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Estimating the onset of natal dispersal for a large diurnal raptor: A methodological comparison

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We estimated the onset of natal dispersal for a large diurnal raptor with high propensity towards large-scaled exploratory movements during the post-fledging period, the White-tailed Sea Eagle (*Haliaeetus albicilla*). We analysed GPS tracking data of 21 juveniles with respect to the onset of natal dispersal comparing six methods available from the recent literature. While none of the methods significantly differed from the visual method, the Distance Threshold method underestimated the dispersal onset for some individuals. Likewise, coefficient of variation methods overestimated the dispersal onset in few cases, presumably because the temporal scale of available GPS fixes did not correspond to the scale of discrete dispersal movements. We conclude that all tested methods are generally suitable to estimate the dispersal onset, specifically if the research question does not depend on an exact but rather a rough estimate. A visual determination might increase flexibility to account for individual behavior and yields consistent results across individuals, but highly reduces the comparability across observers and studies. For research questions relying on exact estimates, we propose using a combination of an automated method and a visual determination as a back-up method for single individuals with clear under- or overestimation. An exploratory comparison showed that the temporal resolution of the GPS may further affect the accuracy of natal dispersal estimates. For individuals with clear movement patterns, high-resolution movement data could increase the accuracy of Coefficient of Variation methods. We underline the necessity for further investigation on the effects of temporal resolution on dispersal onset estimates.

1. Introduction

In many raptor species, the onset of natal dispersal generally forms the end point of the post-fledging period and marks the start of a long and complex dispersal phase (Greenwood & Harvey 1982). Late in the post-fledging period, juveniles are still dependent on their parents for prey deliveries while at the same time exhibiting exploratory behavior in the form of excursions from the nest (Engler & Krone 2021; Soutullo *et al.* 2006b). This way, juveniles can assess the habitat conditions outside the natal territory and potentially lower associated risks or costs of their dispersal.

As juveniles usually become independent from their parents during dispersal, natal dispersal forms a key phase for individuals with respect to their survival, reproduction and adaptations to environmental changes (Morrison & Wood 2009). Thus, the behavioral decision-making process of the individual throughout its dispersal can ultimately not only affect its survival and reproductive success, but also have an impact on population dynamics (Bonte *et al.* 2012; Bowler & Benton 2005).

Accurately describing and analyzing related movement decisions forms the base for understanding the biology of the study species (Serrano 2018). Some research questions address movements throughout the natal dispersal process over large time periods or with large-scaled spatial reference, *e.g.* activity range size over multiple months (Walls & Kenward 2020). While in such cases, accurately determining the time point of the onset of natal dispersal might not always be strictly necessary, other research questions rely specifically on such information. For example, the quality of the natal environment can shape early dispersal movements, and identifying related long-term developments (*e.g.* premature dispersal onset due to habitat degradation) relies on exact and reliable estimates for the onset of natal dispersal (Balbontín & Ferrer 2005; Engler & Krone 2021). Additionally, such information can be crucially important for developing species-specific conservation strategies of raptor species (Balotari-Chiebao *et al.* 2016, Weston *et al.* 2013), *e.g.* by contributing to appropriate spatial and temporal planning of nest protection guidelines in relation to potential anthropogenic disturbance (Engler & Krone 2021).

