e) Fractal dimension

Fig. 5. Trajectory features histograms.

In the Table 3, the date with the longest diffusion distance is presented which is ~12405 meters. The straightness is, as in the last table, a value that corresponds with low straightness, and in this case with a maximal value of 1. It can be seen, that on this day, the average Central velocity is low, with an average value of 1.2 m/s. The fractal dimension has a maximal value of 1.0433 and thus confirms that the movement does not change course significantly.

Based on the fact that a lot of natural phenomenons behave according to a distribution, we performed 6 tests for 5 different distributions to check if the griffon vulture movement will be distributed to one of these distributions: Normal, Log-normal, Exponential, Gamma and Weibull. For the normal distribution we performed the Shapiro-Wilk and Kolmogorov-Smirnov test, while for all other distributions, the performed test is the Kolmogorov-Smirnov test.

The results of the observed characteristics of the trajectories and their p-values are presented in Table 2, while the observed characteristics and their p-values of the date 2016-06-03 are shown in Table 4.

The bold values of the results in the given table indicate that the hypothesis H0 is not rejected, i.e. that the p-value is greater than 0.05.

The histograms for each trajectory feature can be found in Figure 5.

5. Discussion and conclusion

Based on our research, the Griffon Vulture movement in the Kvarner Bay wasn't yet statistically analysed, so the importance of this paper is to show their movement trajectories which could help in studying them and monitoring changes with the goal of saving the species.

The trajectory analysis of Griffon Vultures shows that they usually move slowly, searching for food on the ground with circular trajectories. However, their movement speed can increase with strong wind.

In the future, this work can be extended to compare the flight behavior of Griffon Vultures in the Kvarner Bay with the flight behavior of Griffon Vultures in the Alps and Himalayan Vultures. The project could be expanded to include a graphical interface where users can select a date from a drop-down menu and download the data described in the paper for that chosen date. The downloadable data would include the values obtained by statistical analysis in a tabular format as well as all the generated charts in the form of images.

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