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1 **GPS tracking data can document wind turbine interactions: evidence from a GPS-tagged**

2 **Eurasian curlew**

3

4 Frédéric Jiguet^{1*}, Philipp Schwemmer², Pierre Rousseau³, Pierrick Bocher⁴

5

6 ¹ UMR7204 Centre d'Ecologie et des Sciences de la Conservation, MNHN CNRS SU, CP135, 43 Rue

7 Buffon, 75005 Paris, France

8 ² Research and Technology Centre (FTZ), Christian-Albrechts-Universität zu Kiel, Hafentörn 1, 25761

9 Büsum, Germany

10 ³ National Nature Reserve of Moëze-Oléron, LPO Ligue pour la Protection des Oiseaux, Nouveau,

11 17780 Saint-Froult, France

12 ⁴ Laboratory Littoral Environnement et Sociétés UMR LIENSs 7266 CNRS- La Rochelle University, La

13 Rochelle, France

14 * corresponding author: frederic.jiguet@mnhn.fr

15 **Keywords**

16 Endangered species, GPS tracking, non-lethal impact, *Numenius arquata*, renewable energy, wind
17 farm

18

19 **Abstract**

20 The Eurasian Curlew is an endangered long-lived shorebird breeding in grassland and moorland, with
21 declining numbers across its range due to habitat loss and former hunting. In this context, any
22 additional adult mortality can have a noticeable impact on population dynamics, hence on extinction
23 risk. We report a case of a GPS-tagged individual which track revealed an unusual stopover at the
24 bottom of a wind turbine along its migration route. The curlew rested hours in an unfavourable
25 environment before moving to the adjacent coastal shore, then completed its migration journey the
26 next day. In previous studies, GPS-tags helped to identify death casualties at wind farms, but to our
27 knowledge this is the first detailed report of a non-lethal injury of a tagged animal by a wind turbine,
28 probably by the vortex of rotors. This case alerts on the further potential impacts of wind farm
29 development close to breeding, wintering and stopover sites frequented by Eurasian curlews and other
30 birds. Any wind farm development project should consider the opportunity to avoid, reduce or
31 compensate potential lethal and non-lethal impacts on wildlife.

32 1. Introduction

33 Facing recent human-induced climate change, most nations engaged in an energetic transition by
34 developing renewable energy sources to reduce greenhouse gas emissions. Typical schemas include
35 an increasing energy production from solar panels, wind turbines, and tidal power plants, to reduce
36 the use of fossil energies such as petrol and coal [1]. The impact of wind farms on wildlife, especially
37 birds and bats, needs to be evaluated. Biodiversity has been declining for decades [2] for reasons
38 including climate change and habitat loss [3,4]. Solutions to reduce climate change should mitigate,
39 not increase, the ongoing biodiversity crisis. In a changing world, the development of green energy is
40 more important than ever. One of the most well-developed and cheaply available options is wind
41 power, but there is evidence that wind farms can also have a negative impact on biodiversity. There is
42 now a large body of literature assessing the impacts of wind farms on birds and bats [5,6,7] and
43 proposing mitigations to reduce mortality [8,9]. There are few studies reporting the collision of GPS-
44 tagged migratory birds on wind farms leading to the death of the individual [10].

45 The Eurasian Curlew *Numenius arquata* is a migratory bird threatened mainly by land use
46 changes [11]. It breeds in temperate Eurasia and migrates to spend the non-breeding season (June-
47 July to March-April) on a variety of wetland habitats mainly in north-western Europe. The European
48 population is estimated at 212,000-292,000 pairs and considered to have decreased by 30-49% in 30
49 years. The species is classified as vulnerable to extinction in the regional IUCN Red List [12]. The species
50 is therefore subject to numerous conservation efforts to preserve the birds and their habitats [13] and
51 is listed on Annex II of the EU Birds Directive (Directive 79/409/EEC of the European Council of 2 April
52 1979 on the conservation of wild birds), permitting hunting in few listed Member States, e.g. Denmark,
53 France, Ireland and the United Kingdom. A hunting moratorium was implemented in these countries
54 to help breeding populations to recover [13]. The Eurasian Curlew is long-lived with estimated adult
55 survival of 92% [14] and a generation time of approx. 10 years [15] (e.g. average age of active breeding
56 females), so any additional adult mortality can have a noticeable impact on population dynamics,

57 hence on extinction risk. Here we report on a non-lethal interaction between a migrating GPS-tagged
58 curlew and wind turbine. Data retrieved from the GPS shows potential for use of GPS tracking to
59 detect interactions between wildlife and wind turbine.

