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Investigating daily movement properties of African White-backed Vulture (*Gyps africanus*) in sub – Saharan Africa

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A dissertation submitted for the degree of

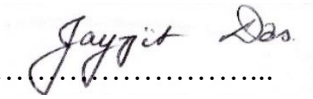
Master of Science in Statistical Ecology

Date: 15th August 2023

Declaration

I hereby certify that this dissertation, which is approximately 4000 words in length, has been composed by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree. This project was conducted by me at the University of St Andrews from May 2023 to August 2023 towards fulfilling the requirements of the University of St Andrews for the degree of MSc in Statistical Ecology under the supervision of Dr Lindesay Scott-Hayward and Dr Hannah Worthington, Centre for Research into Ecological & Environmental Modelling, University of St Andrews.

Date: 15th August 2023

Signature 

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Abstract

The graceful African White-backed Vulture *(Gyps africanus)* has long been a symbol of nature's vast cycles of life and death. Despite its ecological significance, our understanding of its daily movement behaviour remains primitive. This thesis harnessed the prowess of modern telemetry technology to delve deep into the movement patterns of 37 of these vultures, selecting them based on the richness of their monthly data.

At the core of our exploration were four crucial metrics: Daily Distance Travelled (DDT), Daily Maximum Displacement (DMD), Daily Overall Displacement (DOD), and the Straightness of the Daily Path (SDP). Our visual observations highlighted the varied strategies employed by individual birds, from those content to linger in confined regions to more adventurous ones that traversed expansive territories. Generalized Additive Models are used to model the relationships between these daily movement properties and time (Months) as the predictor variable.

The ecological implications of our findings are insightful. The DDT metric offers insights into the distances covered by a bird daily, while DMD reveals if a bird often ventures far from its origin. DOD provides clues about the bird's nesting habits, and SDP helps distinguish between erratic movements and directed, long-distance travels. We found that many vultures reduced their movement ranges between January and June, potentially due to factors like the rainy season, an abundance of food close to roosts, or breeding behaviour.

Conversely, the latter part of the year saw many birds expanding their foraging ranges (based on daily movement parameters), possibly driven by the demands of feeding their young or the dispersed nature of resources. Our findings suggest that these vultures might engage in longer, more direct flights at the start of the year, hinting at possible migratory patterns.

The findings in this study paint a vivid portrait of the life of *Gyps africanus mostly from Tanzania and the neighbouring areas*, revealing their adaptability and strategies in response to changing time (months) and factors associated with the same. In future, leveraging advanced tools and analyses can further deepen our understanding of the species, guiding conservation efforts and fostering a deeper appreciation for these species of immense conservation value, as well as concern.

Motivation

The intricate movement strategy of the African White-backed Vulture (Gyps africanus) against the backdrop of the vast African skies has long intrigued ornithologists and ecologists alike. However, despite the vulture's prominence in the ecosystem and recent studies highlighting their conservation value as well as concern, little is known about its fine-scale daily movement patterns. Given the technological advancements in telemetry, there now exists an opportunity to delve deeper to unravel the fine-scale movement pattern of this important species.

The vast expanses these vultures cover during their daily forays, the erratic or systematic patterns they follow, and their adaptation to the rhythm of the changing seasons—each of these aspects conceals layers of stories waiting to be unraveled. The biological implications of these flight patterns, especially when observed across different individual birds, could be a bring forth interesting insights to aid their on-ground conservation by adding new dimensions to our understanding of this species.

At the core of this study lies the need to harness the power of telemetry data to decode these patterns. With the data provided by dedicated field researchers and the invaluable guidance of my supervisors, I embark on an analytical journey that threads through the daily movement properties of 37 African White-backed Vultures, chosen from a broader pool due to their comprehensive monthly data points.

Our motivation is not just about tracking distances or drawing trajectories. It's about understanding the nuances of these movements. Through metrics such as the Daily Distance Travelled (DDT), Daily Overall Displacement (DOD), Daily Maximum Displacement (DMD), and the Straightness of the Daily Path (SDP), I hope to paint a clearer, more detailed portrait of a day in the life of *Gyps africanus.*

By employing Generalized Additive Models (GAM), I aim to unveil the non-linear relationship between the response variables (birds' daily movements properties) and the progression of time (months).

General Introduction

Movement ecology

The movement patterns of animals, plants, and microorganisms have been a focal point of scientific investigation due to their profound ecological implications. Historically, various fields have delved into these patterns separately. However, the recent emergence of the "movement ecology" framework has sought to integrate these studies into a cohesive discipline [1]. This paradigm hinges on four core elements: three intrinsic to the organism – the inner motivation (why move?), the method of motion (how does it move?), and the navigational decisions (when and where to move?) – and the fourth pertaining to external influences on the movement [1].

At its core, movement can be conceived as the spatial progression of an organism over time [1]. Such mobility plays a pivotal role in shaping individual trajectories, community structures, and broader ecological patterns, operating across various spatiotemporal scales. From an economic standpoint, movement is pivotal as mobile entities, for instance, aid in the dissemination of pollen, seeds, and pathogens, with implications on commodities like crops, which accrue substantial financial value [2]. Hence, understanding animal movement is paramount in decoding biodiversity patterns and ecosystem functionalities [3].

This dynamic of movement is governed by a symbiotic relationship between internal motivations and external stimuli [1]. While intrinsic factors might encompass needs like hunger or safety, external cues can be shaped by environmental structures and the positioning of resources or threats [4]. Additionally, complex social dynamics, reproductive strategies, and territorial behaviours further dictate movement patterns [5]. The quest for essential resources often drives organisms to explore, a behaviour commonly termed "foraging" [4]. The spatial expanse an organism typically traverses for its usual activities is referred to as its "home range" [6], with its size and characteristics modulating according to both environmental and internal changes [7]. Different species manifest varied movement strategies, and within these strategies, it's pivotal to discern the repetitiveness of movement and the level of synchronization among multiple individuals [6].

Such movements can be cyclical, as observed in migratory species that oscillate between discrete home ranges with seasonal variations. Conversely, "nomadism" is characterized by erratic shifts across multiple non-recurring home ranges. On the other hand, "residents" are organisms that remain confined to a consistent spatial boundary throughout the year [6]. While interspecies movement variability is well-documented, intraspecies movement diversity is relatively underexplored [5]. Internal factors, from physiological attributes to behavioral traits, can cause individuals of the same species to adopt varied movement strategies, especially in resource-diverse environments [8]. A noteworthy instance is the "partial migration," where a single species may comprise both migratory and resident members, evident in many large raptors [8]. A case in point is the Pyrenean bearded vultures (*Gypaetus barbatus*; France, Spain), where territoriality dictates distinct movement patterns [9]. A deeper dive by Wheat et al. [8] into bald eagles (*Haliaeetus leucocephalus*; Alaska (USA)

and Canada) unveiled pronounced individualized movement patterns, categorized into four primary strategies.

Further, it's imperative to assess individual movement variability to demystify population-level behaviours. Individual behaviours can significantly influence population viability by affecting vital demographics like dispersal rates, survival chances, and reproductive outcomes. By mapping these individual strategies, researchers can garner insights into the adaptability of species to fluctuating environments, thereby informing conservation and management initiatives more effectively on ground [8].

Species ecology

Species Overview:

The African White-backed Vulture (*Gyps africanus*) emerges as a predominant avian species across Africa, marking its presence, particularly in Namibia and neighbouring territories. While historically abundant [10] , recent trends have been disconcerting. With populations dwindling to an estimated 270,000 individuals, certain regions have seen a near-collapse, with decreases up to 90% over three generations. This alarming trajectory has culminated in the IUCN's classification of the species as Critically Endangered [11].

Habitat and Geographical Distribution:

These vultures exhibit a strong preference for open savannahs dotted with Acacia trees, a habitat choice that aligns with their nesting needs [11]. Namibia serves as a stronghold for this species, with the Etosha National Park and the Zambezi Region emerging as primary habitats. Moreover, central and eastern Namibia witness their notable presence [12]. Despite their extensive range, recent observations have documented declines in areas like Kenya, notably in the Laikipia district [13]. Previously, the vulture's dominance extended throughout Kenya, particularly with breeding concentrations in southern and central areas [11]. Data for this thesis mostly pertains to the birds from Tanzania and its surrounding areas.

Dietary Habits:

As proficient scavengers, these vultures rely predominantly on medium to large mammals' carcasses, including domesticated animals [11]. Their collective and coordinated foraging behavior, combined with their soaring flight and sharp eyesight, positions them to identify and access food sources efficiently, often pre-empting mammalian competitors [14].

Flight Dynamics and Societal Behavior:

Characterized by their efficient soaring capabilities, they utilize thermals to ascend to around 800 meters, cruising between thermals at approximately 65 km/h . Their social tendencies are evidenced by group formations at feeding grounds, during flight, and at roosting sites [11]. Fascinatingly, some populations seem to modify their territorial boundaries, possibly influenced by shifts in food abundance and periodic rainfall [11].

Reproductive Patterns:

Research rooted in Namibia pinpoints a winter-centric breeding pattern for the African White-backed Vultures. Predominantly, egg laying is centred around May, but this pattern exhibits regional shifts. For instance, data from Etosha (1998-2012) denotes egg-laying between March and July, in contrast to the central areas which reflect a timeline between April and June during 2003-2013 [12]. This reproductive phase witnesses collaborative efforts, with both partners engaging in joint parental responsibilities [15]. The vultures typically nest in trees, often forming relatively loose colonies. Their nests, rather modest in size given their stature, are often perched atop tall trees, preferably near rivers or drainages [16]. Regarding reproductive timeline, critical observations from the Serengeti National Park in Tanzania highlight a primary laying phase around mid-April, possibly synchronised with the availability of their preferred food source – large ungulate carcasses[11] .

Conservation Concerns:

The catastrophic declines witnessed in vulture populations, especially in South Asia [17] and specific African territories [18], [19] have amplified the need for rigorous surveys and monitoring initiatives across eastern and southern Africa [20].

In conclusion, the African White-backed Vulture's ecological significance mandates urgent conservation strategies. Their integral role in Africa's ecosystems and concerning decline underscores the imperative of targeted preservation efforts.

Method

Telemetry data collected from the field was provided by the supervisors for analysis.

In this thesis, we delve into the daily movement patterns of the focal species - African White-backed Vulture (*Gyps africanus*), examining four distinct metrics for each vulture: Daily Distance Traveled (DDT), Daily Maximum Displacement (DMD), Daily Overall Displacement (DOD) and The Straightness of the Daily Path (SDP). We further analyze how these metrics evolve over time (months of a year), building upon existing literature. By comparing patterns across individual vultures, we highlight the significant biological implications of our findings. 37 birds out of the available list of birds had data points across the months and were used to investigate movement behaviour based on the daily movement properties across the months, as explained below.

Daily Movement Properties:

Based on the methods delineated by Spiegel et al.[4] and Claudia [11], four distinct metrics were employed to analyze the daily movement dynamics. It's worth noting that the calculated distances were essentially minimum distances due to their reliance on the data's temporal granularity. Additionally, a "day" was demarcated as a complete twenty-four-hour cycle, starting from one midnight and concluding at the subsequent midnight. All the distances were Euclidean.

The *Daily Distance Travelled (DDT) was* computed by aggregating the Euclidean distances between consecutive points recorded within a single day. Meanwhile, the *Daily Overall Displacement (DOD)* was determined as the direct linear distance from the initial to the concluding point of a particular day. The *Daily Maximum Displacement (DMD)* was derived by calculating the maximum displacement between the first and each consecutive fixes. The *Straightness of the Daily Path* (SDP) was estimated by determining the quotient of the DMD over the total straight-line distances among sequential points from the starting location to the most distant point within the day.

While most of these metrics (three out of the four) produce a distance-based outcome, the SDP presents a unique metric in the form of a ratio. Given that its numerator (DMD) invariably remains smaller than its denominator – DDT , the SDP can range only between zero and one. A ratio nearing zero would indicate erratic flight paths, whereas a ratio closer to one signifies a more linear flight trajectory. The assessment of distances between recorded locations was accomplished within the R environment [21].

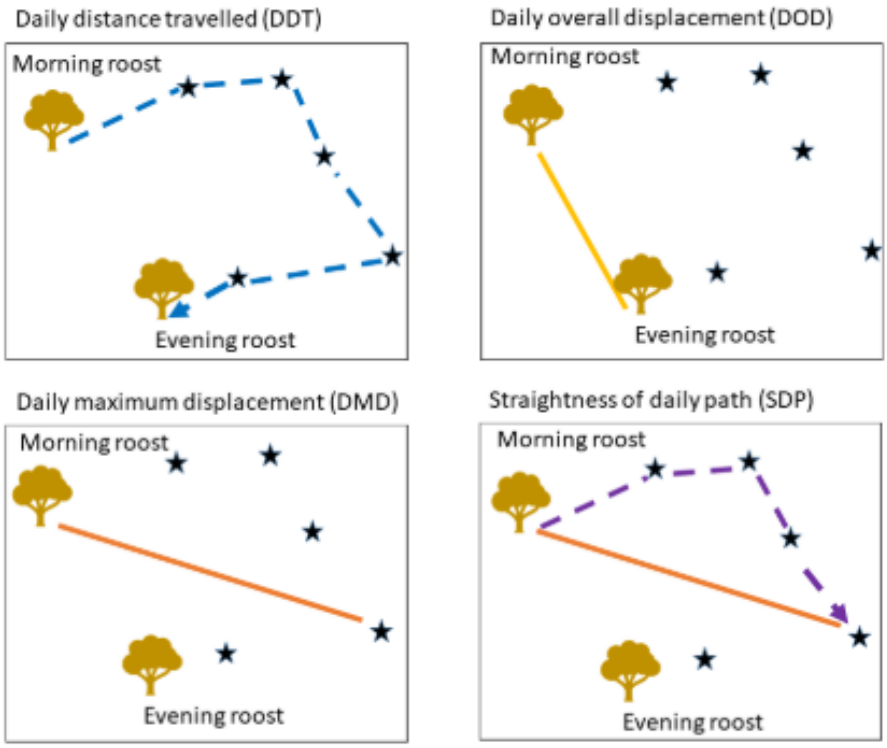

Figure 1 Illustration depicting the four metrics used to analyze daily movement properties.

The above diagram highlighted by Claudia [11] shows the four properties calculated to examine the daily movement patterns. Trees represent the start and end point each day (morning and evening roost), stars represent the GPS locations received, arrows point to a sequence of movement (distances measured), and straight lines show displacements.