Accurately estimating the time point of natal dispersal onset is challenging, as assessment methods are not suitable for all raptor species due to complex movement behavior and high levels of individual variation in the time point of natal dispersal (Weston *et al.* 2013, Cadahía *et al.* 2010, Soutullo *et al.* 2006a, Engler & Krone 2021). Different approaches have been used in the recent literature and on different raptor species to estimate the time point of natal dispersal, including Distance Threshold (DT) methods and Coefficient of Variation (CV) methods and visual inspection. DT methods incorporate territory metrics such as home range sizes derived at the population level (Weston *et al.* 2013, Soutullo *et al.* 2006a 2006b, Walls & Kenward 1995, Ferrer 1993a) and rely on the assumption that the defined distance thresholds robustly reflect both an appropriate distance and duration to distinguish dispersal from other movement types (Weston *et al.* 2013). CV methods, on the contrary, use a mathematically based approach by integrating coefficients of variation to determine rates of increase in the distance from the nest over given time periods (Weston *et al.* 2013, Cadahía *et al.* 2008, Soutullo *et al.* 2006b, Walls & Kenward 1995, Ferrer 1993b). They hence compute a metric that describes the variability of movement and are based on the assumption that dispersal from the parental territory forms the most distinctive phase by means of an increased variability in distance from the nest of origin during the exploratory stage (Cadahía *et al.* 2008, Soutullo *et al.* 2006a). Accordingly, the onset of dispersal should be represented by the highest variation in distance over a certain time period (Weston *et al.* 2013).

Inconsistent estimates are the dominant outcome from the majority of available dispersal methods and very few studies have compared their applicability and accuracy (Weston *et al.* 2013, Cadahía *et al.* 2008, Soutullo *et al.* 2006b). Further, as such methodological comparisons have only been made for Golden Eagles *Aquila chrysaetos* (Weston *et al.* 2013, Soutullo *et al.* 2006b) and Bonelli's Eagles *Hieraaetus fasciatus* (Cadahía *et al.* 2008), comparisons for additional raptor species are necessary to develop suitable and reliable methods for identifying the onset of natal dispersal of species that exhibit complex movement patterns during the post-fledging period.

Over the last decades, the ongoing technical development of tracking devices has led to an exponential increase in tracking data, thus expanding the spatio-temporal scale at which movement patterns can be analysed (Hooten *et al.* 2017; Kays *et al.* 2015). The value of high resolution tracking data for studying animal movements with the goal to infer an understanding as the base for conservation strategies has been demonstrated by multiple studies on raptor species, including the Montagu's Harrier (*Circus pygargus*, Schaub *et al.* 2020) and the Northern Goshawk (*Accipiter* *gentilis*, Blakey *et al.* 2020). However, the effect of temporal resolution of tracking data on the outcome of analyses is still scarcely addressed and likely depends on the movement scale and behavior of the animal (Gunner *et al.* 2021, Ryan *et al.* 2004).

Therefore, the focus of this study was to compare DT methods, CV methods and a visual determination with regards to their accuracy in estimating the onset of natal dispersal using a raptor species that displays large-scaled exploratory movements with high individual variability during the post-fledging period, the White-tailed Sea Eagle (WTSE, *Haliaeetus albicilla*, Engler & Krone 2021). The WTSE is a large diurnal raptor that inhabits undisturbed areas in forests, on islands and along coastal areas, with access to fish-rich freshwater lakes that offer perching possibilities along the shoreline to increase foraging success (Fischer 1984, Krone *et al.* 2013, Nadjafzadeh *et al.* 2016). Additionally, we aimed to examine whether the temporal resolution of data affected dispersal onset estimates, using a small sample size of two exemplary individuals.