60

61 **2. Material and Methods**

62 Data was collected as part of research into migration connectivity in the Eurasian Curlew [16]. In
63 February 2020, we captured, ringed and GPS-tagged 10 Eurasian curlews wintering in a National
64 Nature Reserve in Western France. One of them left the non-breeding area to reach its breeding
65 grounds on Spiekeroog Island, in the German Wadden Sea (53,77°N 7;74°E). This curlew was captured,
66 ringed and tagged on 23 February 2020 at Moëze-Oléron National Nature Reserve, Charente-Maritime,
67 France (45.90°N, 1.08°W). We tagged the bird with Ornitrack-10 solar-powered backpack tag with
68 Global System for Mobile Communication (GSM) data transmission (weighing 10 grams) and a brown
69 case, the harness being a leg-loop Teflon rubber (2.5mm wide) closed by a glued knot. The device,
70 labelled 200208, recorded time (UTC), geographical position, flight speed, altitude and acceleration
71 along three spatial axes. Data acquisition depended on battery charge, and range from one location
72 recorded every five to thirty minutes. Data transmission occurred once a day. The bird was ringed with
73 colour rings representing a unique combination for identification in the field. The bird weighed 728
74 grams, so the material (tag, harness and rings) represented, e.g. 1.6% of the body mass. The bird was
75 sexed as a male, because of a short bill length (117mm) [17].

76

77 **3. Results**

78 The bird stayed in the wintering grounds of Pertuis Charentais until 2nd March 2021, when it left late
79 in the evening between 21:00 and 22:00 (UTC), to arrive on its breeding grounds on Spiekeroog island,
80 Germany, on 4th March at 14:49. On its way, the curlew made a short stopover in Zeeland, the

81 Netherlands, at 51.457°N 4.284°E during two hours on 3rd March (between 7:54 and 9:54), then a
82 second short stopover in Groningen province, the Netherlands, at 53.288°N 6.970°E during one hour
83 the same day (between 13:48 and 14:55), then a longer stopover west of Eemshaven harbour
84 (53.435°N, 6.883°E) between 16:08 and 17:58. The curlew then flew west and landed exactly under
85 the deployment area of the wind turbine blades before 18:18 (53.4602°N, 6.8221°E), where it stayed
86 without moving for three hours until 21:19. It then moved 1.3 Km west to a coastal mudflat, resting
87 there 7 hours until 4:19 on 4th March (Fig. 1). The curlew left this mudflat to perform a continuous
88 flight to reach its breeding island of Spiekeroog, Germany, where it landed on 4th March at 14:49.

89 At 18:13, the last recorded data before being grounded under the turbine, the bird was in
90 flight, at an altitude of 27 meters and flying at a speed of 32 km.h⁻¹. After landing, the average altitude
91 recorded by the tag was -4±6 meters (min -13, max 7, n=35) with a nul speed. The average altitude at
92 Eemshaven is reported as 0 meter (sea level, source: topographic-map.com).

93 Accelerometer values recorded by the GPS tag between 17:30 and 21:50 on 3rd March changed
94 very slightly, indicating that if the bird was stationary and immobile, the tag was not totally immobile,
95 i.e. the bird was not dead (it was at least breathing; Fig. 2). The peak value of the z accelerometer value
96 recorded at 18:13 reflects a sudden change in elevation immediately before ground recordings began.
97 The precise location of the bird in relation to the wind turbine at the time of the elevation change
98 could not be determined, because the gps data were not recorded at the precise time of the turbine
99 interaction. This elevation drop was at least recorded during the last in-flight fix before the bird was
100 recorded as immobile at the ground next to the wind turbine, from 18:18 onwards.

