Comment

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GNSS spoofing in conflict zones disrupts wildlife tracking and hampers research and conservation efforts

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In war and conflict zones, the jamming of Global Navigation Satellite System (GNNS) signals by military forces disrupts the tracking of tagged animals, and has increased in frequency following the recent escalation of conflicts in Eastern Europe and the Middle East. Such disruption to data collection strongly hampers research into the protection and conservation of endangered animals.

For decades, scientists have been uncovering the secrets of animal movements using various technological solutions[1]. Many of these technologies rely on the GNSS (including the Global Positioning System—GPS) to geolocate the tagged animals[2]. Although originally developed for military purposes[3], GNSS has gained enormous popularity in a wide range of civilian applications, including those related to research on animal movement and conservation biology. By receiving signals from multiple satellites, a GNSS tracking device can gain a high-accuracy location of the carrying animal almost everywhere on the globe within milliseconds. Yet due to the common use of GNSS-enabled applications in military operations, the disruption of GNSS signals is becoming frequent, especially in conflict areas. This jamming or spoofing of GNSS signals is intended to disrupt navigation systems of enemy forces. However, the non-specific nature of this electronic warfare affects all GNSS based devices, including multiple civilian applications such as civilian aircraft[4] and research involving animal tracking devices[5].

GNSS spoofing

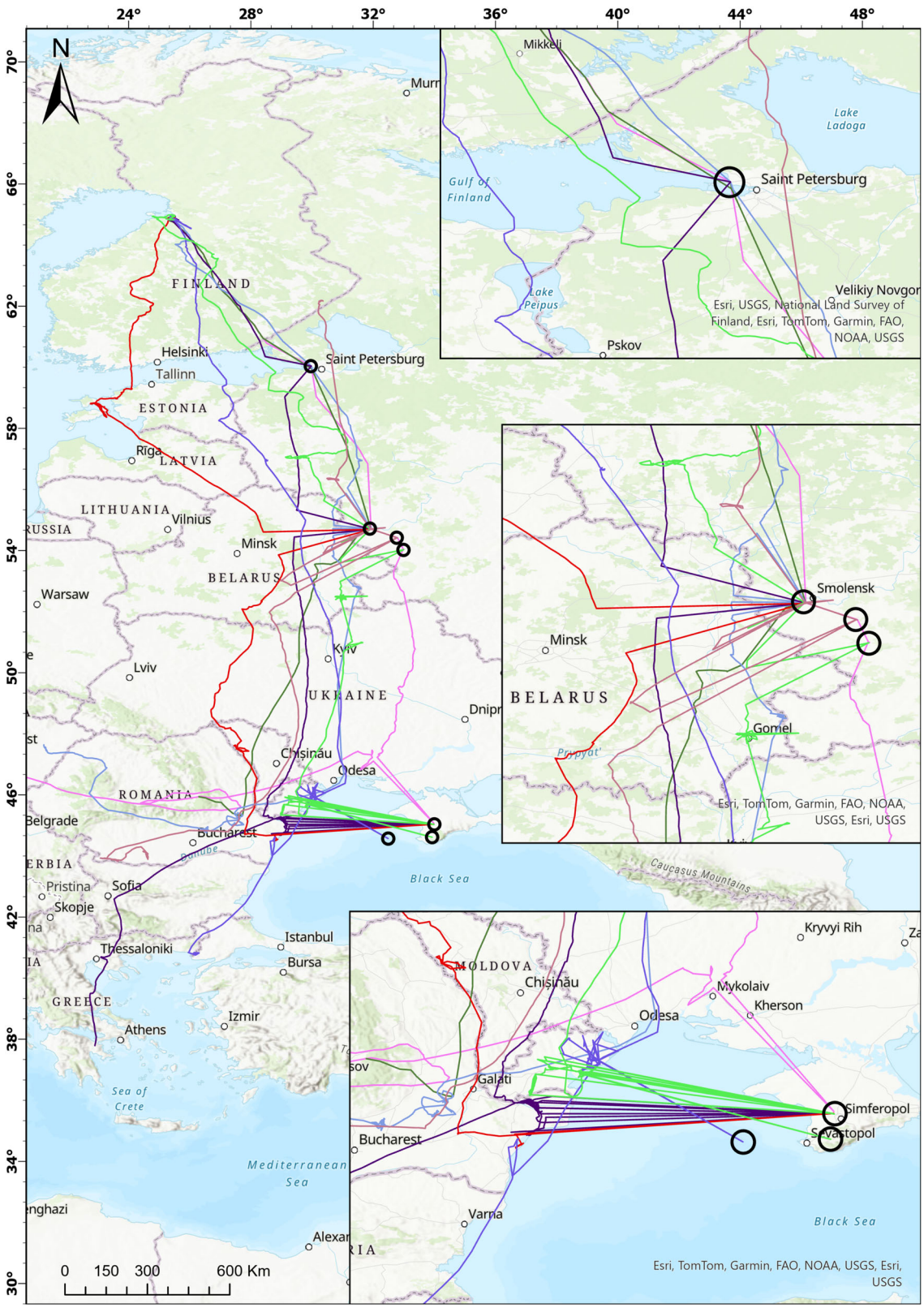
We report here the strong effects of GNSS spoofing on bird tracking following the recent escalation of conflicts in Eastern Europe and the Middle East. By remotely monitoring the daily movements of birds across these regions during autumn 2023 to summer 2024, we repeatedly recorded erroneous positioning for many individuals across multiple species. This resulted in a significant loss of invaluable data, which in turn may have a severe impact on the ability to monitor and interpret animal movements and draw relevant conclusions for understanding their biology and developing conservation strategies. We observed such cases for multiple species (including eagles, falcons, shorebirds, and bustards), involving both resident and migratory birds. The erroneously recorded positions occurred over multiple countries and were often—but not exclusively—translocated to international airports, for example in Russia, Ukraine, Lebanon, Jordan, Syria, and Egypt. We illustrate the issue with the tracks of black-tailed godwits (*Limosa limosa*) migrating from Finland to Romania while flying in or near Russia, Belarus, and Ukraine, and of Bonelli's eagles (*Aquila fasciata*) dispersing from their natal sites in Israel.