2. Methods

2.1. GPS tracking

We analysed tracking data from 21 WTSE fledglings that were equipped with Global Positioning System (GPS) or Global System for Mobile Communications (GSM) satellite transmitters between 2004 and 2016 in North-East Germany. Nestlings were fitted using a backpack-style harness system (Krone *et al.* 2013) at an age of 42 to 66 days. The transmitters' weight accounted for 3% of the eagles' body weight on average (3.3 ± 0.6%, n = 21, range: 1.7–4.2%). We determined the individual date of fledging by visually by mapping GPS positions using the distance to the center of the nest, while taking individual positioning errors into account (Engler & Krone 2021). Locations were recorded at different intervals from every 30 minutes to once per day between hours 06:00 and 20:00 (UTC+2). For a uniform temporal scale, GPS fixes were filtered to one location per day closest to 12:00 (Engler & Krone 2021). Additionally, data at 30-minute intervals was available for two individuals (4876, 4877) and we used data from these individuals for a separate investigation with higher resolution. Additional information on transmitter models and data preparation are reported by Engler and Krone (2021). Originally, 31 nestlings were tagged, ten of which were removed from the analysis due to early technical failure or large data gaps (Engler & Krone 2021). The animal permits were issued by the following authorities with the permit numbers indicated in parentheses: State Veterinary and Food Inspection Office Mecklenburg-Western Pomerania (LVL M-V/3104), Lower Saxony State Office for Consumer Protection and Food Safety (33.42502-080/06) and Brandenburg State Office for Consumer Protection, Agriculture and Land Consolidation (23-2347-3-2009).

2.2. Estimation of natal dispersal onset

We used the number of days since fledging as the metric for onset of natal dispersal, using a DT method, CV methods and a visual approach (Table 1): For method 1, we defined circular and temporally fixed parental home-range (HR) sizes for breeding pairs as the mean of available HR sizes from the literature. We used averaged HR sizes of 13.48 km² (radius of 2.07 km, n = 20) for breeding pairs from the two core areas of the study region and 53.25 km² (radius of 3.90 km, n = 11) for all other breeding pairs, as described by Engler and Krone (2021). To avoid underestimation of the onset of dispersal caused by pre-dispersal excursions we used a threshold of spending at least five days outside the parental territory. Based on recommendations by Walls and Kenward (1995), we chose this particular time period as we considered it to reflect the time period at which juveniles would be capable of returning from an excursion without serious impact to their health, at a life stage when they are still not capable of foraging on their own (authors' pers. observation.).

Among the CV methods (Table 1, methods 2–4), we calculated the coefficient of variation in distance (CV_D) as the ratio of standard deviation to the mean distance for consecutive time periods of the respective length in days. For example, method 2 calculated CV_D as the standard deviation

Table 1. Applied methods to estimate the time point of natal dispersal of juvenile White-tailed Sea Eagles. DT = Distance Threshold method. CV = Coefficient of Variation method. Visual = Visual determination method.

Method	Type	Description	Reference
1	DT	First day of five consecutive locations beyond the radius of respective circular parental territory.	Soutullo *et al.* (2006b), Walls and Kenward (1995)
2	CV	Highest coefficient of variation (3-day period)	Weston *et al.* (2013), Cadahía *et al.* (2008), Soutullo *et al.* (2006b)
3	CV	Highest coefficient of variation (5-day period)	See references in method 2
4	CV	Highest coefficient of variation (10-day period)	See references in method 2
5	CV	Maximum change in proportion of locations inside the fixed circular parental territory between –30 days and +30 days, per day.	Weston *et al.* (2013)
6	Visual	Observed location pattern, subjective assessment	Walls and Kenward (1995)

of distance to the nest over a rolling 3-day period divided by the mean of distance to the nest over the same time period. We defined the dispersal date as the day midway between the first and last location of the time period for which CV_D was highest. We only considered CV_Ds of relocations with a distance >1 km from the nest for >3 consecutive days, to make sure that estimates are biologically relevant. By choosing a distance of only 1 km, we aimed to maintain the character of a mathematical computation rather than adding the approach of detection based on distance thresholds as in method 1.

For method 5, we similarly tried to identify time periods with maximum rates of change while accounting for the large temporal scale at which dispersal can occur (Weston *et al.* 2013). Here, the proportion of locations inside the fixed, circular parental territory was determined for 30 days before (T_1) and 30 days after (T_2) each relocation and the difference in proportions ($T_{diff} = T_1 – T_2$) was calculated for a 60-d time period. In daily time steps, this window was shifted forward, resulting in T_{diff} for multiple consecutive time periods. The time point of dispersal was then defined as the date for which T_{diff} was maximal (Weston *et al.* 2013).