101 We further compared the x-, y- and z-accelerometer values obtained for early periods after
102 landing, for four examples: (A) bird 200208 during the reported wind turbine interaction; (B) bird
103 200208 during a former stopover in the Netherlands; (C) and (D), birds 200185 and 200187,
104 respectively, tagged at the same wintering site during the same night, with the same tag and harness
105 material, which started their migration together in spring 2020 and made a stopover near Beauvais,

106 eastern France (Jiguet et al. 2021). The stop duration varies slightly between these examples: (A) 181
107 minutes (see above); (B) from 13:43 to 15:13 on 3 March 2021 (90 minutes), (C) from 5:33am to 7:53am
108 on 18 April 2020 (140 minutes); (D) from 5:31 to 20:05 18 April 2020 (874 minutes). We considered
109 the first 90 minutes after landing to compare the values of the four examples. To better compare
110 changes in accelerometer values during a stop, we computed the difference between successive
111 accelerometer values, e.g. the differences between the first value and the second, then between the
112 second and the third and so on. Fig. 3 presents the tracks of these four stopovers, and Fig. 4 reports
113 boxplots of changes in accelerometer values, in the three dimensions, for each bird/stop. In all cases,
114 the stop was preceded by a peak in the z-accelerometer value, attesting a landing (as shown by the
115 red arrow in Fig. 2). There was less terrestrial movement for the stopover occurring in the vicinity of
116 the wind turbine (A) than for three stopovers occurring distant to wind turbine sites (B, C, and D).
117 Although there were no significant statistical differences between individuals for the three values
118 (linear models), probably because of the small statistical power for such small sample size, case A has
119 obviously the less variable values, with the smallest differences between the 25% and 75% quartiles
120 and between the minima and maxima (see Fig. 4).

121

122 **4. Discussion**

123 *4.1. Stunned by the vortex of turbine rotors*

124 The movements of turbine rotors create a vortex near-wake [18,19], reminiscent of the helicopter
125 rotor tip vortex [20]. The vortex created by the rotor movements can act as a dangerous trap for fly-
126 by wildlife, as it represents unusual turbulence of the aerial environment [21] that moving birds and
127 bats are not able to predict and anticipate. If not directly hit by a rotor, being stunned by the vortex
128 can provoke a crash on the ground and body injuries, potentially leading to death. There is very little
129 evidence of birds being forced to the ground as a result of being drawn into the vortex created by
130 moving rotors [22], and GPS-tagged migratory birds might provide an opportunity to detect and

131 document such rare casualties. There is also the possibility that the curlew collided with a rotor, was
132 then forced to the ground but suffered no lethal injury, so was able to escape after some rest. The
133 tagged curlew reported here landed on the ground just at the bottom of a wind turbine, but did not
134 die, and later continued migrating. Indications obtained from the data collected by the tag included an
135 extreme altitudinal acceleration just before landing at the bottom of the turbine, and very low
136 acceleration values in all three dimensions during one and half an hour after landing, compared to
137 three examples of normal stopovers for the same and two other individuals. Furthermore, the habitat
138 frequented below the wind turbine cannot be considered as suitable and attractive for a resting
139 stopover, being close to a road and with dry and hard soil where a curlew could not probe for worms.

140

141 *4.2. Implications for the conservation of the endangered Eurasian Curlew*

142 The majority of studies reporting collisions caused by wind turbines have recorded relatively low levels
143 of mortality [23,24]. This is perhaps largely a reflection of the fact that many of the studies are based
144 only on finding corpses, with no correction for corpses that are overlooked or removed by scavengers
145 [25] or for injured animals that die further from the turbines. If accepting that many wind farms result
146 in only low levels of mortality, even a low additional mortality may be significant for long-lived species
147 with low productivity and slow maturation rates, especially when rarer species of conservation concern
148 are affected. In such cases there could be significant effects at the population level (locally, regionally
149 or nationally), particularly in situations where cumulative mortality takes place as a result of multiple
150 installations or multiple human-induced mortality sources (e.g. including agricultural practices,
151 hunting). This is typically the case for the Eurasian Curlew, which is a long-lived shorebird with a high
152 survival [26], so that any additional adult mortality can have a noticeable impact on population
153 dynamics, hence on extinction risk. For the sample of 10 adult curlews we tagged, a single additional
154 mortality by turbine collision or vortex stunning could double the annual mortality rate, but this of

155 course is based on a small sample. If such events are rare, they should not impact the global population
156 dynamics, but if they are frequent, they might contribute to the decline of the breeding population.

157

158 *4.3. Conclusion*

159 Acquiring tracking data in the vicinity of wind turbines may be instructive to document such
160 interactions. The current developments in tag programming, including the implementation of multiple
161 geofences, i.e. defined areas where data acquisition can be amplified, will certainly increase the
162 frequency and details of the documentation of lethal and non-lethal interactions. This case alerts on
163 the further potential impacts of wind farm development close to breeding, wintering and stopover
164 sites frequented by Eurasian curlews and other birds. Any wind farm development project should
165 consider the opportunity to avoid, reduce or compensate potential both lethal and non-lethal impacts
166 on wildlife.