Black-tailed godwits

Fifteen black-tailed godwits were tagged in Finland in May 2024, as part of the Habitrack EU-funded research program (https://habitrack.eu). Breeding near Oulu or in Karelia, the godwits migrated southwards later in June or July. Most godwits followed a migratory pathway over Russia, Belarus and Ukraine leading to the Danube River delta in Romania. Eight displayed spoofed geolocations during their migrations, many birds being localized at the exact same place despite not migrating simultaneously (Fig. 1). We identified three obvious locations: west of St Petersburg (4 individuals), in Smolensk oblast (for 7 individuals migrating over Belarus), and in Crimea (5 individuals). For the latter, the tags mostly pointed to Simferopol airport in Crimea (45.037°N, 33.966°E) when the birds actually reached the Odessa region of Ukraine. As examples, one female godwit (ring ST340089, in pink) had her location moved to Simferopol airport on 22 June 2024 while she was flying just north of Mykolaiv. The total distance added to this migration track was estimated at 550 km, though covered in 16 min only. For another female godwit (ringed ST320391, in black), we recorded 9 locations at Simferopol airport, while the interleaved positions recorded by the tag indicated that the bird was in the Danube River delta in Romania, close to the Ukrainian border: 4 on 28 June, 1 on 29 June, 2 on 4 July, 1 on 14 July and 1 on 21 July. The distance between the actual locations and the airport ranged between 380 and 420 km, so that the nine erroneously-recorded round trips represented a total distance of ~7200 km. This however represents less than 0.1% of all locations (9 out of 9 053) obtained while the bird lingered in the Danube River delta between 26 June and 10 August 2024. Seven other godwits took more western migratory routes and their tracking devices did not record spoofed geolocations.

Bonelli's eagles

Forty-eight Bonelli's eagles were tracked with GPS tags across Israel between October 2023 and September 2024, as part of a national conservation program led by the Israel Nature and Parks Authority. Electrocution has been identified as the primary threat to this population[6]. Most of the tagged eagles typically exhibit local dispersal movements within Israel and adjacent Jordan, Egypt, Lebanon, and Syria. Coinciding with escalating regional conflict from October 2023 onwards, an increase in GPS interference was observed. The majority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Bucharest
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Esri, USGS, National Land Survey of Finland, Esri, TomTom, Garmin, FAO, NOAA, USGS
Mikkeli
Lake Ladoga
Gulf of Finland
Lake Peipus
Pskov
Velikiy Novgor
Esri, TomTom, Garmin, FAO, NOAA, USGS, Esri, USGS
Smolensk
Gomel
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MOLDOVA
Kryvyi Rih
Mykolaiv
Kherson
Galati
Simferopol
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Esri, TomTom, Garmin, FAO, NOAA, USGS, Esri, USGS