Thirdly, a visual determination of the onset of dispersal from visual exploration of movement trajectories served as a base reference (method 6), for which we mapped relocations for each individual using the fixed circular parental territory sizes reported in Engler and Krone (2021) as boundary thresholds for each bird. We then closely inspected movement paths individually to identify the most likely time point at which the onset of natal dispersal took place.

2.3. Effect of temporal resolution of GPS time intervals

To preliminarily investigate whether the temporal resolution of GPS time interval affected estimates of dispersal onset compared to the visual determination method, we additionally calculated differences in estimates ($|\Delta_{days}|$) based on the high-resolution data set for each method in comparison to the visual determination method. Additionally, we compared low-resolution estimates to high-resolution estimates. We used a very limited sample size of two individuals for this investigation.

2.4. Statistical analysis

Differences in estimates of dispersal onset between methods were tested using a non-parametric Quade-test for repeated measures, due to the comparatively small sample size and preliminary diagnostics of the distribution of the data. We performed a post-hoc Quade multiple-comparison test with BH correction (Benjamini & Hochberg 1995) to further identify between-group differences. The significance level α was set at $p<0.05$ for all statistical tests. Summarizing group values are presented as mean ± standard deviation (SD), if not stated otherwise. Data processing and statistical analyses were performed in software R, version 3.5.1 (R Core Team 2018).

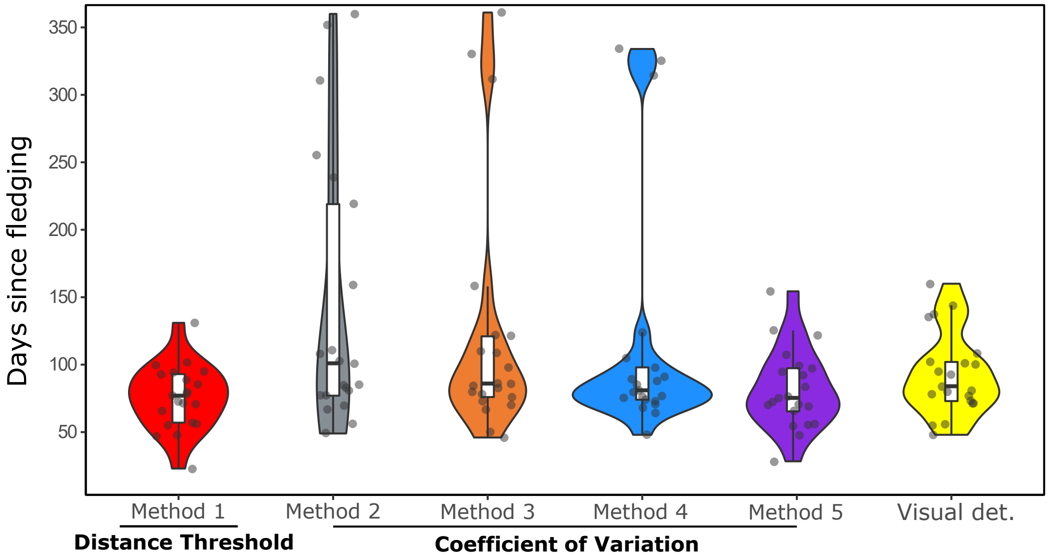
3. Results

3.1 Estimation of natal dispersal onset

Across methods, mean estimates of the time point of dispersal ranged from 82.4 to 145.1 days after fledging and showed large variability within methods (between individual eagles) but little between methods (Fig. 1). While estimations based on a visual determination averaged 92.8 (±30.2) days after fledging, the DT method yielded the lowest mean estimates (75.8±23.8 days) as well as the lowest within-method variation among all methods. Within CV methods, methods 2–4 showed the highest means and standard deviations (Fig. 1). The differences in mean estimates and standard deviations in CV methods compared to the visual determination method reduced with increasing length of the time period over which the coefficient of variation was calculated. For multiple individuals, the time point of emigration was estimated long after the time point of emigration measured by the visual determination (Fig. S1).