167

168 **Acknowledgements and ethical statement**

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170 especially members of the national nature Reserve of Moeze-Oléron. The GPS tags have been funded
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172 BirdMan). The capture, ringing and tagging of the curlews were licensed by the CRBPO (French
173 national ringing scheme) under the reference PP1083, following the guidelines for guidelines on
174 animal experiments of the EU Directive 2010/63/EU.

175

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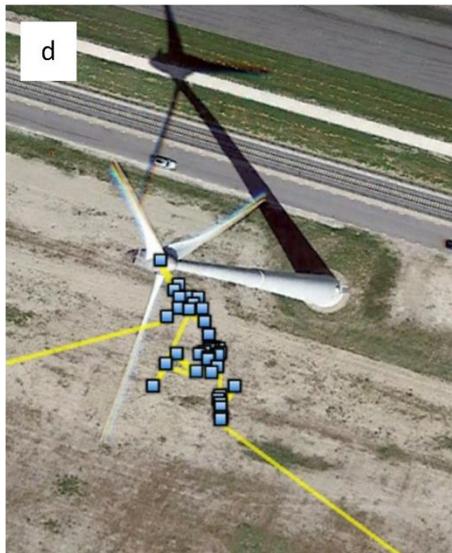
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250 season but not breeding origin. Wader Study 127 (2020) 25-30,
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252

FIGURE CAPTIONS

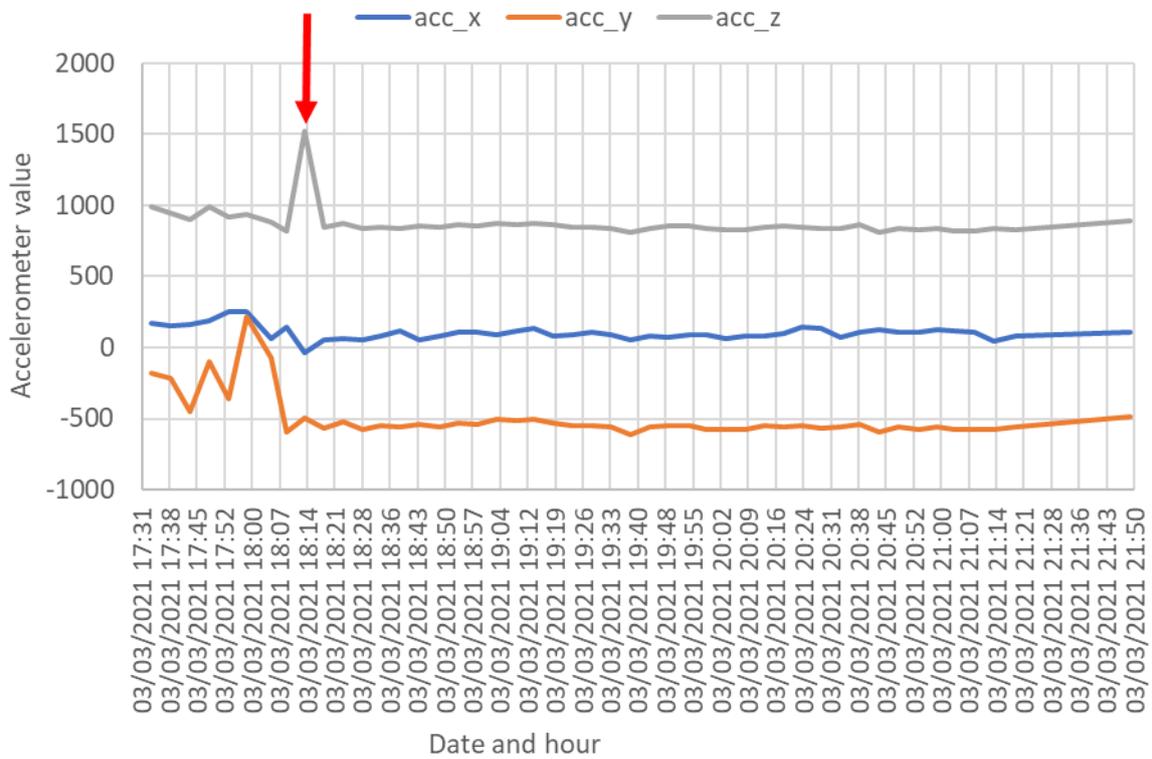
253 Figure 1. GPS locations obtained from the Eurasian Curlew from February 2020 to May 2021: (a)
254 complete tracks of spring 2020 (yellow), autumn 2020 (blue) and spring 2021 (red) migration, and
255 zooms on: (b) the track between 16pm on 3rd March 2021 and 4am on 4th March 2021, with arrows
256 signalling the direction of the movement, and (c-d) the 37 locations recorded at the bottom of the
257 wind turbine. (e) is a ground view of the bottom of that wind turbine, taken on 6 March 2021 by Henk-
258 Jan Ottens.