Fig. 1 | Tracking of Finnish black-tailed godwits migrating over Russia, Belarus and Ukraine to the Danube River delta in Romania. Details of GPS spoofing are illustrated in the region of (upper insert) Saint Petersburg, (middle insert) Smolensk (near the Belarus-Russian border), and (lower insert) Odessa (Ukraine) and Tulcea (Romania). Tracks of 8 individuals are shown, each bird with a different color, for tracking periods between mid-June and the end of September, depending on the individual. Black circles enclose spoofed locations. Godwits have been captured under licenses VARELY/968/2024 and POPELY/1475/2024, while tagging was authorized under ESAVI/12867/2024. Black-tailed godwits were equipped with 5.5 g solar-powered GPS-GSM transmitters (Ornitela OT-6). The incubating adults were captured at nest with a clapnet at the late incubation stage. The tags were fitted by a leg-loop silicone harness (1.6 mm-diameter tube). Sampling frequency was set to every 10–60 min, depending on battery level. The total mass of the tag, including harness, was on average 2.5% of the bird's body mass. Data reported here is archived on the movebank.org platform, under the study identity reference 4595061729.

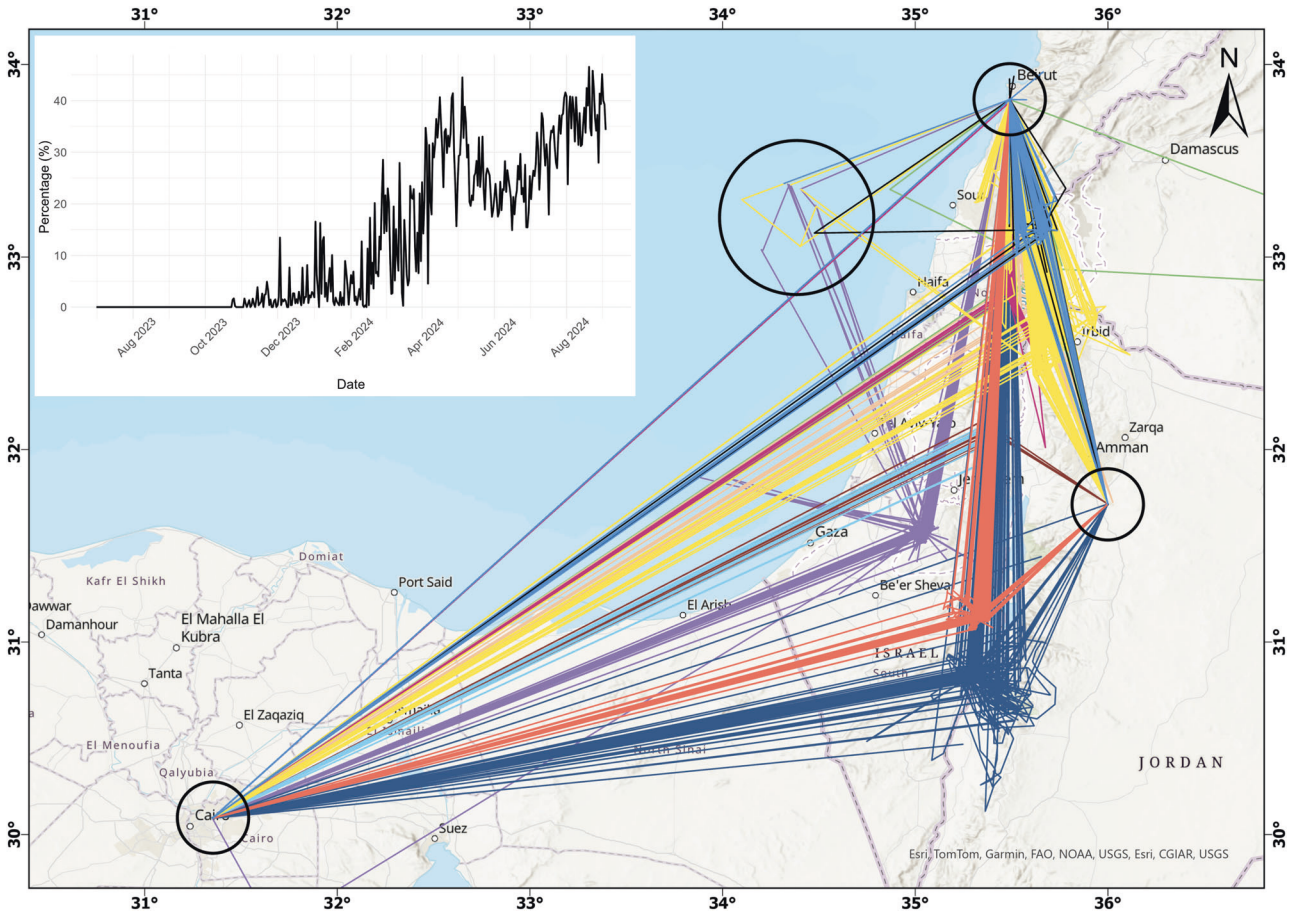

Fig. 2 | Tracks of 10 tagged Bonelli's eagles from 1 April to 1 September 2024, each individual represented with a different color. Black circles enclose spoofed locations. The inserted graph reports the daily proportion (in %) of spoofed locations for 18 randomly selected eagles out of the 48 tagged. Tracks of only ten individuals are shown for clarity. Bonelli's eagle were equipped with 30 g solar-powered GPS-GSM transmitters (Ornitela OT-30). The tagging process was performed in the nest when the nestlings were 45–60 days old. The tags were fitted by a Teflon and Silicon pelvic harness (4 mm wide Teflon tube and 2 mm thick silicone string). Sampling frequency was set to every 15–60 min, depending on battery level. The total mass of the tag, including the harness, was below 3% of the bird's body mass. The eagle study is licensed by the Israeli Nature and Parks Authority (License 2495/2018). Data reported here is archived on the movebank.org platform, under the study identity reference 108979007.

of spoofed locations were diverted to international airports in the region, while some outliers appeared in a specific area in the Mediterranean Sea (Fig. 2). By early April 2024, interference levels reached 100% for some individuals, with the entire monitored population experiencing 20–50% spoofed locations (Fig. 2 insert). This disruption hampers efforts to identify risk factors such as hazardous power pylons, poisoning events, and direct persecution, thereby significantly weakening long-term conservation and mitigation efforts.