In contrast, the variability in estimates was roughly three times lower for method 5 compared to CV methods 2–4 (Fig. 1) and it yielded the closest estimates (82.4±29.3 days) to the visual approach among all methods.

Overall, the choice of method significantly affected the outcome of estimates for the onset of natal dispersal (Quade's test, $F(5, 100)=3.15$, $p<0.02$). Among all group combinations, only



	Method 1	Method 2	Method 3	Method 4	Method 5	Visual det.
mean	75.8	145.1	123.8	116.2	82.4	92.8
sd	23.8	100.7	91.9	88.5	29.3	30.2

Fig. 1. Estimations of dispersal onset in White-tailed Sea Eagles (n=21) by a Distance Threshold method, Coefficient of Variation methods and visual determination represented as violin and boxplots with whiskers to 1.5 Inter-Quartile Range (IQR). Points indicate time of dispersal (days since fledging) of individuals.

estimates of the DT method and method 2 (Pairwise Quade's test, p=0.014) as well as method 2 compared to method 4 (Pairwise Quade's test, p=0.037) and method 5 (Pairwise Quade's test, p=0.024) differed from each other, as shown by a post-hoc analysis. None of the methods significantly over- or underestimated the dispersal onset compared to the visual determination.

3.2. Effect of temporal resolution of tracking data

The comparison of dispersal onset estimates between two levels of temporal resolution of two individuals yielded widely different results (Fig. 2). For individual no. 4876, which went on multiple excursions (n=9) up to 28.6 km distance from the nest prior to onset of natal dispersal (Fig. S1), estimates of all methods based on a higher resolution data set generally underestimated the onset of dispersal. $|\Delta_{days}|$ ranged from 34 days (method 4) to 75 days (method 1), averaging at 35.7 (±15.3) days for estimates of CV methods 2–4 (Fig. 2). Estimates based on the low-resolution data set were generally higher and closer to a visual determination than those based on higher resolution data, with a difference of 46 days for method 1 and an average of 29.8 (±12.4) days across all methods.

In contrast, for individual no. 4877, which undertook fewer excursions (n=6) with shorter maximum distance (2.9 km) and a single event of rapid increase in distance from the nest site (Fig. S1), $|\Delta_{days}|$ was highest for method 1 with a premature detection of dispersal onset by 37 days (Fig. 2). All CV methods (methods 2–5) yielded highly consistent estimates when calculated with the high-resolution data set, differing by only 1.0 days (±0) on average compared to the visual determination method. Additionally, while low resolution estimates were lower for methods 3 and 4 (24 days ±0) in comparison to the high-resolution estimates, method 2 overestimated the dispersal onset by 148 days for low resolution data with reference to the visual determination estimate.

For both individuals, estimates of dispersal onset for the visual determination were identical between the high- and the low-resolution data set.