Generalized Additive Model:

In the realm of statistical modelling, generalized additive models (GAMs) emerge as versatile tool to model non-linear relationship between variables. They can be conceptualised with the following formula:

- $y = b_0 + f_1(x_1) + f_2(x_2) + e$

In this representation, the individual coefficient b from traditional models is substituted by entire smooth functions (f_1), (f_2) or splines. Each of these splines is a composite of smaller foundational units known as basis functions. A number of these basis functions is available and can be aptly selected via like the mgcv [22] package in R . Smooth functions are not bounded by the linearity assumption that constrains many other model types. Instead, they carefully trace the data's contours, providing a more nuanced understanding of underlying relationships. GAM are extensions of GLM where the linear predictor may describe a smooth non-linear function of the mean of the response, the response variable can follow any family distribution [23].

Example of a model structure from an R code via mgcv package:

gam_model <- gam (DMD ~ s(Month, bs = cc), data = DMP1, family = Gamma(link = "log")

Here, the relationship between Daily Maximum Displacement (DMD), a response variable is being investigated with “Month” being used as the predictor variable. The smooth function “s” allows fr flexibility in fitting the data. Spline type being used here is cyclic cubic to try and line up the relationship between end of months such as December and January. It is being used to capture the cyclic pattern in the data. Family of distribution is gamma which explains that the DMD values are positive (>0) and continuous. The link = "log" means that we are using a logarithmic link function. This is typical for a Gamma family where we are modeling the logarithm of the expected response as a linear function of predictor.

Model fitting:

Initially, different spline types with fitted to the models investigating relationship between different daily movement parameters. Based on the fitness metric – Akaike Information Criteria [24], the spline types giving lowest possible AIC values were selected. As the difference between the AIC values were not signification (<2) in most cases, cyclic cubic splines were selected to model the relationship as they were assumed to meaningfully capture the variation in data around different times of the year i.e. data at the end of December and beginning of January would be more related to each other. Codes showcasing the model structure to model the relationship between the daily movement parameters and Months (January to December) are as follows:

1. gam_model <- gam (DDT + 0.0000005 ~ s(Month, bs = “cc”), data = DMP1, family = Gamma(link = "log")
2. gam_model <- gam (DMD + 0.0000005 ~ s(Month, bs = “cc”), data = DMP1, family = Gamma(link = "log")
3. gam_model <- gam(DMD + 0.0000005 ~ s(Month, bs = “cc”), data = DMP1, family = Gamma(link = "log")
4. gam_model <- gam(SDP + 0.0000005 ~ s(Month, bs = “cc”), data = DMP1, family = betar (link = "logit")

A small constant value of 0.0000005 was introduced to try and do away with any values of 0 as that would violate the assumption of gamma family distribution for respective cases. Beta distribution was used to model the relationship between SDP and Month as the values were ratio and lied between 0 and 1. Therefore, “logit” link function was used in case of SDP.

Model Diagnostics:

Model diagnostics helps to check to make sure that the models are well fit. Model diagnostic was performed using gam.check() function from the mgcv package in R for each model.

Number of basis functions determines how wiggly a smooth can be. Not enough basis functions may result in not capturing the relationship in the data. Full convergence after “n” number of iterations suggests that R has computed a best solution. K value, effective degrees

of freedom, k-index and p-value are shown in the basis checking results part of the model diagnosis output.

Basis Dimension Checking: GAMs use splines to model non-linear relationships. The "k" value represents the number of basis functions (i.e., the "wiggliness" of the spline). The edf (estimated degrees of freedom) tells you how many of these basis functions the model is effectively using. If edf is close to k, it might mean the spline is using almost as much flexibility as it's allowed, and increasing k might be considered. The k-index and its associated p-value test the adequacy of k. A low p-value suggests that k may be too small, and we can increase it to capture more nuanced patterns in the data.

Small p-values are indicative of the non-random distribution of the residuals. It may be due to insufficient basis functions in the model. We also observe 4 different plots provided by gam.check function. The QQ plot based on the assumed distribution shows if there is significant departure of the residuals from the diagonal line. The histogram plot should reflect the distribution pattern of the response variable. The residual values in the residual vs linear predictor plot should be evenly distributed around the value of 0. The response vs fitted values plot for well-fit model should form a linear pattern from left bottom to top right diagonally, clustering around 1 to 1 line.

Result

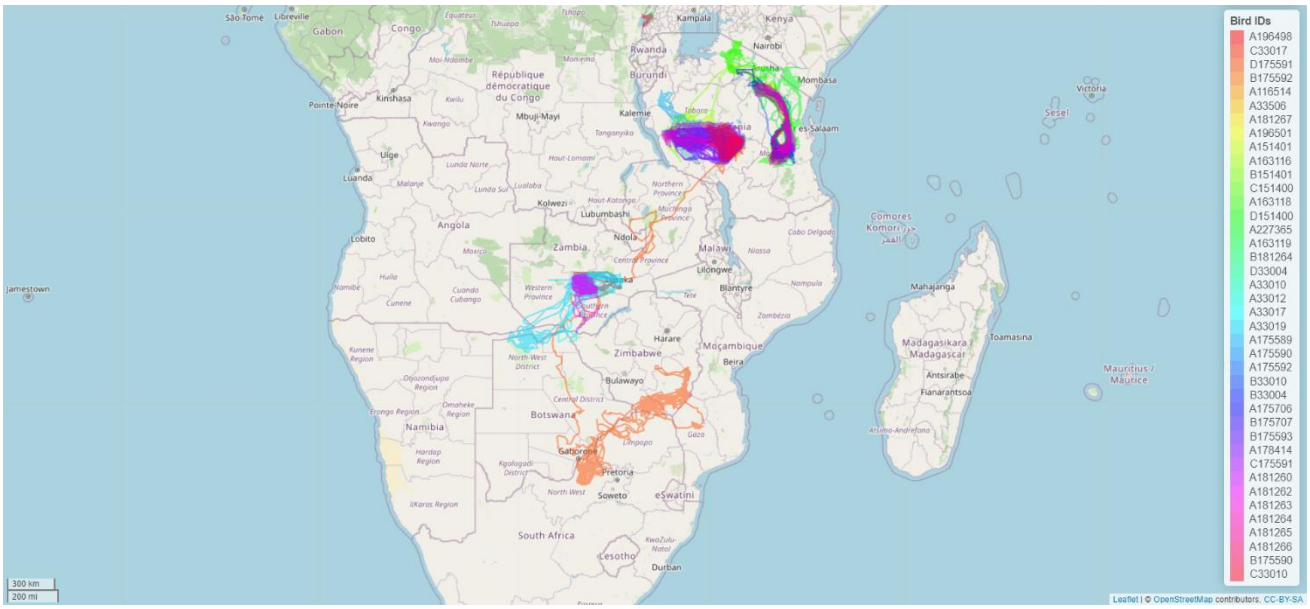

Figure 2 Locations and trajectory shown for all individuals (coloured by individual).

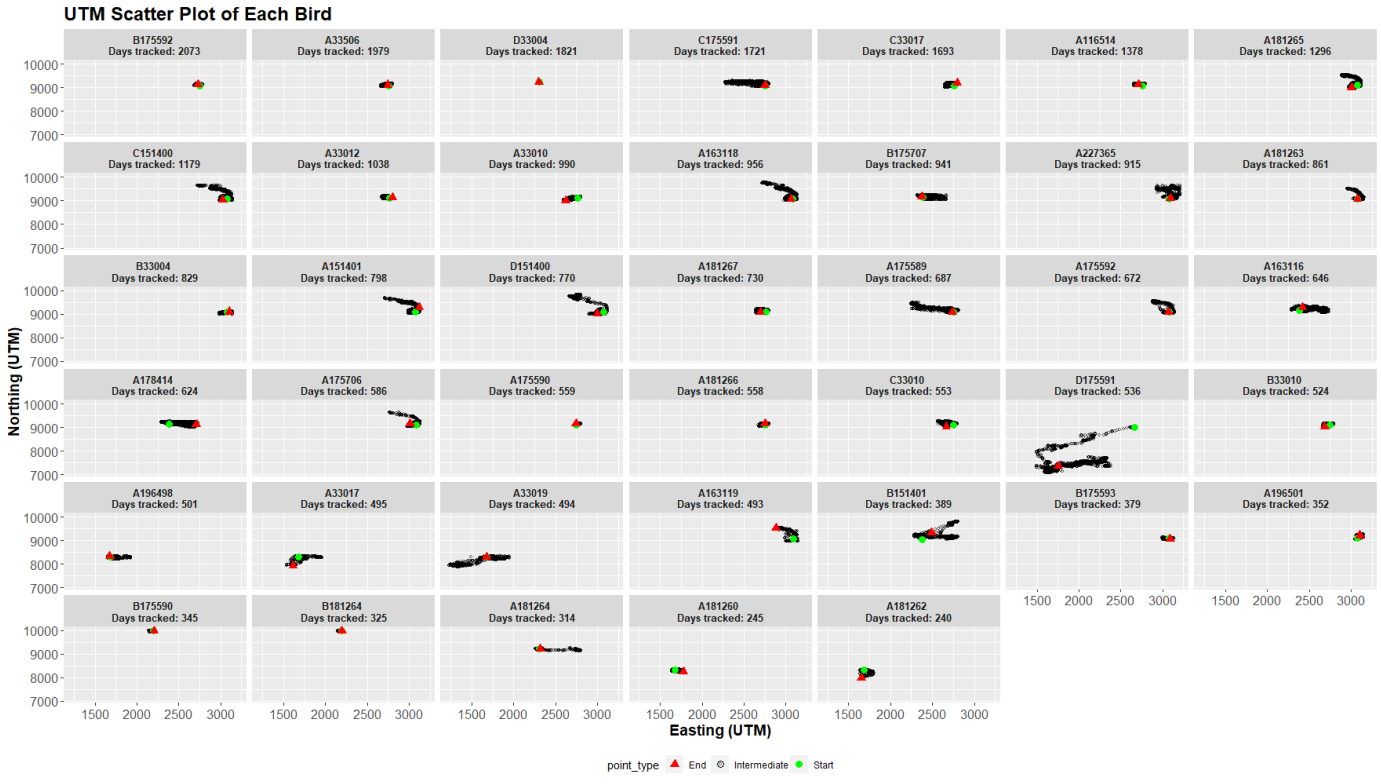

Figure 3 Scatter plot for each bird showing the trajectory including start and end GPS locations for visualization of their movement pattern over the days tracked.

Exploratory Data Analysis:

Exploratory data analysis showed a non-linear pattern for the mean of all the four daily movement parameters across the months (figure 4 – 7). This paved the way to use non-linear modelling approach using Generalized Additive Models to investigate the behaviour of the birds based on daily movement parameters, across the months.

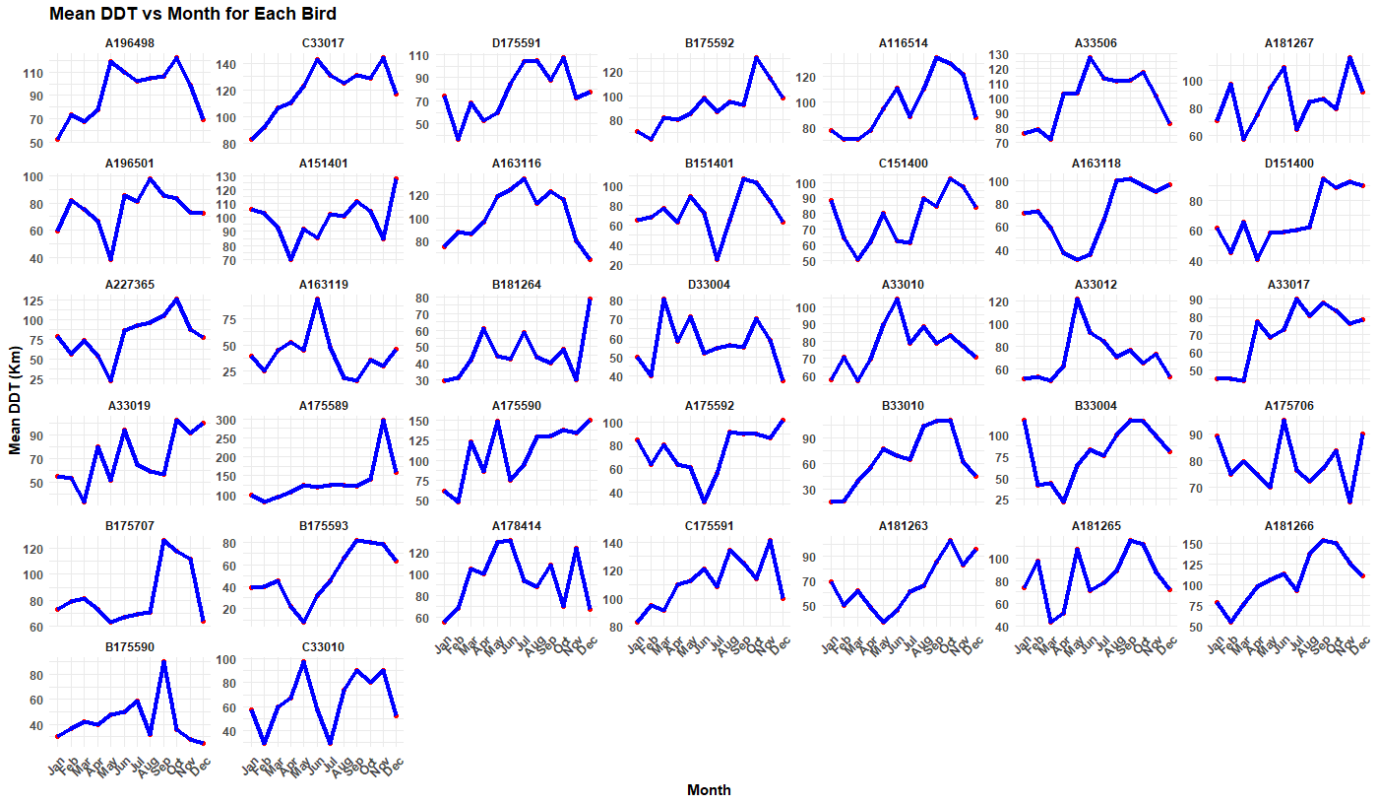

Figure 4 Mean values of Daily Distance Travelled by each bird across months.