259

260

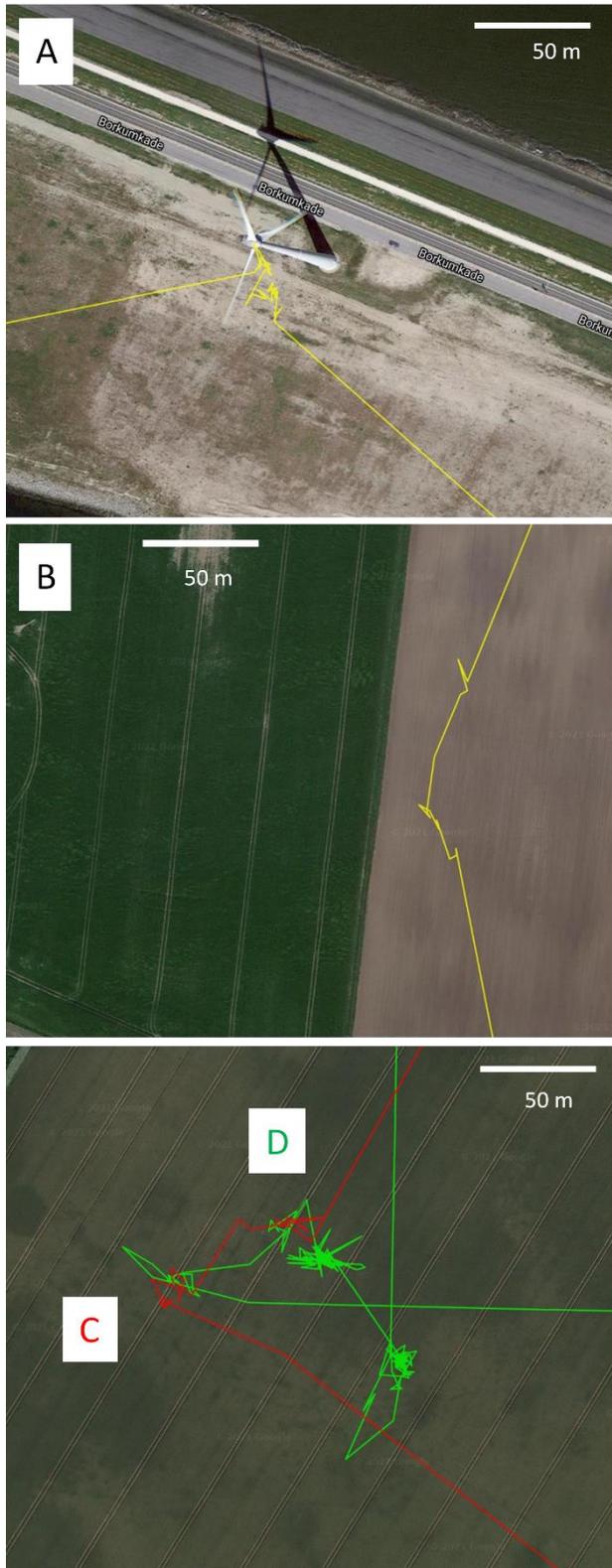
261 Figure 2. Accelerometer data recorded during and after the incident. Slightly changing values along the
262 x-axis indicate that the tag is not totally immobile. The peak value of z accelerometer, recorded at
263 18:13 and signaled by a red arrow, reflects a sudden change in elevation.