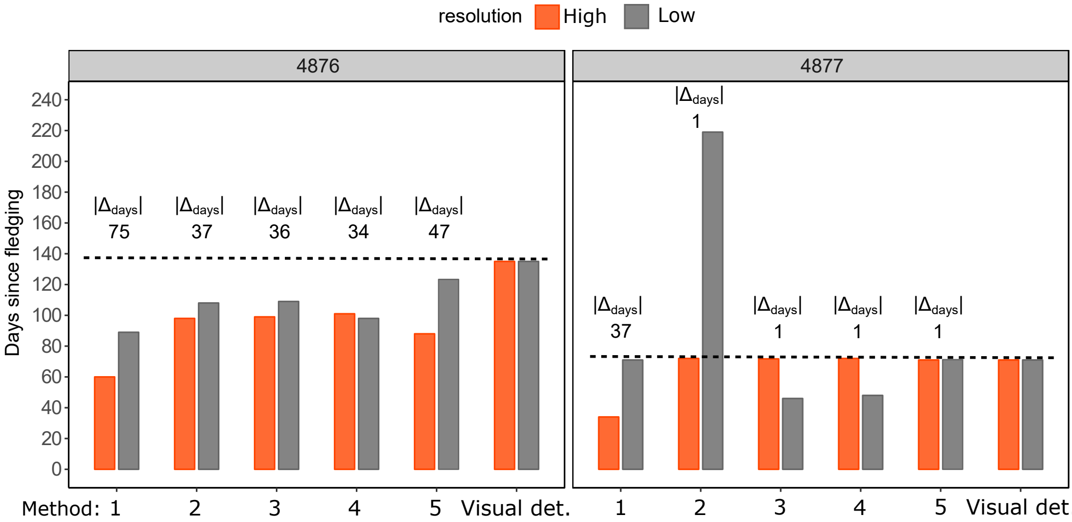


Fig. 2. Comparison of estimates in dispersal onset for two individuals (no. 4876 and 4877) with two levels of temporal resolution. Orange bars represent the days since fledging based on a data set with 48 GPS fixes per day, grey bars are based on the low-resolution data set with a resolution of a single GPS fix per day. $|\Delta_{days}|$ represents the absolute difference in days between estimates of the high-resolution data set with the visual determination. The horizontal, dashed lines mark estimates of the onset of dispersal using visual determination.

4. Discussion

4.1. Estimation of natal dispersal onset

To our knowledge, our study is one of few that compares different methods of estimating dispersal time of young raptors from the nest. Overall, none of the tested methods significantly over- or underestimated the onset of natal dispersal compared to the visual determination method. The DT method, using methodological adaptations to account for pre-dispersal excursions of WTSE on a biologically meaningful level (Walls & Kenward 1995), yielded precise estimates for most individuals. However, for some individuals the method wrongly detected clear events of exploratory excursions during the pre-emigration phase as the onset of natal dispersal. This result was mainly linked to individuals with extensive exploratory behavior regarding the number, distance and the duration of excursions (Engler & Krone 2021). The results highlight, that accounting for individual variation and complexity in post-fledging movement patterns remains the major challenge for such methods, particularly for species with high propensities towards excursive behavior (Weston *et al.* 2013, Cadahía *et al.* 2008, 2005, Kenward *et al.* 1993). We conclude, however, that universally applied measurements of distance thresholds might form an alternative to a rather subjective visual determination of dispersal. The methodological drawbacks of risking underestimation due to using fixed biological parameters could be tolerated compared to the disadvantages of a highly subjective approach of a visual determination and makes results more comparable between studies.

Although not significantly different from the visual method, CV methods 2–4 yielded the highest variation in dispersal estimates and the variance of estimates decreased with an increasing time interval, over which the estimate was calculated. In several cases, rapid small-scaled movements over short time periods caused an overestimation of dispersal onset due to delayed detection. These results for rate-based methods are consistent with findings reported for two other large raptor species, the Bonelli's Eagle *Hieraaetus fasciatus* (Cadahía *et al.* 2010, 2008) and the Golden Eagle *Aquila chrysaetos* (Weston *et al.* 2013, Soutullo *et al.* 2006a, 2006b), which show similar (pre-) dispersal behavior. In these cases, the results highlight the disadvantages of solely rate-based estimation methods reported in the recent literature, as they do not take the spatial scale of movements into account (Weston *et al.* 2013).

Method 5, however, yielded the lowest within-method variation and resulted in estimates closest to the visual determination. By operating on a larger temporal scale while taking a presence/absence ratio within the parental HR into account, method 5 seemed to integrate the scale of natal dispersal movements the best, hence coping with individual variation and movement patterns acting on similar spatio-temporal scales. Compared to the DT method and the other CV methods, method 5 did not show signs of under- or overestimation for outlier individuals with either strong exploratory behavior or rapid small-scaled movements. Therefore, we rate this method as an accurate alternative to a visual estimation.