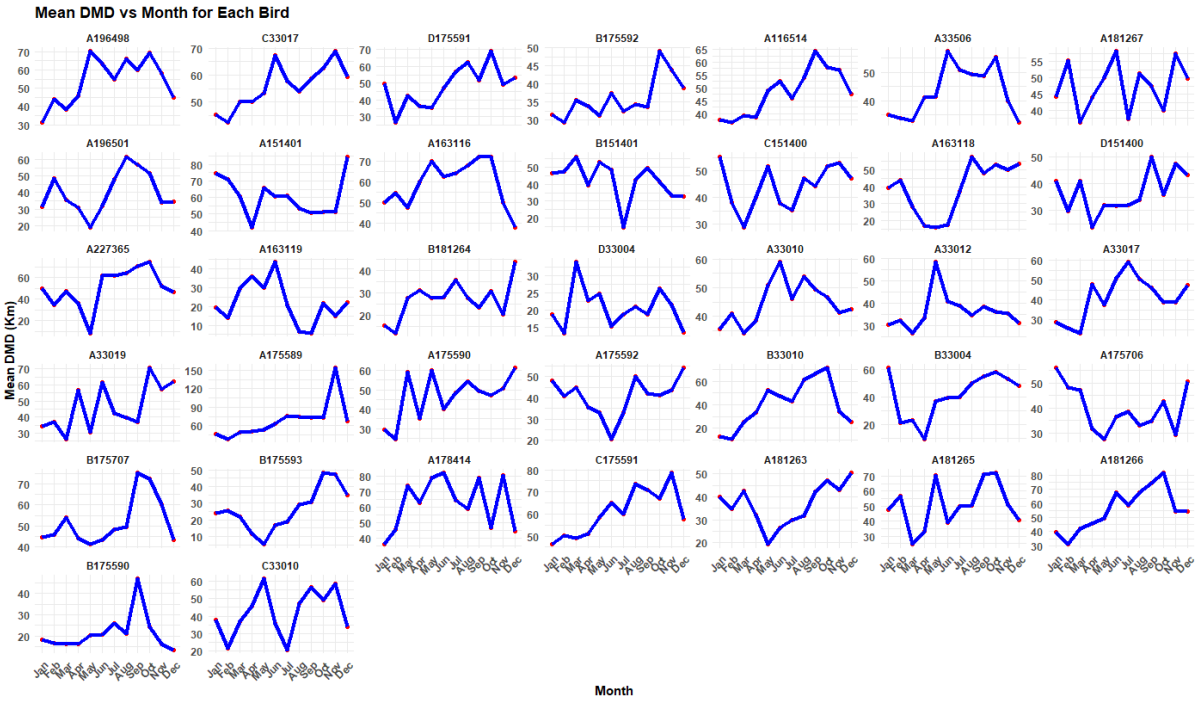

Figure 5 Mean values of Daily Maximum Displacement of each bird across months

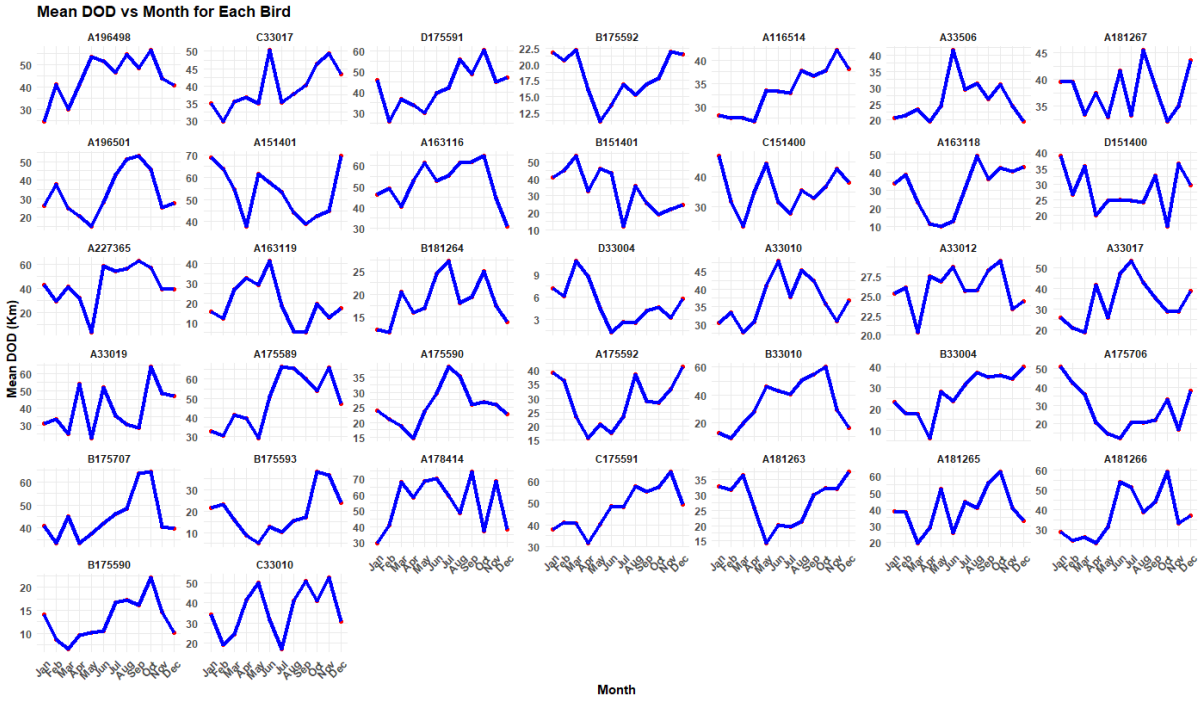

Figure 6 Mean values of Daily Overall Displacement of each bird across the months.

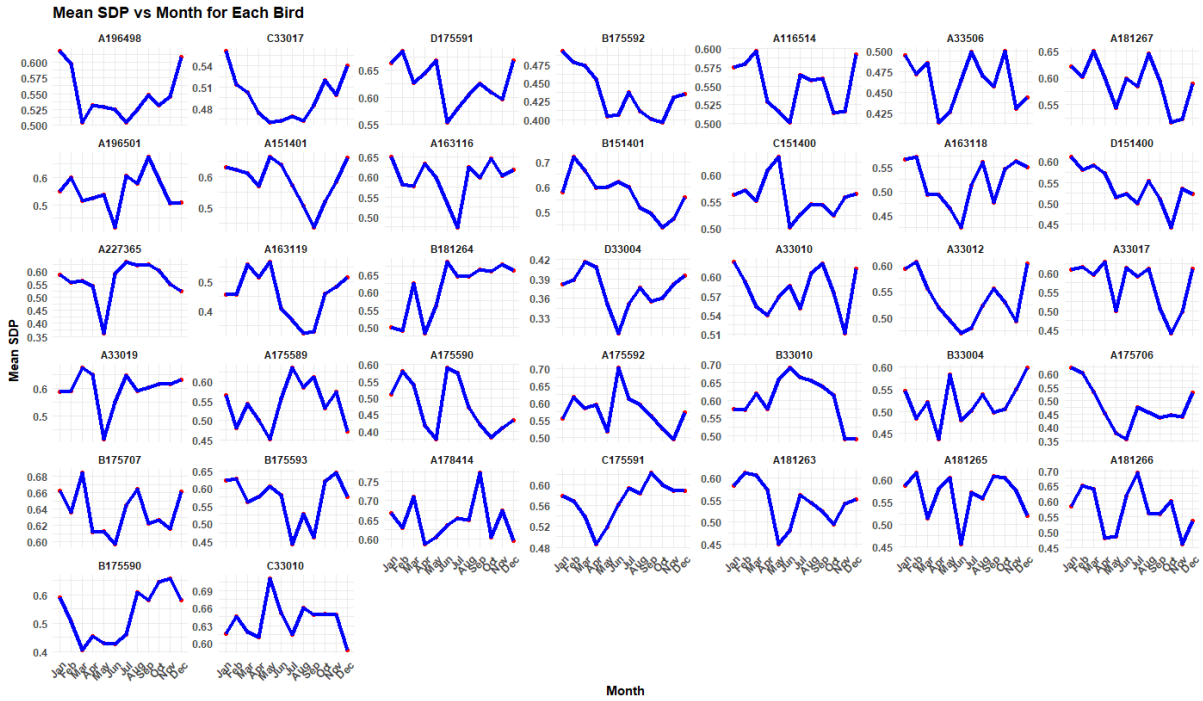

Figure 7 Mean value of Straightness of Daily Path of each bird across Months

Model selection:

Best models (based AIC for each spline type) for each bird and their daily movement property are provided in figure 8– 11.

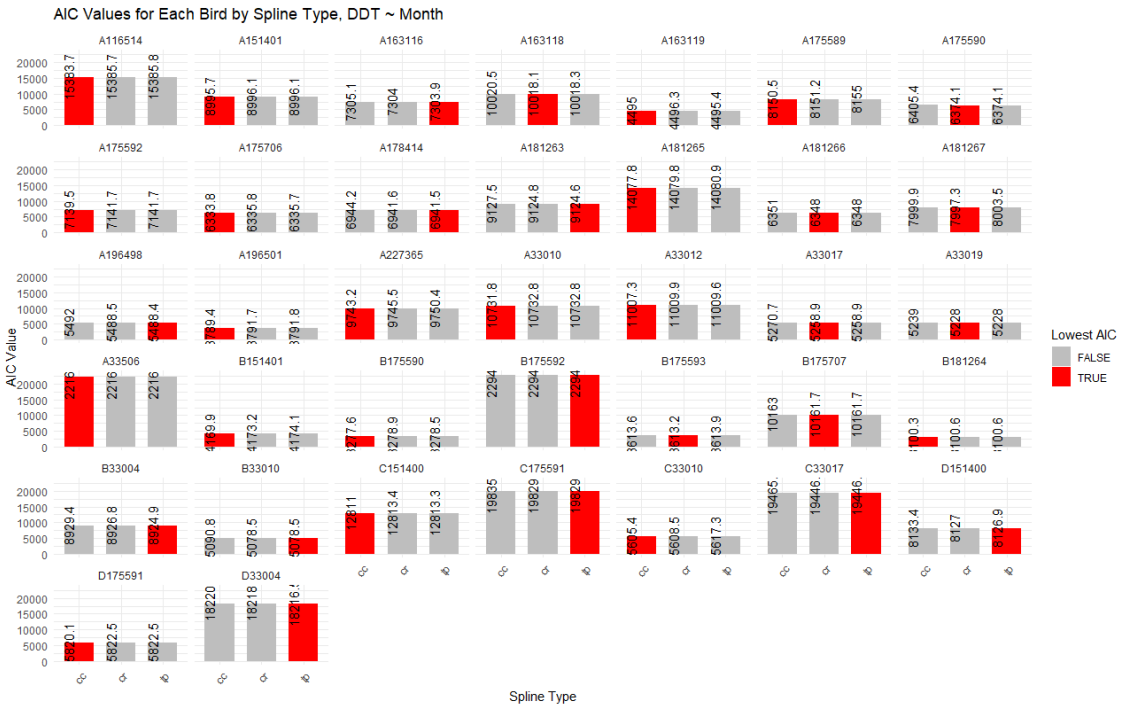

Figure 8 AIC values for each model (for DDT ~ Month) based on spline type for every bird. The model (spline type) with lowest value is coloured in red.

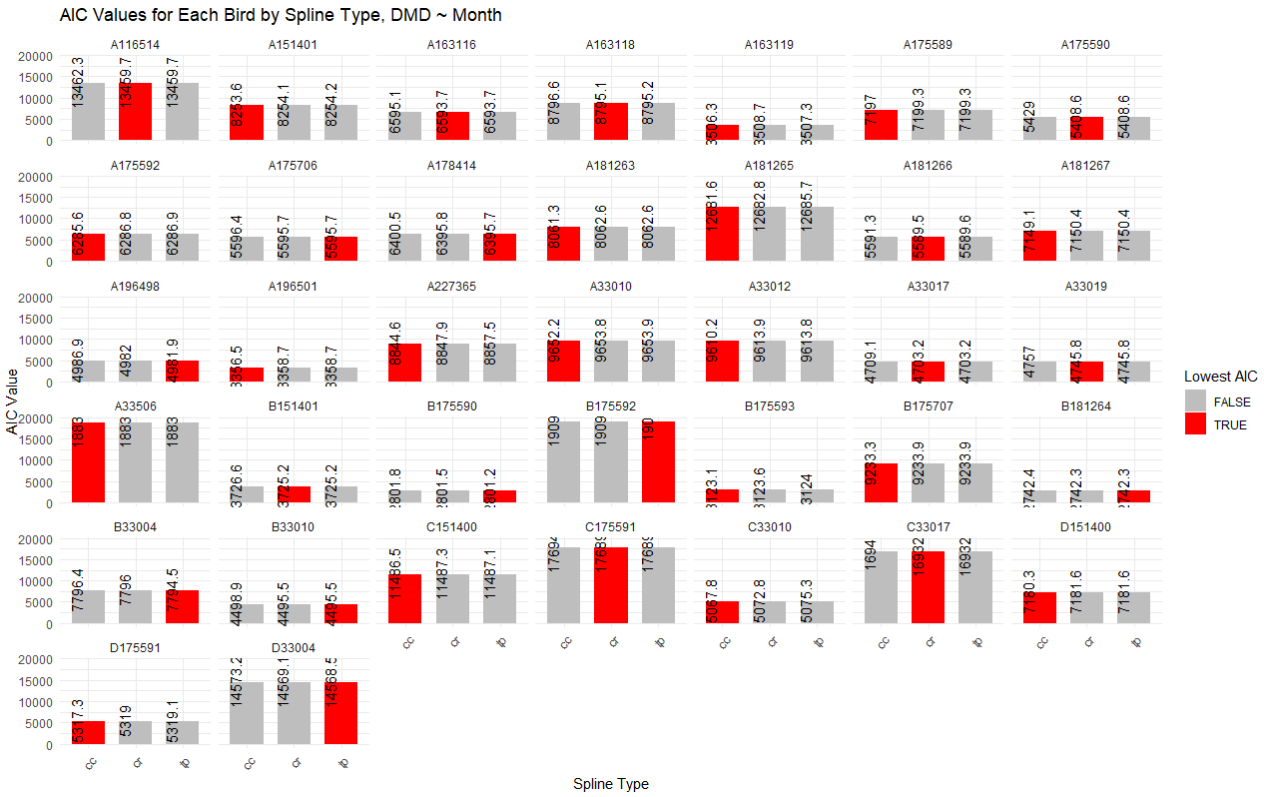

Figure 9 AIC values for each model (for DMD ~ Month) based on spline type for every bird. The model (spline type) with lowest value is coloured in red.