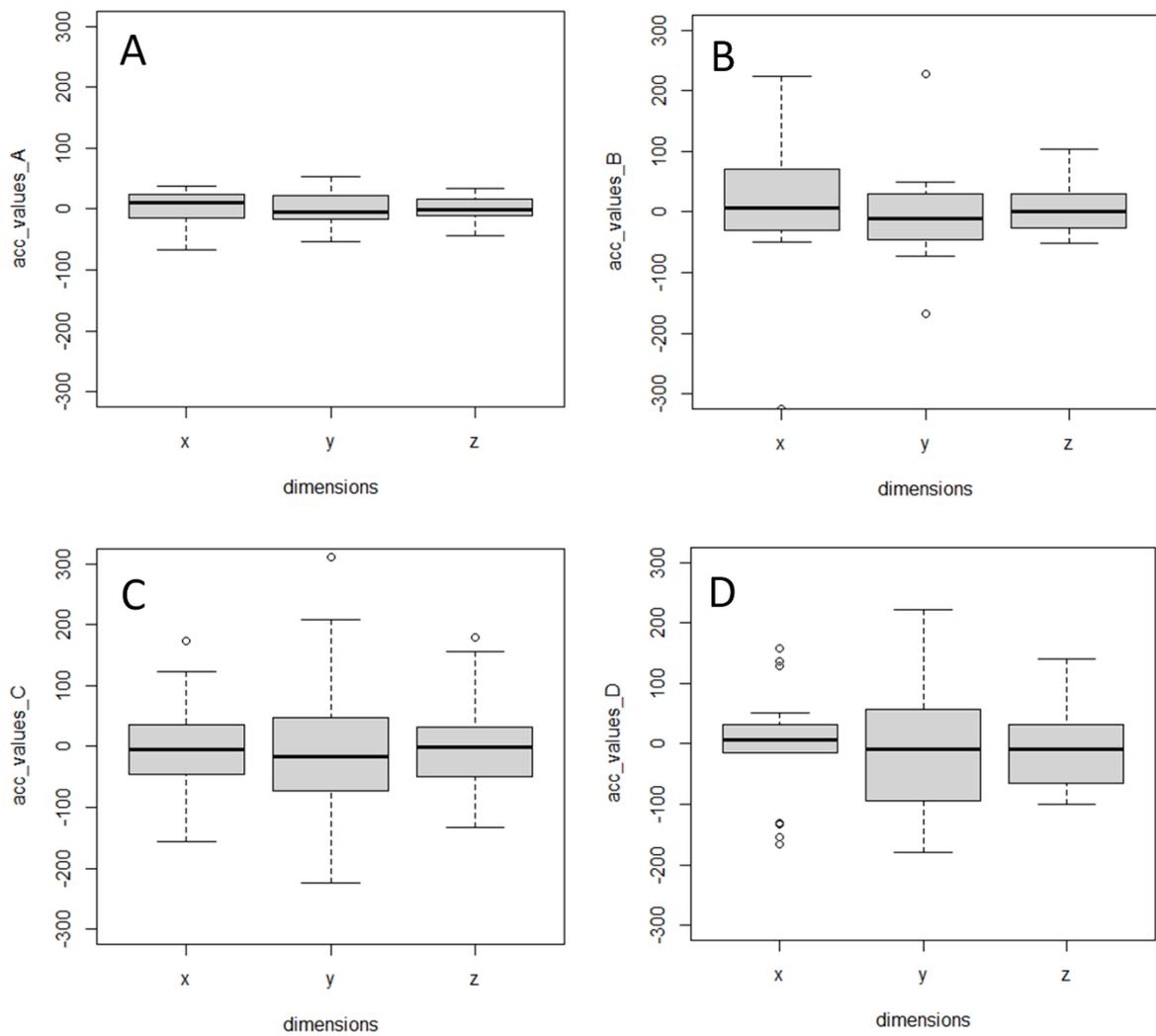
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265

266 Figure 3. Tracks obtained from the GPS positions for three individuals during short stopovers occurring
267 during spring migration. A: the reported case of bird 200208 at a wind turbine; B: the same individual
268 during a short terrestrial stopover in the Netherlands in the morning of the same day; C and D:
269 stopovers of birds 200185 and 200187 near Beauvais, France (after a joint flight bout).



272 Figure 4. Comparison of differences in successive accelerometer data obtained for three individuals
273 during short stopovers occurring during spring migration; same individuals and stopovers as in Figure
274 3, labelled similarly (A to D). The boxplots report the median (black horizontal bar), first (25%) to
275 third (75%) quartiles (grey box) and the minimum and maximum values (dotted lines) of each
276 accelerometer value (x,y,z) for each bird/stop. For comparison purposes, the y-axis has been
277 standardized to range between -300 and 300.



278