We used a visual determination as the reference, because it is a direct approach, offers the highest levels of flexibility for scientists and lets them integrate their personal experience on the study species the most. Equally, this represents a major drawback for the method, as estimates are highly subjective and inter-observer comparability is therefore strongly compromised (Cadahía *et al.* 2008). Accordingly, estimates based on visual determination need to be presented as transparently as possible and conclusions should be drawn with caution, particularly when comparing results between species with different dispersal behavior.

Ultimately, both DT and CV methods generally appear to form suitable alternatives to a subjective visual estimation of the time point of dispersal for WTSE. However, in multiple cases only a visual determination coped with the irregular movement patterns during the post-fledging period. These results are highly consistent with a respective comparison for Golden Eagles, which showed similarly complex movement patterns prior to emigration (Weston *et al.* 2013). We highlight that the choice of method should also be made based on the respective research question and the purpose of calculating the date of dispersal onset in the first place. If the main research goal does not rely on an exact date, and aims for larger temporal time periods, *e.g.* when calculating and comparing temporal activity ranges (Murphy *et al.* 2017), both DT and CV methods might be suitable options. In such situations, the advantages of producing automated, objective estimates without the risk of reduced comparability due to subjective estimation could justify the risk of premature or delayed estimates for few individuals (Cadahía *et al.* 2008).

On the contrary, if the research question requires precise estimates of the natal dispersal onset, specifically method 5 appears to be a suitable alternative to a visual estimation, as it appears to cope well with outlier individuals. Precise estimations become increasingly important, *e.g.* when identifying effects of the natal environment on the dispersal onset (*e.g.* premature dispersal onset due to habitat degradation; Balbontín & Ferrer 2005; Engler & Krone 2021). In the same context, researchers rely on exact estimates for the onset of natal dispersal, when the main goal is to develop species-specific conservation strategies such as planning of temporal nest protection guidelines for raptor species (Balotari-Chiebao *et al.* 2016, Engler & Krone 2021, Weston *et al.* 2013).

In general, we propose to use a combination of a) an automated method such as method 5 as the primary choice and b) a visual determination as the backup method specifically for raptor species with high propensities towards rapid movements on large spatio-temporal scales and strong excursive behavior. The latter could be used only on individuals, where both DT and CV methods clearly yielded under- or overestimated time points of dispersal onset.

Although we were not able to incorporate precise, individual-based yet data-intensive representations of the parental HR as described and proposed by McLeod *et al.* (2002) and Weston *et al.* (2013), they could additionally form a promising alternative to adequately estimate the onset of dispersal for raptor species with strong excursive behavior.

We highlight that accurately determining the onset of natal dispersal and differentiating between pre-dispersal movements is not solely important for raptor species, but also for other bird groups and even mammals that display excursive behaviour. For example, studies on seabirds (*e.g.* frigatebirds *Fregata minor,* Collet *et al.* 2020) and mammals such as flying squirrels *Pteromys volans* (Selonen & Hanski 2006) and roe deer *Capreolus capreolus* (Ducros *et al.* 2020) frequently applied spatial metrics such as parental home range boundaries similar to method 1 in order to account for and discriminate between excursions and natal dispersal.

4.2. Effect of temporal resolution of tracking data

The exploratory comparison of low and high temporal resolutions indicated that an interaction between excursive behavior, method and temporal resolution may further influence the outcome of dispersal onset estimates for raptor species.

For the individual with strong excursive behavior (no. 4876), all methods yielded better estimates on low- rather than on high-resolution data, as high-resolution based estimates generally underestimated the onset of dispersal compared to the visual method.