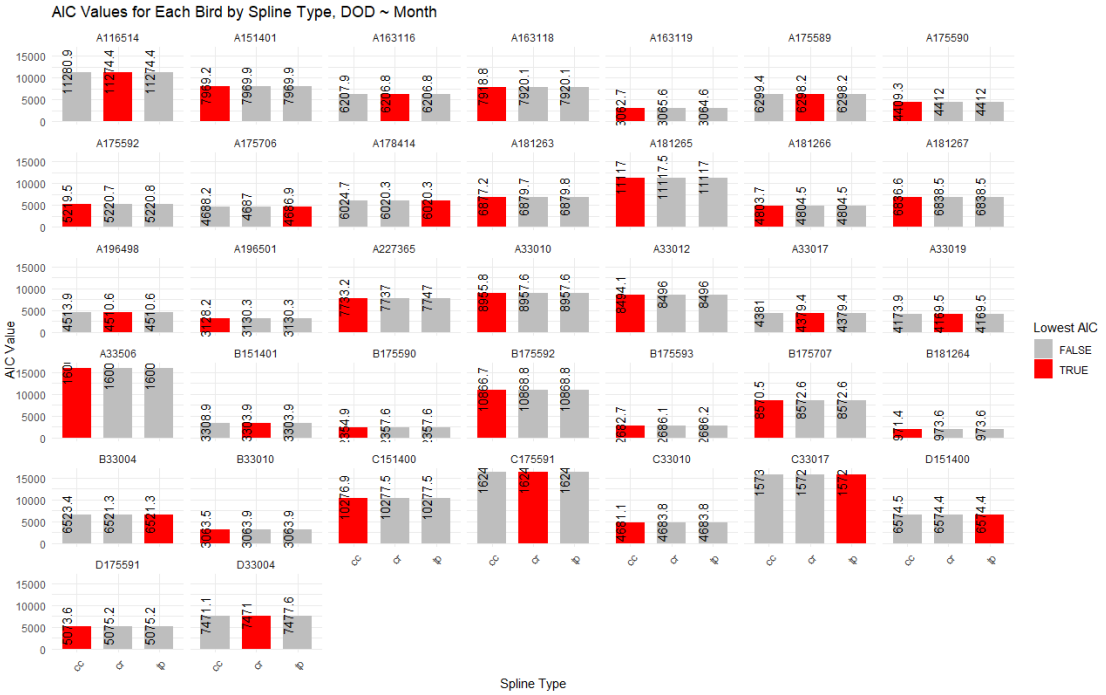

Figure 10 AIC values for each model (for DOD ~ Month) based on spline type for every bird. The model (spline type) with lowest value is coloured in red.

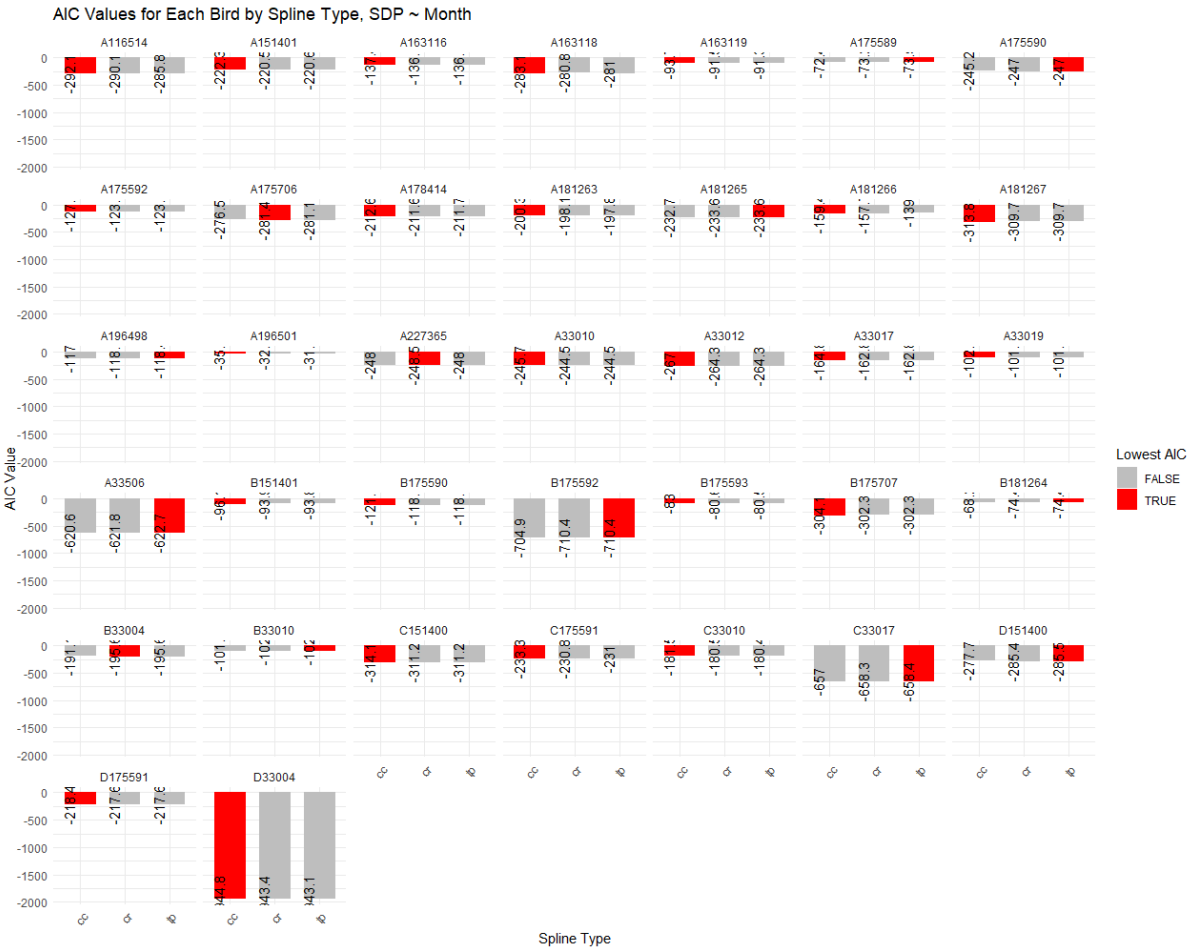

Figure 11 AIC values for each model (for SDP ~ Month) based on spline type for every bird. The model (spline type) with lowest value is coloured in red.

Model Diagnostics:

Full model outputs for each bird for each daily movement property (DDT, DMD, DOD and SDP) as provided in appendix 1.