Handling spoofed positions

For scientists studying animal movements, these virtual translocations can be detected if they are truly outlying, or repeated. For example, an animal commuting back and forth daily to an international airport, or several birds that receive the same geolocation despite their routes diverge so they are clearly not migrating in the same flock. However, some cases might be less obvious and may require a refined knowledge of the species' typical movement patterns in order to be detected.

Whether obvious or not, researchers must consider the risk of location errors caused by GNSS spoofing when analyzing movement trajectories or habitat use. As we show with these data samples, such errors are widespread, and might appear in many new places in the future. GNSS spoofing in conflict zones poses a significant challenge to wildlife tracking and conservation efforts. This phenomenon compromises not only the accuracy of migration studies but also critical conservation activities such as mortality detection and epidemic monitoring. The implications extend beyond scientific research, potentially affecting endangered species management and human-wildlife conflict mitigation[7–9]. In response to these challenges, researchers may start exploring potential solutions to mitigate the effects of GNSS spoofing. While advanced anti-spoofing algorithms and encrypted signals are being developed in other fields like civil aviation and military applications, such technologies have not yet been widely applied to wildlife tracking due to cost and complexity. Given the gravity of environmental crises worldwide and the ubiquity with which wildlife research relies on GNSS technologies, such solutions are no less imperative and should be developed and shared among practitioners.

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Author contributions

Conceptualization: F.J., Y.P., A.M., Writing—original draft: F.J., A.M., M.P., R.E., T.S., N.S., S.T., Y.W., A.B., P.B., A.K., A.L., A.C.M., P.P., Y.P., Writing—review & editing: F.J., A.M., Funding acquisition: F.J., A.M., M.P., R.E., T.S., N.S., S.T., Y.W., A.B., P.B., A.K., A.L., P.P., Y.P.

Competing interests

The authors declare no competing interests.

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