We assume that the higher resolution of GPS fixes increased the chances of premature detection of dispersal onset due to the frequent small-scaled movements in the form of excursions. In these cases, the temporal scale of available GPS fixes and hence the scale on which methods are applied might not correspond to the temporal scale on which discrete dispersal movements take place. The results could indicate that the compared methods do not necessarily perform better on high-resolution tracking data, if the propensity of the individual or species towards large-scaled exploratory movements during the post-fledging period is high.

On the contrary, CV methods based on high-resolution data yielded particularly highly consistent and precise estimates for the individual (no. 4877) with a distinct event of emigration and a rapid increase in distance from the natal territory. Similar effects for different temporal resolutions have already been demonstrated, for example, in inferential models or when calculating travel distances (Postlethwaite & Dennis 2013; Rowcliffe *et al.* 2012). In line with the comparison between methods, this further indicates that for single individuals, CV methods based on low-resolution data could not accurately detect the singular event of dispersal. Possibly, the temporal scale over which the coefficient of variation was calculated was too small to account for the distance covered during natal dispersal onset (method 2).

We conclude that for raptor species with rather clear movement patterns the availability of high-resolution movement data could additionally increase accuracy and consistency of estimates when using methods based on coefficients of variation. Although these findings are only exploratory, we underline that in future studies special consideration should be given to the effect of temporal resolution on estimates of natal dispersal characteristics, particularly for target parameters with high individual variability and species with strong excursive behavior.

Due to the increasing number of GPS tagged animals and an increasing temporal resolution of the data, automatized pattern detection methods and the need for validation of their reliability will become increasingly relevant for wildlife research.

En jämförelse av metoder för att uppskatta påbörjandet av spridningsfasen hos en stor dagrovfågelart

Vi undersökte tidpunkten för när havsörnens (*Haliaeetus albicilla*) ungar påbörjar sin spridningsfas. Havsörnens flygga ungar utför relativt långa utforskande flygturer innan de beger sig iväg, vilket försvårar uppskattningarna. Vi analyserade GPS spårningsdata från 21 juvenila havsörnar där vi jämförde den uppskattade tidpunkten för påbörjandet av spridningsfasen med hjälp av sex metoder som nyligen beskrivits i litteraturen. Ingen av metoderna skiljde sig från metoden att visuellt bestämma tidpunkten, men 'Distance Threshold' metoden underskattade tidpunkten för spridningsfasens början. Däremot överskattade varianskoefficient-metoden påbörjandet av spridningsfasen, antagligen på grund av att datapunkterna från GPS spårningen inte tillräckligt exakt sammanföll med informationen från de separata spridningshändelserna. Vi sammanfattar att alla metoder som testades generellt sett är ändamålsenliga för att uppskatta påbörjandet av spridningsfasen, speciellt ifall forskningsfrågan inte kräver en väldigt exakt uppskattning. En visuell uppskattning ökar flexibiliteten att ta i beaktande individuell variation och ger överensstämmande resultat mellan örnindivider, men försvårar jämförandet mellan observatörer och studier. För studier som kräver exakt information om påbörjan av spridningen rekommenderar vi att kombinera en automatiserad metod med visuella metoder som stöd ifall uppskattningarna av vissa individer är tydligt över- eller underskattade. Våra data tyder även på att den temporala upplösningen i data påverkar uppskattningarna av påbörjandet av spridningsfasen. För de individer som har tydliga rörelsemönster kunde data med hög upplösning förbättra noggrannheten i varianskoefficient-metoden. Vi understryker att det behövs mera studier i effekten av temporal upplösning vid studier av tidpunkten för påbörjan av spridningsfaser.

Competing interests. The authors declare that they have no competing interests.

Data availability statement. We will make individual-wise dispersal onset estimates publicly available by adding a table to the supporting information (Table S1). As underlying raw movement data contains highly sensitive information on nest location of White-tailed Sea Eagles, we will not make such information available.

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Online supplementary material

Supplementary material available in the online version includes Figure S1 ana Tables S1–S2.