Here we see model diagnosis output for one bird (ID - A196498) for SDP.

```
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001971541,7.473634e-06]
(score 2494.623 & scale 0.9557384).
Hessian positive definite, eigenvalue range [0.8488003,324.3919].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

         k' edf k-index p-value
s(Month)  8   3    0.84   0.075 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

The optimization procedure converged or found the best-fit model after 5 iteratons suggesting the estimates are reliable. K' shows the number of basis functions used to represent the smoother for "Month". "edf" or effective degrees of freedom is a measure of flexibility or wiggliness of the smoother. Here, edf of 3 for s'(Month) suggests the smoother is relatively simple, if the values were close to the value of k' – 8,it would imply a relatively wiggly curve.

k-index is used to check the adequacy of "k". Values near or below 1 may suggest that "k" might be too low.

p-value tests the hypothesis that the chosen "k'" is adequate. A low p value (<0.05) suggests "k'" might be too small. Here, 0.075 suggests that the choice of "k'" is almost adequate (borderline).

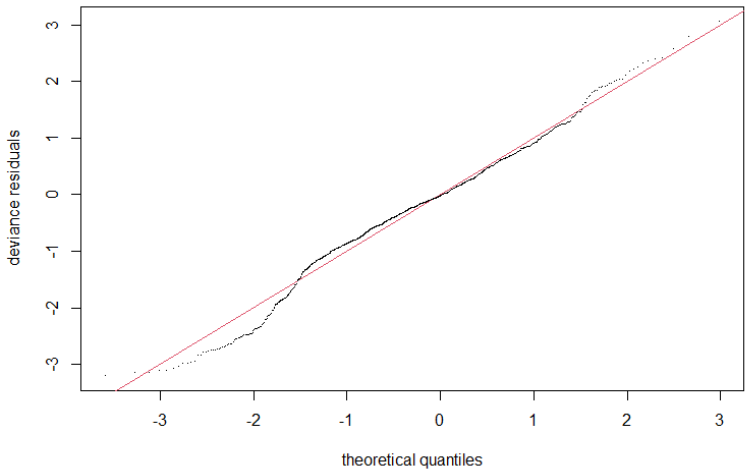

Figure 12 QQ plot of deviance residuals against quantiles.

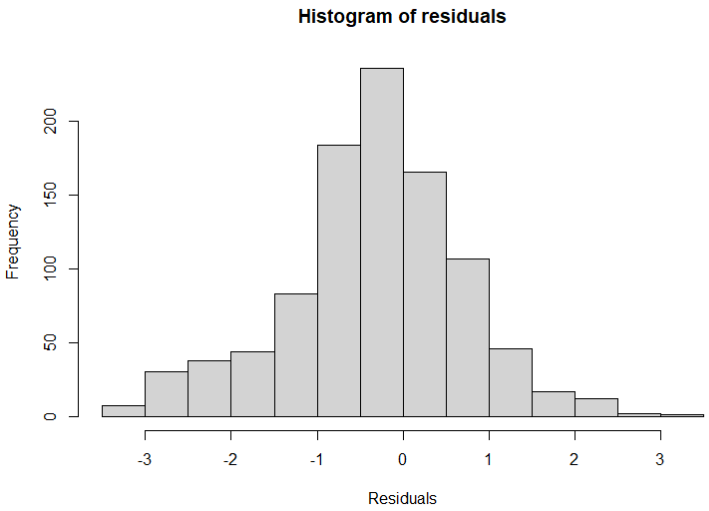

Figure 13 Histogram plot for residuals

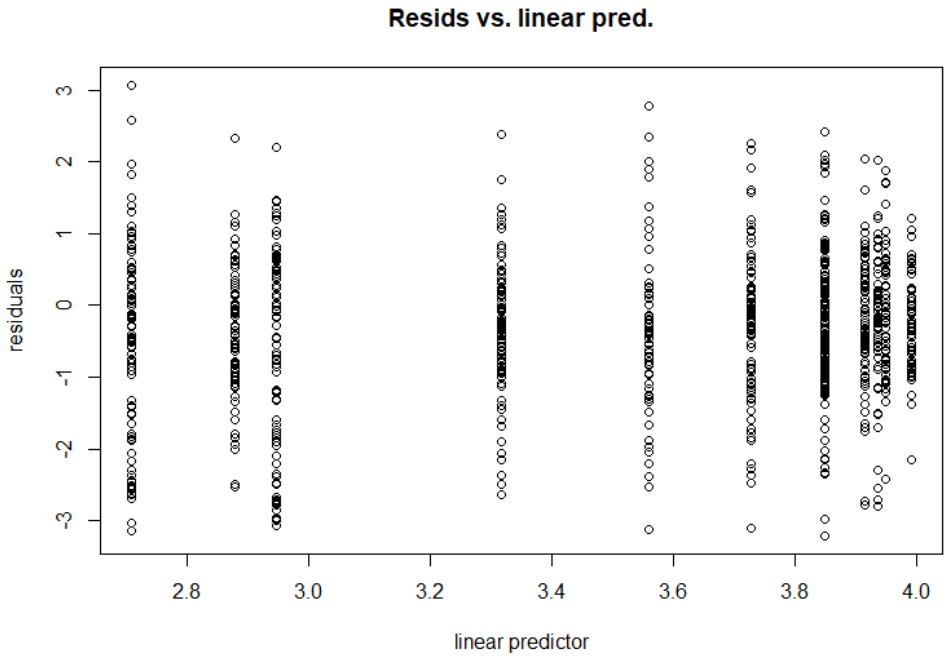

Figure 14 Residual vs Linear Predictor plot

The QQ plot plot (Figure 12) does not show any significant deviations from the diagonal line, suggesting that the model's assumption about the distribution is not violated. The jitters towards the end points may be explained by the values close to zero in the model for the response variable. The histogram plot (Figure 13) seems like the residuals come from the assumed distribution – gamma. Figure 14 – Residual value vs linear predictor should show values evenly distributed around 0. Figure 15 – plot of response vs fitted values, an ideal model shall show a end to end diagonal clustering pattern.

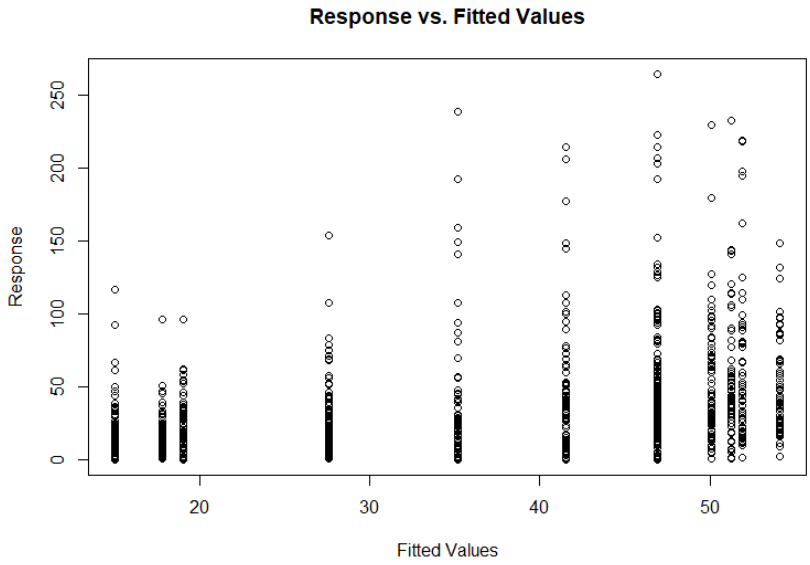

Figure 15 Response vs Fitted values plot.

Model results:

Predictions were generated across months for each bird using cyclic cubic spline to model all the daily movement properties (DDT, DMD, DOD and SDP) and predict them for all the months. The plots (figure 16, 18, 20, 22) enabled visual observation of fluctuations in movement behaviour of each bird. For each bird, minimum and maximum of the monthly fluctuation of estimates were selected (figure 17,19,21,23). Thirty-four (91.9%) birds had their minima for expected monthly DDT between January to March while maxima was observed for twenty five (67.5%) birds between September to November. For DDM values, twenty-seven (72.9%) birds showed their expected monthly minima to be between February to May while twenty-two (59.5%) birds showed their maxima between September to November. For DOD properties, thirty four (91.9%) birds showed expected minima between February to June and twenty-five (67.6%) birds showed their maximum expected mean DOD values between July to October. For straightness of daily path (SDP), equal numbers (16, 43.2%) of birds showed their maxima and minima values between months of January to February and May to June respectively.

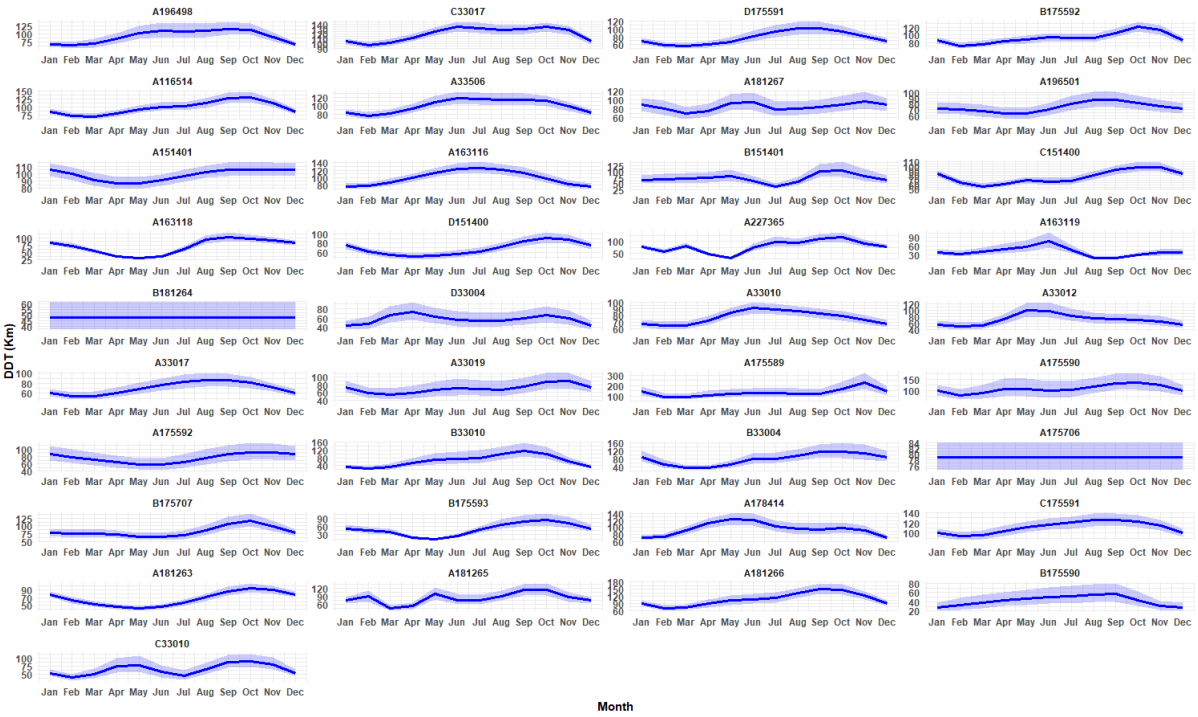

Figure 16 Variation in the daily distance travelled (DDT, km) for each individual generated by the best candidate model. Mean predictions with respective 95% CI bands are shown.

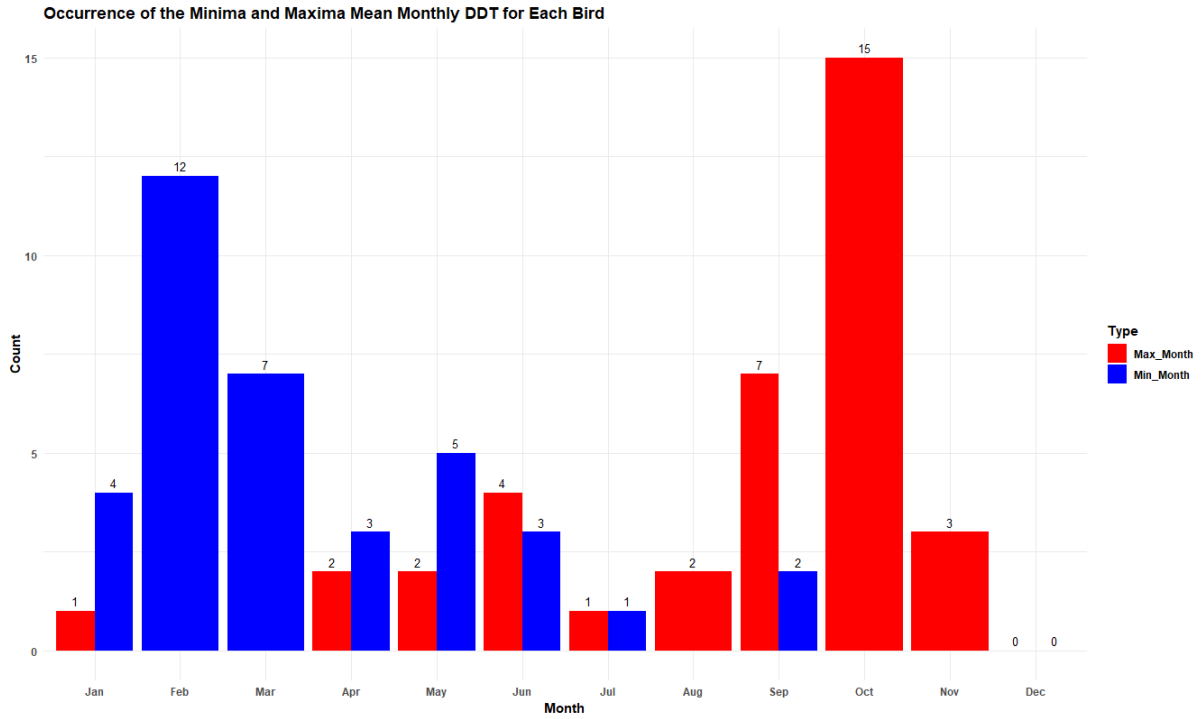

Figure 17 Occurrence of the minima (blue) and maxima (red) mean monthly daily distance travelled (DDT) predicted for each bird along the year. All birds are present, note each coloured count will sum to 37.

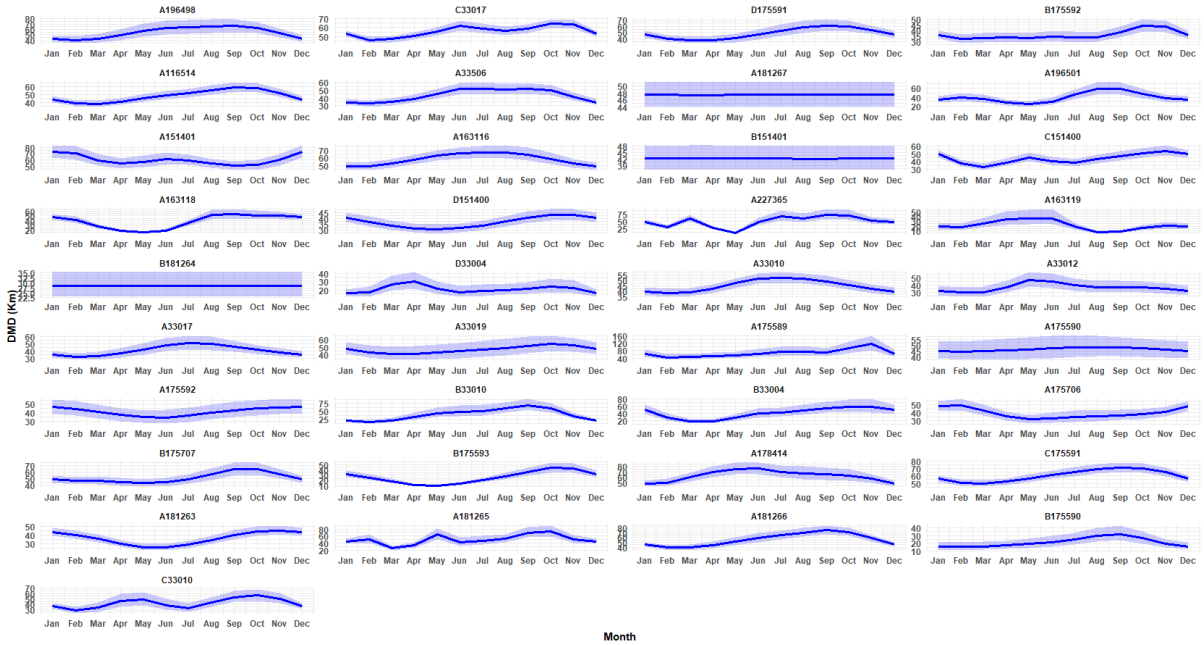

Figure 18 Variation in the daily maximum displacement (DMD, km) for each individual generated by the best candidate model. Mean predictions with respective 95% CI bands are shown.

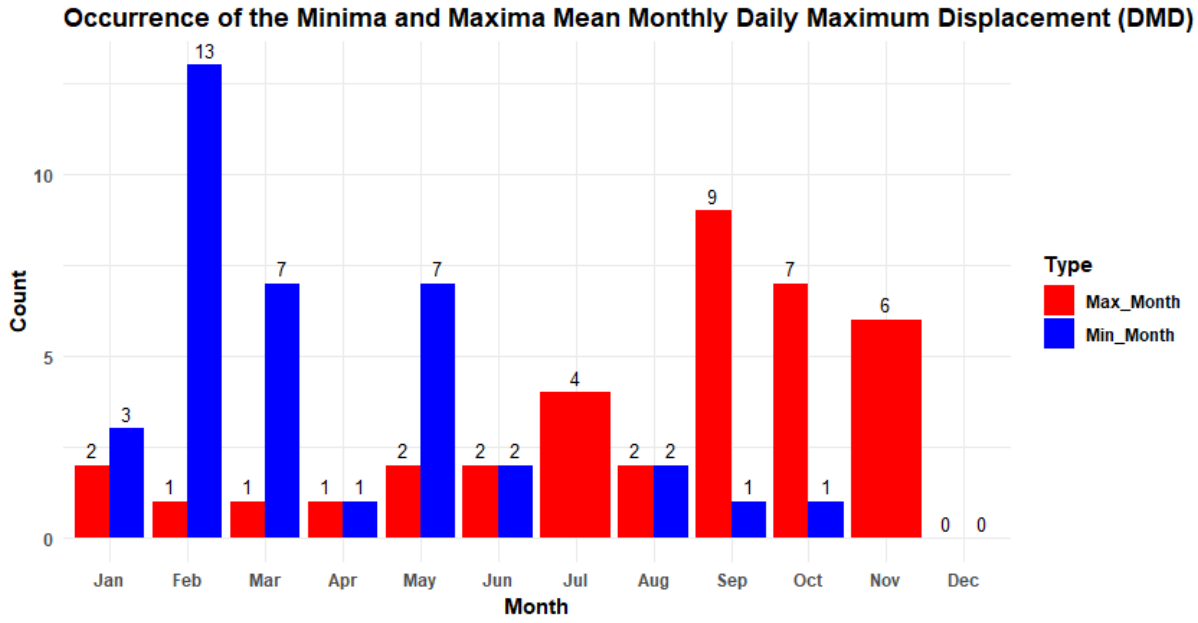

Figure 19 Occurrence of the minima (blue) and maxima (red) mean monthly daily maximum displacement (DMD) predicted for each bird along the year. All birds are present, note each coloured count will sum to 37.

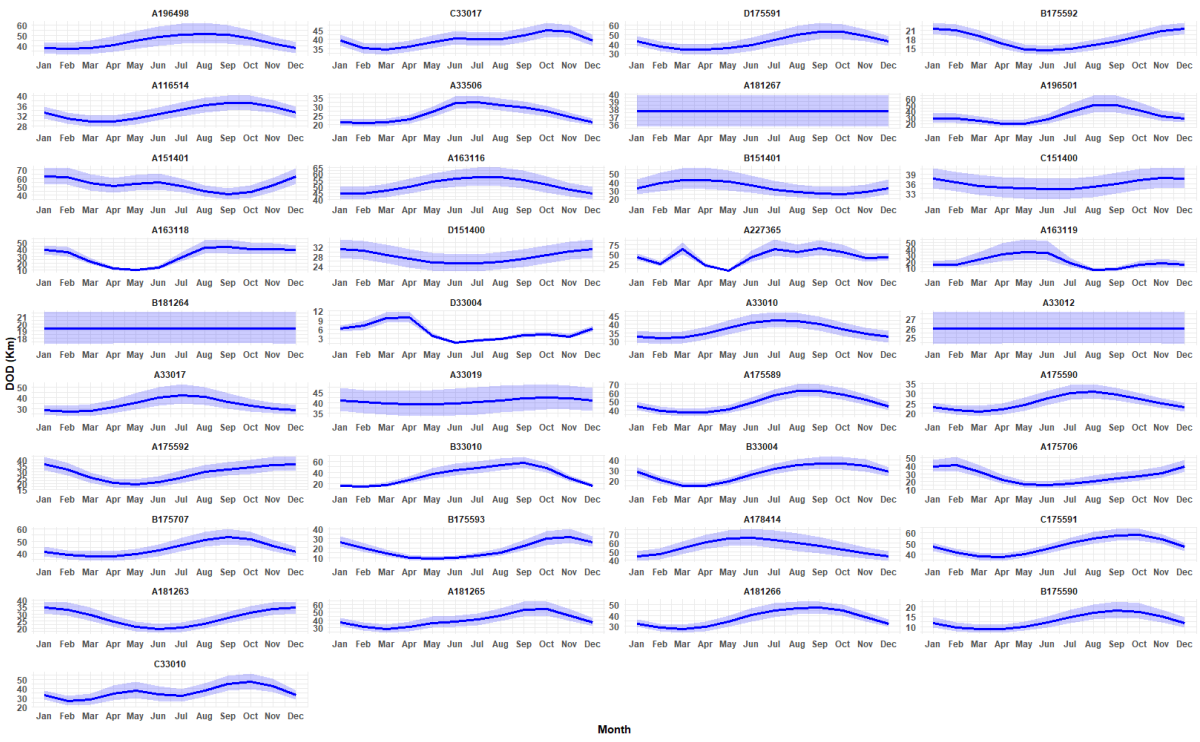

Figure 20 Variation in the daily overall displacement (DOD, km) for each individual generated by the best candidate model. Mean predictions with respective 95% CI bands are shown

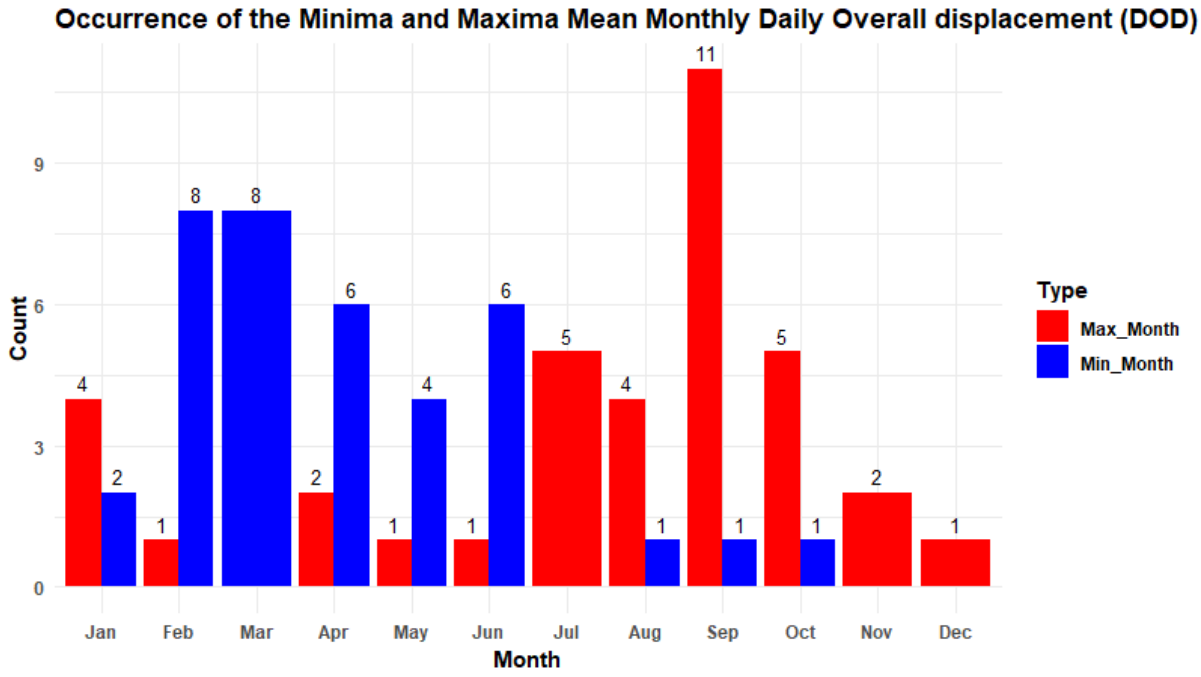

Figure 21 Occurrence of the minima (blue) and maxima (red) mean monthly daily overall displacement (DOD) predicted for each bird along the year. All birds are present, note each coloured count will sum to 37.Figure 22 Variation in the daily overall displacement (DOD, km) for each individual generated by the best candidate model. Mean predictions with respective 95% CI bands are shown.

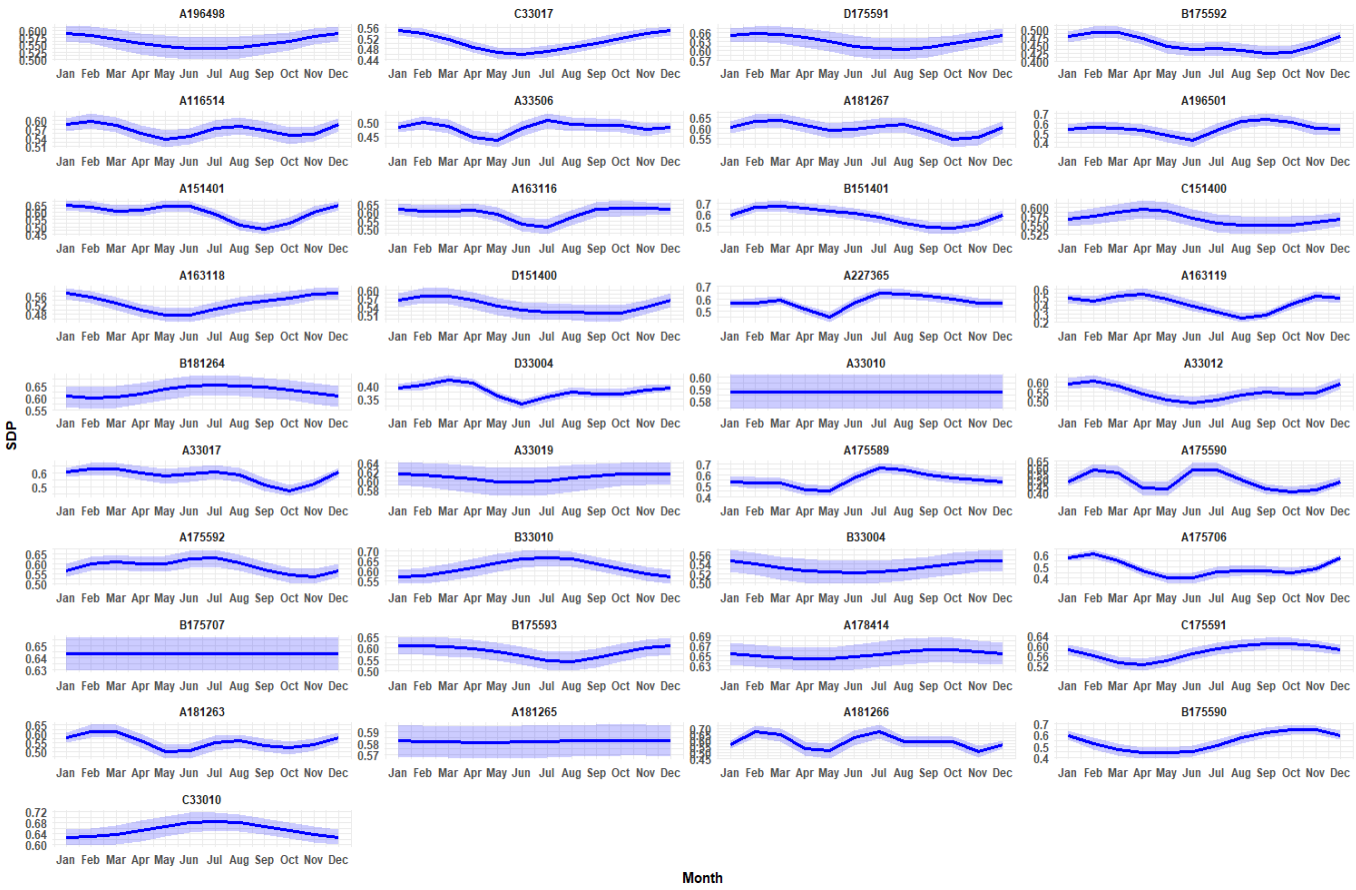

Figure 23 Variation in the Straightness of Daily Path (SDP) for each individual generated by the best candidate model. Mean predictions with respective 95% CI bands are shown.

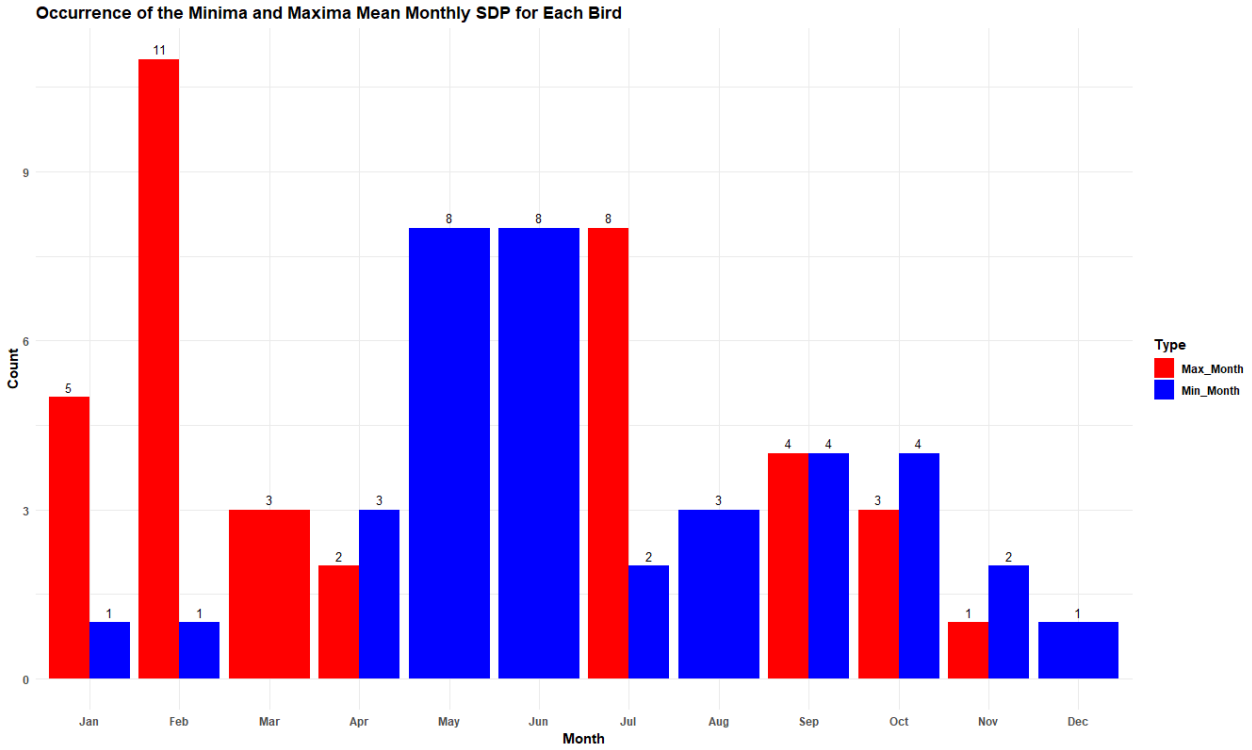

Figure 24 Occurrence of the minima (blue) and maxima (red) mean monthly straightness of daily path (SDP) predicted for each bird along the year. All birds are present, note each coloured count will sum to 37.

Discussion

Visual inspection

Visual inspection of individual bird trajectories showed variety of movement strategies. While some birds remained in a smaller area, others explored farther. Individual distribution varied considerably as seen in figure 2 and 3.

Daily Movement Properties

Ecologically, DDT indicates how much ground a bird covers in a day, DMD tells us if a bird flies far away from home on a daily basis and DOD gives an insight into whether the bird sleeps in the same roost on consecutive nights while values of SDP close to 0 indicates erratic movement of birds while values close to 1 indicates directed long-distance travels [11].

The model used in the study enabled detection of variations in the daily movement properties of birds. Literatures suggest vertebrates forage farther during low abundance of resources and with low spatio-temporal predictability [25]. Vultures are recognized for covering vast territories in their search for food, hinting at an irregular and infrequent availability of their primary food source, which is mostly carcasses of ungulates [26], [27]. Several studies have identified a connection between the patterns of prey availability and the periodic movements of African vultures [28]. Moreover, during their breeding seasons, there's a tendency for vultures to forage even more widely, as breeding pairs often venture to distant feeding locations away from their nesting sites or colonies [29].

Most of the birds exhibited their minima for DDT, DMD and DOD between Jan to June. These could indicate either rainy season as majority minima during hot wet season has been reported in past study through data as well as personal observation [11] validating rain affecting bird's ability to fly. Plenty of prey biomass because of rains leading to increase in available resources to forage close to roost may also contribute to the minima during the period. Another factor could be restricted movement or return to the same place (DOD) due to formation of breeding pair, requiring investment of time in a particular space (nest) or activity e.g. parental care.

If breeding pair are nurturing their young and resources are not available sufficiently to cater to the energetic needs or are scattered, mean maxima will increase. This is observed for the period of September to November for DDT and DMD, and July to October for DOD for most birds.

Erratic flights indicating non-directional smaller distance movement were high in May and June possibly suggesting no directed migratory or long-distance coverage by birds during that time of the year. These could be either breeding individuals or those scavenging for food locally. Majority of maxima of SDP were in starting of the year suggesting flights approximating perfectly straight paths, as the birds travelled longer distances, possibly suggesting migration.

Future directions

Given the vast options of novel tools and technique being made available to explore and investigate spatio-temporal data, it would be interesting to learn more about the species's movement ecology by conducting more trajectory and area-based analysis.

Some of the interesting analysis which can be performed are recursion [30]– to understand the revisitations of the individuals at different sites across the landscape, over different ecologically relevant time periods. Similarly, another trajectory-based analysis which may yield interesting insights about the individuals could be analysis of least squared displacement [31] to tease apart travellers and locals and see if there exists migratory, nomadism or resident/local pattern between individuals.

It would also be prudent to do further analysis on the time-series data to investigate about autocorrelations and use mixed models to tease apart the difference in strategies of individual birds by introducing the idea of fixed and random effects to check the effect of relevant environmental or ecological variables such season, sex, etc on the response variable of interest.

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Appendix 1

Model Diagnostics result for each bird.

- **Modelling Daily Maximum Displacement**

1. `gam_model <- gam(DMD + 0.0000005 ~ s(Month, bs = spline_type), data = DMP1, family = Gamma(link = "log"), method = "REML")`

```
Bird ID sequence: [1] A196498 C33017  D175591 B175592 A116514 A33506  A181267
A196501 A151401 A163116 B151401 C151400 A163118
[14] D151400 A227365 A163119 B181264 D33004  A33010  A33012  A33017  A33019
A175589 A175590 A175592 B33010
[27] B33004  A175706 B175707 B175593 A178414 C175591 A181263 A181265 A181266
B175590 C33010

Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001971541,7.473634e-06]
(score 2494.623 & scale 0.9557384).
Hessian positive definite, eigenvalue range [0.8488003,324.3919].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

         k' edf k-index p-value
s(Month)  8   3    0.84   0.075 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-9.535222e-08,3.607803e-10]
(score 8476.995 & scale 0.4599499).
Hessian positive definite, eigenvalue range [1.099248,1026.685].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.78    0.75  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 7 iterations.
Gradient range [-1.652502e-05,4.358001e-06]
(score 2659.219 & scale 0.805245).
Hessian positive definite, eigenvalue range [1.036708,367.7196].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
           k'  edf k-index p-value
s(Month) 8.00 2.39    0.58  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-3.49296e-08,8.878054e-11]
(score 9550.247 & scale 1.448384).
Hessian positive definite, eigenvalue range [0.9789863,1342.847].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.68    0.64  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.005347874,3.473956e-06]
(score 6732.477 & scale 0.8490244).
Hessian positive definite, eigenvalue range [1.088211,915.8706].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.26    0.69  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-3.523769e-08,6.944223e-11]
(score 9423.736 & scale 1.674267).
Hessian positive definite, eigenvalue range [1.382956,1249.664].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 4.3    0.69  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 8 iterations.
Gradient range [-0.001415067,0.0002654921]
(score 3575.04 & scale 1.076699).
Hessian positive definite, eigenvalue range [0.001412707,455.7723].
```

```
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

              k'     edf k-index p-value
s(Month) 8.00000 0.00336    0.83   0.005 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001144364,3.724267e-06]
(score 1681.067 & scale 0.8934078).
Hessian positive definite, eigenvalue range [1.322067,228.6404].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.27    0.73  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.722043e-08,6.139311e-11]
(score 4129.354 & scale 0.8588123).
Hessian positive definite, eigenvalue range [0.9685485,511.4829].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.09    0.74  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.002439522,5.275506e-06]
(score 3297.947 & scale 0.6371351).
Hessian positive definite, eigenvalue range [0.7677484,434.0475].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.18    0.71  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
```

```
full convergence after 8 iterations.
Gradient range [-0.0007566326,0.00538992]
(score 1863.17 & scale 1.729475).
Hessian positive definite, eigenvalue range [0.000794933,270.9762].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

             k'    edf k-index p-value
s(Month) 8.0000 0.0163    0.68  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.333626e-08,6.073675e-11]
(score 5747.157 & scale 0.726882).
Hessian positive definite, eigenvalue range [1.05081,784.9795].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.96    0.66  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001395749,9.260005e-05]
(score 4403.83 & scale 0.9773819).
Hessian positive definite, eigenvalue range [2.288373,629.9619].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.45    0.64  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-2.479562e-05,8.095603e-07]
(score 3591.009 & scale 0.8760647).
Hessian positive definite, eigenvalue range [1.096488,507.0594].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.27    0.61  <2e-16 ***
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0002600446,0.0001412131]
(score 4436.304 & scale 1.305579).
Hessian positive definite, eigenvalue range [3.066917,616.0947].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 7.63     0.6  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0003669305,6.397273e-06]
(score 1735.378 & scale 2.57718).
Hessian positive definite, eigenvalue range [1.381918,381.5943].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.53    0.59  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 8 iterations.
Gradient range [-0.0005900662,0.0001126581]
(score 1370.858 & scale 3.853368).
Hessian positive definite, eigenvalue range [0.0005897699,232.7335].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

             k'    edf k-index p-value
s(Month) 8.0000 0.0014    0.74   0.005 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-4.0633e-06,2.204781e-06]
(score 7296.176 & scale 6.842699).
Hessian positive definite, eigenvalue range [2.893535,1119.291].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
           k'  edf k-index p-value
s(Month) 8.00 6.75    0.82  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.31048e-08,3.33924e-11]
(score 4827.098 & scale 0.6536311).
Hessian positive definite, eigenvalue range [0.8999266,652.2545].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 2.5    0.66  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.003839304,1.497386e-05]
(score 4807.978 & scale 2.468448).
Hessian positive definite, eigenvalue range [0.785097,695.3746].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.08    0.79  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001793945,9.045443e-06]
(score 2354.956 & scale 0.9589832).
Hessian positive definite, eigenvalue range [0.6651614,332.1182].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.37    0.73  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0009295943,-4.184246e-05]
(score 2378.234 & scale 1.741635).
Hessian positive definite, eigenvalue range [0.2812112,353.8531].
```

```
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.74    0.63  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001571074,1.597352e-05]
(score 3600.42 & scale 2.719139).
Hessian positive definite, eigenvalue range [1.25669,471.1916].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.67    0.68  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-9.990645e-06,5.125556e-06]
(score 2714.354 & scale 2.44586).
Hessian positive definite, eigenvalue range [0.1520531,354.6289].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

            k'   edf k-index p-value
s(Month) 8.000 0.821    0.59  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001601316,4.97087e-06]
(score 3142.915 & scale 2.491958).
Hessian positive definite, eigenvalue range [0.5201188,475.6728].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.96    0.67  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
```

```
full convergence after 5 iterations.
Gradient range [-0.0003565128,-1.745636e-07]
(score 2250.344 & scale 2.009018).
Hessian positive definite, eigenvalue range [1.556718,396.3079].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.03    0.39  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001478577,3.428737e-05]
(score 3903.223 & scale 2.932333).
Hessian positive definite, eigenvalue range [1.956423,560.8193].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.25    0.56  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.195303e-08,6.785905e-11]
(score 2799.985 & scale 0.9115366).
Hessian positive definite, eigenvalue range [0.5347274,372.2221].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.53    0.63  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.00240703,-4.647647e-05]
(score 4617.9 & scale 1.114817).
Hessian positive definite, eigenvalue range [0.5898553,661.3779].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.09    0.74  <2e-16 ***
---
```

```
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0003367374,5.193887e-06]
(score 1563.58 & scale 0.8657796).
Hessian positive definite, eigenvalue range [0.7641366,262.5544].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.19    0.65  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001953073,9.89555e-06]
(score 3201.603 & scale 0.7455087).
Hessian positive definite, eigenvalue range [0.3380461,418.9358].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.32    0.77  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-2.497063e-08,3.50109e-09]
(score 8848.688 & scale 0.8517192).
Hessian positive definite, eigenvalue range [1.055878,1144.663].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.15    0.77  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-5.127813e-06,3.988259e-06]
(score 4032.356 & scale 0.8789053).
Hessian positive definite, eigenvalue range [1.126702,581.7681].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
           k'  edf k-index p-value
s(Month) 8.00 3.13    0.63  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0002896222,8.344137e-06]
(score 6351.86 & scale 1.960259).
Hessian positive definite, eigenvalue range [2.17621,892.6627].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 7.26    0.63  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-7.157496e-09,1.970069e-11]
(score 2797.512 & scale 0.5421103).
Hessian positive definite, eigenvalue range [1.280077,346.7053].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.36    0.75  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-2.756224e-09,3.253309e-11]
(score 1402.883 & scale 1.719892).
Hessian positive definite, eigenvalue range [0.9004691,216.0529].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.46    0.79    0.01 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0008402379,5.537215e-06]
(score 2536.219 & scale 1.188263).
Hessian positive definite, eigenvalue range [0.7192118,407.9025].
```

```
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.35    0.64  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

- **Modelling Daily Distance Travelled**

2. `gam_model <- gam(DDT + 0.0000005 ~ s(Month, bs = spline_type), data = DMP1, family = Gamma(link = "log"), method = "REML")`

```
Sequence of Bird ID: [1] A196498 C33017  D175591 B175592 A116514 A33506  A181
267 A196501 A151401 A163116 B151401 C151400 A163118
[14] D151400 A227365 A163119 B181264 D33004  A33010  A33012  A33017  A33019
A175589 A175590 A175592 B33010
[27] B33004  A175706 B175707 B175593 A178414 C175591 A181263 A181265 A181266
B175590 C33010


Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-7.663971e-09,5.318057e-11]
(score 2748.402 & scale 0.7178359).
Hessian positive definite, eigenvalue range [1.078756,308.8379].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.91     0.8  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.05814e-07,3.814451e-10]
(score 9736.829 & scale 0.3901736).
Hessian positive definite, eigenvalue range [1.114615,1014.771].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.69    0.72  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001167269,0.0004322739]
(score 2911.127 & scale 0.7024485).
Hessian positive definite, eigenvalue range [1.144043,360.5989].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.75    0.59  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-3.070159e-08,2.274438e-10]
(score 11479.99 & scale 1.084965).
Hessian positive definite, eigenvalue range [1.6389,1340.066].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.13    0.65  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.004665644,7.852241e-06]
(score 7694.488 & scale 0.9850878).
Hessian positive definite, eigenvalue range [1.432097,916.7367].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.21    0.68  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-4.579738e-08,-1.273381e-11]
(score 11086.17 & scale 1.317159).
Hessian positive definite, eigenvalue range [1.689513,1238.878].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
           k'  edf k-index p-value
s(Month) 8.00 4.16     0.7  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-7.695365e-07,6.225592e-09]
(score 4003.619 & scale 1.208833).
Hessian positive definite, eigenvalue range [0.35295,452.9356].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 4.8    0.82  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-9.598324e-09,2.93225e-10]
(score 1895.381 & scale 0.5171318).
Hessian positive definite, eigenvalue range [0.2043135,216.7507].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.55    0.82   0.005 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-4.808351e-08,1.501457e-10]
(score 4498.751 & scale 0.4746383).
Hessian positive definite, eigenvalue range [0.4752717,487.4623].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.34    0.76  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.002615834,4.792359e-06]
(score 3653.753 & scale 0.5191371).
Hessian positive definite, eigenvalue range [1.233969,421.9539].
Model rank =  9 / 9
```

```
Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.72    0.73  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001218388,1.697499e-05]
(score 2089.333 & scale 1.209995).
Hessian positive definite, eigenvalue range [0.8680374,262.0153].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.52    0.77  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.911053e-08,9.268986e-11]
(score 6408.954 & scale 0.5603574).
Hessian positive definite, eigenvalue range [1.037464,758.9804].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.61    0.64  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.00183726,5.524744e-05]
(score 5015.505 & scale 0.6171009).
Hessian positive definite, eigenvalue range [2.5339,608.3443].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.25    0.62  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
```

```
Gradient range [-9.781218e-09,1.678302e-11]
(score 4068.644 & scale 0.6840951).
Hessian positive definite, eigenvalue range [1.347703,493.9305].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.19     0.6  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0007451082,0.0001331733]
(score 4883.568 & scale 0.7633637).
Hessian positive definite, eigenvalue range [2.677021,583.9963].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 7.41    0.66  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0007385505,1.558955e-05]
(score 2251.767 & scale 1.548454).
Hessian positive definite, eigenvalue range [1.262731,348.3391].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.84    0.61  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 9 iterations.
Gradient range [-0.0006072448,0.0002678333]
(score 1549.872 & scale 5.518592).
Hessian positive definite, eigenvalue range [0.0006069293,229.2298].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

              k'     edf k-index p-value
s(Month) 8.00000 0.00175    0.76   0.025 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-2.459526e-07,7.238588e-08]
(score 9117.79 & scale 4.377319).
Hessian positive definite, eigenvalue range [2.516109,1104.262].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 6.14    0.82  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-2.107345e-08,6.01128e-11]
(score 5367.301 & scale 0.5075515).
Hessian positive definite, eigenvalue range [0.7524278,633.9663].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.96    0.65  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.003565125,2.136428e-05]
(score 5507.971 & scale 2.293532).
Hessian positive definite, eigenvalue range [1.475123,683.3404].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.77    0.78  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-6.366747e-09,2.425837e-11]
(score 2636.004 & scale 0.6862983).
Hessian positive definite, eigenvalue range [0.8768119,322.7948].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
           k'  edf k-index p-value
s(Month) 8.00 2.57    0.73  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001298975,-0.000486691]
(score 2620.664 & scale 1.875258).
Hessian positive definite, eigenvalue range [0.4947385,341.1639].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.32    0.67  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001958037,3.589972e-05]
(score 4079.906 & scale 2.75967).
Hessian positive definite, eigenvalue range [1.553376,460.354].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.71    0.65  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-8.540439e-09,5.778711e-11]
(score 3205.021 & scale 2.353871).
Hessian positive definite, eigenvalue range [0.4155935,355.6783].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.09    0.58  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001622779,1.620815e-05]
(score 3570.579 & scale 3.009586).
Hessian positive definite, eigenvalue range [0.6905355,471.5726].
Model rank =  9 / 9
```

```
Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.51    0.68  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0003751178,9.863883e-07]
(score 2546.787 & scale 2.886491).
Hessian positive definite, eigenvalue range [1.556522,390.2532].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 4.2     0.4  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001524543,3.61241e-05]
(score 4469.923 & scale 3.261168).
Hessian positive definite, eigenvalue range [1.770688,548.9224].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.34    0.59  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 8 iterations.
Gradient range [-0.001639136,0.000474772]
(score 3167.392 & scale 0.5267864).
Hessian positive definite, eigenvalue range [0.001636739,355.239].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

              k'     edf k-index p-value
s(Month) 8.00000 0.00425    0.71  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
```

```
Gradient range [-0.002490038,4.757867e-06]
(score 5083.924 & scale 1.383584).
Hessian positive definite, eigenvalue range [1.042931,652.2456].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.04    0.73  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.000331743,4.714881e-06]
(score 1811.112 & scale 0.9535601).
Hessian positive definite, eigenvalue range [0.8695328,261.4027].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.55    0.63  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.002243135,1.446233e-05]
(score 3474.631 & scale 0.5579915).
Hessian positive definite, eigenvalue range [0.673457,408.5288].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.24    0.77  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.003122003,6.313765e-06]
(score 9919.79 & scale 0.8747351).
Hessian positive definite, eigenvalue range [0.6742623,1114.869].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.22    0.79  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-5.568626e-05,6.452451e-05]
(score 4566.317 & scale 0.7066243).
Hessian positive definite, eigenvalue range [1.426486,565.3532].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.63    0.65  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.404526e-06,1.050427e-07]
(score 7049.848 & scale 1.750434).
Hessian positive definite, eigenvalue range [2.223761,859.8199].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 7.21    0.71  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.002181939,1.229899e-05]
(score 3177.806 & scale 0.7046947).
Hessian positive definite, eigenvalue range [1.078084,349.4456].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.98    0.76  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001336908,1.673985e-05]
(score 1641.36 & scale 2.06292).
Hessian positive definite, eigenvalue range [0.7499567,213.5913].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
           k'  edf k-index p-value
s(Month) 8.00 3.99    0.72  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0008853131,7.989409e-06]
(score 2805.928 & scale 1.484581).
Hessian positive definite, eigenvalue range [0.9463487,402.5802].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.93    0.66  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

- **Modelling Daily Overall Displacement**

3. `gam_model <- gam(DDT + 0.0000005 ~ s(Month, bs = spline_type), data = DMP1, family = Gamma(link = "log"), method = "REML")`

```
Sequence of Bird ID: [1] A196498 C33017  D175591 B175592 A116514 A33506  A181
267 A196501 A151401 A163116 B151401 C151400 A163118
[14] D151400 A227365 A163119 B181264 D33004  A33010  A33012  A33017  A33019
A175589 A175590 A175592 B33010
[27] B33004  A175706 B175707 B175593 A178414 C175591 A181263 A181265 A181266
B175590 C33010


Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0007215927,9.012366e-07]
(score 2247.727 & scale 1.297356).
Hessian positive definite, eigenvalue range [0.5254669,375.869].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.63    0.77   0.055 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.004651476,3.755875e-06]
```

```
(score 7858.208 & scale 0.751406).
Hessian positive definite, eigenvalue range [0.3362152,1186.917].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.16    0.69  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-4.785346e-05,-3.23784e-07]
(score 2532.879 & scale 1.00425).
Hessian positive definite, eigenvalue range [0.8815508,391.7151].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.07    0.59  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001292397,8.371864e-07]
(score 5001.99 & scale 1.587929).
Hessian positive definite, eigenvalue range [0.8335009,1739.93].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.37     0.5  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001648052,-2.81421e-06]
(score 5558.503 & scale 0.7698354).
Hessian positive definite, eigenvalue range [0.5217897,1069.672].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.68    0.66  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:
```

```
Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.003501127,0.001031304]
(score 7943.238 & scale 1.280478).
Hessian positive definite, eigenvalue range [0.6446179,1468.25].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.35    0.61  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-0.00186958,0.0003910279]
(score 3418.759 & scale 0.5835038).
Hessian positive definite, eigenvalue range [0.001865805,472.9998].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

              k'     edf k-index p-value
s(Month) 8.00000 0.00452    0.79  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0005011254,-6.022127e-06]
(score 1560.452 & scale 1.465823).
Hessian positive definite, eigenvalue range [0.7757114,255.3649].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.37     0.8   0.095 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.002253883,-6.152516e-05]
(score 3983.542 & scale 1.194308).
Hessian positive definite, eigenvalue range [0.6857813,557.4156].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
```

```
s(Month) 8.00 3.48    0.67  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001177681,1.232378e-06]
(score 3091.653 & scale 0.8550485).
Hessian positive definite, eigenvalue range [0.532782,476.7427].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.61    0.68  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-0.000205346,-1.658455e-05]
(score 1646.435 & scale 2.821541).
Hessian positive definite, eigenvalue range [0.6306543,298.1353].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.01    0.65  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 7 iterations.
Gradient range [-0.003325866,0.005595353]
(score 5103.67 & scale 1.135881).
Hessian positive definite, eigenvalue range [0.1382176,901.0652].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 1.1    0.69  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0007285227,2.497756e-05]
(score 3951.676 & scale 1.595444).
Hessian positive definite, eigenvalue range [2.300543,713.5432].
Model rank =  9 / 9
```

```
Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.26    0.58  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 7 iterations.
Gradient range [-0.0008086483,-0.0007362299]
(score 3284.26 & scale 1.414986).
Hessian positive definite, eigenvalue range [0.5316487,553.9332].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.56    0.65  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-4.982358e-05,2.06418e-05]
(score 3853.372 & scale 2.008638).
Hessian positive definite, eigenvalue range [2.861204,706.9524].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 7.59    0.51  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0002766045,3.289639e-06]
(score 1495.392 & scale 3.039503).
Hessian positive definite, eigenvalue range [1.256368,397.3247].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.21    0.58  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 8 iterations.
Gradient range [-0.0003636399,0.002736352]
```

```
(score 931.6978 & scale 1.01282).
Hessian positive definite, eigenvalue range [0.0003731984,265.1485].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

              k'     edf k-index p-value
s(Month) 8.00000 0.00744     0.6  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001288214,2.642765e-05]
(score 3576.2 & scale 1.851815).
Hessian positive definite, eigenvalue range [2.031249,1418.984].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 6.98    0.54  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.002037059,2.348612e-06]
(score 4477.114 & scale 0.9787986).
Hessian positive definite, eigenvalue range [0.7565745,720.7619].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.02     0.7  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-0.001851151,0.002850998]
(score 4244.96 & scale 1.101718).
Hessian positive definite, eigenvalue range [0.001855894,767.0891].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

              k'     edf k-index p-value
s(Month) 8.00000 0.00966    0.71  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:
```

```
Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0009439709,4.075911e-06]
(score 2186.596 & scale 1.362836).
Hessian positive definite, eigenvalue range [0.5501072,359.5902].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.12     0.7  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.000488306,5.076435e-07]
(score 2070.034 & scale 1.774978).
Hessian positive definite, eigenvalue range [0.04840428,388.4873].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

            k'   edf k-index p-value
s(Month) 8.000 0.507     0.6  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0008288872,1.195629e-05]
(score 3102.596 & scale 0.7602755).
Hessian positive definite, eigenvalue range [0.9067034,530.4178].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.28    0.58  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0007202941,3.842168e-07]
(score 2170.469 & scale 0.6234715).
Hessian positive definite, eigenvalue range [0.5468215,423.6273].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k' edf k-index p-value
```

```
s(Month) 8.0 1.8    0.68  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0006366502,9.522344e-07]
(score 2570.726 & scale 1.498032).
Hessian positive definite, eigenvalue range [0.6971266,527.1107].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.69     0.7  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0002058269,-1.101014e-06]
(score 1385.972 & scale 1.263033).
Hessian positive definite, eigenvalue range [1.137808,443.9874].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.35    0.31  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0008094066,8.047576e-07]
(score 3221.632 & scale 1.298048).
Hessian positive definite, eigenvalue range [1.118289,639.8582].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.43    0.59  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0005309642,2.852937e-06]
(score 2327.343 & scale 2.057768).
Hessian positive definite, eigenvalue range [0.8357136,455.33].
Model rank =  9 / 9
```

```
Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.39    0.52  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001425353,1.674501e-06]
(score 4259.708 & scale 0.8928147).
Hessian positive definite, eigenvalue range [0.6924336,708.3877].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 2.1    0.73  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0002536463,2.277458e-06]
(score 1333.321 & scale 1.317183).
Hessian positive definite, eigenvalue range [1.132234,286.5094].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.16    0.69  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.001009822,3.675356e-06]
(score 3005.752 & scale 1.015722).
Hessian positive definite, eigenvalue range [0.4679439,457.1479].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.16    0.74  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.003333469,0.000137636]
```

```
(score 8103.538 & scale 0.9444753).
Hessian positive definite, eigenvalue range [1.235311,1266.255].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.81    0.68  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0009687162,2.329606e-06]
(score 3405.939 & scale 1.405628).
Hessian positive definite, eigenvalue range [1.01731,670.1955].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 2.5    0.62  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-9.572398e-08,8.713319e-10]
(score 5522.634 & scale 2.281449).
Hessian positive definite, eigenvalue range [0.3892719,999.7771].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 3.6    0.51  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0006646508,1.904849e-06]
(score 2378.233 & scale 0.7117026).
Hessian positive definite, eigenvalue range [0.7695178,422.1182].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.22    0.67  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:
```

```
Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.0004975042,4.768031e-07]
(score 1173.304 & scale 1.323556).
Hessian positive definite, eigenvalue range [1.069967,252.0087].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.35    0.82    0.16
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-0.000370721,-0.0003463854]
(score 2333.42 & scale 1.173797).
Hessian positive definite, eigenvalue range [0.2587738,426.2942].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.43    0.62  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

- Modelling for Straightness of Daily Path

gam_model <- gam(SDP + 0.0000005 ~ s(Month, bs = spline_type), data = DMP1, family = betar(link = "logit"), method = "REML")

Sequence of Bird ID:

```
[1] A196498 C33017  D175591 B175592 A116514 A33506  A181267 A196501 A151401 A
163116 B151401 C151400 A163118
[14] D151400 A227365 A163119 B181264 D33004  A33010  A33012  A33017  A33019
A175589 A175590 A175592 B33010
[27] B33004  A175706 B175707 B175593 A178414 C175591 A181263 A181265 A181266
B175590 C33010

Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [3.657971e-10,7.715278e-08]
(score -58.37943 & scale 1).
Hessian positive definite, eigenvalue range [0.488653,311.2989].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.79    0.96    0.15
```

```
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [6.489101e-05,8.341694e-05]
(score -320.1318 & scale 1).
Hessian positive definite, eigenvalue range [1.430584,1018.587].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.21    0.97    0.12
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [1.524463e-10,2.254011e-07]
(score -109.0309 & scale 1).
Hessian positive definite, eigenvalue range [0.6294926,328.2112].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.76    0.91    0.02 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [3.246623e-08,9.212693e-06]
(score -347.4294 & scale 1).
Hessian positive definite, eigenvalue range [0.9151527,1256.61].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.75    0.92  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-6.644568e-07,1.117372e-06]
(score -143.2923 & scale 1).
Hessian positive definite, eigenvalue range [1.046521,865.4116].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.03     0.9  <2e-16 ***
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [2.112225e-08,6.484938e-06]
(score -303.7588 & scale 1).
Hessian positive definite, eigenvalue range [0.8638504,1202.502].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.09    0.84  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-4.602411e-08,1.074322e-06]
(score -154.0299 & scale 1).
Hessian positive definite, eigenvalue range [0.9854476,435.0253].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.26     0.9  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [2.610356e-12,5.893686e-11]
(score -14.50057 & scale 1).
Hessian positive definite, eigenvalue range [0.467636,230.5386].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.76    0.92    0.07 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [1.581029e-08,9.72333e-08]
(score -107.0076 & scale 1).
Hessian positive definite, eigenvalue range [2.037815,498.8748].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
```

```
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.74     0.8  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 7 iterations.
Gradient range [-1.029024e-06,7.698405e-07]
(score -66.18531 & scale 1).
Hessian positive definite, eigenvalue range [0.5777776,409.5323].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.19     0.9  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [1.441334e-08,7.401002e-08]
(score -46.12406 & scale 1).
Hessian positive definite, eigenvalue range [1.098639,244.2288].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.57    0.94    0.12
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.151808e-06,6.824356e-07]
(score -155.976 & scale 1).
Hessian positive definite, eigenvalue range [0.2307541,738.6003].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.41    0.92  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [6.82216e-07,2.080891e-06]
(score -139.7031 & scale 1).
Hessian positive definite, eigenvalue range [0.933252,592.2527].
Model rank =  9 / 9
```

```
Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

         k' edf k-index p-value
s(Month)  8   3    0.84  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [2.555279e-08,5.776957e-06]
(score -137.7124 & scale 1).
Hessian positive definite, eigenvalue range [0.4944084,465.4699].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.65    0.88  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [3.522671e-09,1.621596e-07]
(score -117.3655 & scale 1).
Hessian positive definite, eigenvalue range [1.504064,563.8885].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 6.14    0.75  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 4 iterations.
Gradient range [4.967941e-09,9.183769e-08]
(score -54.37452 & scale 1).
Hessian positive definite, eigenvalue range [1.554874,337.0001].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.18    0.92   0.065 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 4 iterations.
```

```
Gradient range [9.821041e-08,1.630176e-05]
(score -34.52889 & scale 1).
Hessian positive definite, eigenvalue range [0.3191168,210.8887].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.42    0.84   0.005 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [3.811276e-10,4.137249e-08]
(score -965.894 & scale 1).
Hessian positive definite, eigenvalue range [1.756602,989.0329].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.69    0.92  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 9 iterations.
Gradient range [-9.462037e-05,-2.652296e-05]
(score -122.2349 & scale 1).
Hessian positive definite, eigenvalue range [2.652727e-05,625.1414].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

               k'      edf k-index p-value
s(Month) 8.000000 0.000231    0.94   0.045 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [2.648324e-09,4.615056e-07]
(score -130.3967 & scale 1).
Hessian positive definite, eigenvalue range [0.8266444,643.5601].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.36    0.96   0.075 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [2.936878e-08,7.081788e-07]
(score -79.00313 & scale 1).
Hessian positive definite, eigenvalue range [1.491141,301.5612].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 4.52    0.91   0.035 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 7 iterations.
Gradient range [-1.381264e-05,-1.319814e-05]
(score -51.67154 & scale 1).
Hessian positive definite, eigenvalue range [0.1046854,316.7922].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

            k'   edf k-index p-value
s(Month) 8.000 0.832    0.92    0.03 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [1.127987e-13,5.038192e-12]
(score -30.90553 & scale 1).
Hessian positive definite, eigenvalue range [1.320858,454.9604].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.28    0.91    0.01 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [6.128497e-07,8.908937e-06]
(score -115.2546 & scale 1).
Hessian positive definite, eigenvalue range [2.02311,325.7517].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.
```

```
           k'  edf k-index p-value
s(Month) 8.00 6.31     0.9    0.01 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-1.783684e-08,8.174317e-09]
(score -62.24883 & scale 1).
Hessian positive definite, eigenvalue range [0.4301976,427.0211].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.42    0.97    0.24
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [4.033218e-12,4.421985e-11]
(score -49.96223 & scale 1).
Hessian positive definite, eigenvalue range [1.048069,336.8021].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.16    0.86  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [-9.013855e-10,1.101962e-08]
(score -95.37483 & scale 1).
Hessian positive definite, eigenvalue range [0.1992386,517.5117].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.38    0.87  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [7.705924e-06,3.14252e-05]
(score -133.3818 & scale 1).
Hessian positive definite, eigenvalue range [1.960786,346.5953].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
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indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 5.12    0.81  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 10 iterations.
Gradient range [-4.809211e-05,-3.667458e-05]
(score -151.5148 & scale 1).
Hessian positive definite, eigenvalue range [4.809088e-05,589.2053].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

               k'      edf k-index p-value
s(Month) 8.000000 0.000201    0.98    0.33
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [1.214013e-10,1.700781e-08]
(score -41.34686 & scale 1).
Hessian positive definite, eigenvalue range [0.373578,236.6384].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 2.05    0.94    0.12
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [-1.459644e-11,2.338661e-09]
(score -106.4398 & scale 1).
Hessian positive definite, eigenvalue range [0.1201968,385.1948].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

            k'   edf k-index p-value
s(Month) 8.000 0.922    0.92   0.025 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [1.138814e-08,1.264318e-08]
(score -110.7507 & scale 1).
Hessian positive definite, eigenvalue range [0.9531057,1131.548].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
```

```
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.25    0.99    0.28
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [1.621019e-09,1.192535e-07]
(score -96.45395 & scale 1).
Hessian positive definite, eigenvalue range [1.42185,541.4069].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

          k' edf k-index p-value
s(Month) 8.0 4.6     0.9  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 8 iterations.
Gradient range [-5.878378e-05,-6.909421e-06]
(score -115.7828 & scale 1).
Hessian positive definite, eigenvalue range [0.003171655,830.946].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

            k'   edf k-index p-value
s(Month) 8.000 0.142    0.72  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [3.831636e-09,6.274706e-08]
(score -72.50704 & scale 1).
Hessian positive definite, eigenvalue range [1.942476,337.9284].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 6.35    0.97    0.24
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 6 iterations.
Gradient range [1.311929e-09,1.894299e-09]
(score -58.62544 & scale 1).
Hessian positive definite, eigenvalue range [1.498852,206.7401].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
```

```
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 3.33    1.02    0.65
Diagnostics for Bird ID:

Method: REML   Optimizer: outer newton
full convergence after 5 iterations.
Gradient range [2.930434e-12,3.606145e-10]
(score -90.61653 & scale 1).
Hessian positive definite, eigenvalue range [0.6991682,345.6714].
Model rank =  9 / 9

Basis dimension (k) checking results. Low p-value (k-index<1) may
indicate that k is too low, especially if edf is close to k'.

           k'  edf k-index p-value
s(Month) 8.00 1.79     0.9   0.015 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```