Focus

# Digital twins for conflict management: the Human-Bear Conflict Radar

Photo: Anna Marie Davison

**Anna Marie Davison[a*], Ilya Acosta-Pankov[b], Melanie Arp[c], Nikola Doykin[d], Nikola Ganchev[b], Jan-Kees Schakel[c], Vladimir Todorov[b] and Koen de Koning[a]**

[a] Wageningen University and Research, Wageningen, Gelderland, the Netherlands
[b] Bulgarian Academy of Sciences, Sofia, Bulgaria
[c] Stichting Sensing Clues, Nieuwegein, Utrecht, the Netherlands
[d] Vitosha Nature Park Directorate, Sofia, Bulgaria
*Contact: anna.davison@wur.nl

## Introducing digital twins

Digital twins (DT) are virtual replicas of physical objects, systems and processes. They are designed to simulate their physical counterparts as closely as possible by updating in real-time. The concept was championed by the US National Aeronautics and Space Administration (NASA) [1] but has since become integrated into various industrial fields. Recent years have seen a dramatic increase in the popularity of DTs and their adoption within environmental sciences [2–4]. In the context of conflict with large carnivores, DTs have the potential to be powerful tools for supporting timely interventions and adaptive decision-making.

There are several different definitions of DT, the most relevant of which for ecologists is, “digital counterparts of a physical object or process that are linked to each other to continuously update and improve realism and reduce uncertainty about the physical object/process” [4]. In simple terms, DTs are models which are continually and automatically updated with new data from the field. In addition to this definition, there is also an emphasis on the importance of the intentional development of ecological DTs for the purpose of real-world decision-support [5]. DTs enable the vast quantities of data already being collected in the field to be automatically converted into meaningful information which can be used by relevant decision-makers. Therefore, DTs have the potential to expedite appropriate action in fast-paced ecological issues, such as human–wildlife conflict [6].

The rapid advancement of technology for wildlife monitoring and the increasing quantity of ecological data which is digital at the point of collection in the field means that there are more resources than ever to enable DT development [4,7,8]. Near real-time data collected in the field informing responses to conflict with large carnivores is not a new concept. Readers may be familiar with geofencing systems or camera-traps with remote access, AI species identification and automatic alerts [9,10]. These systems could be classified as simple DTs and would currently be the most widely available form of DT. However, the real potential of DTs comes from integrating

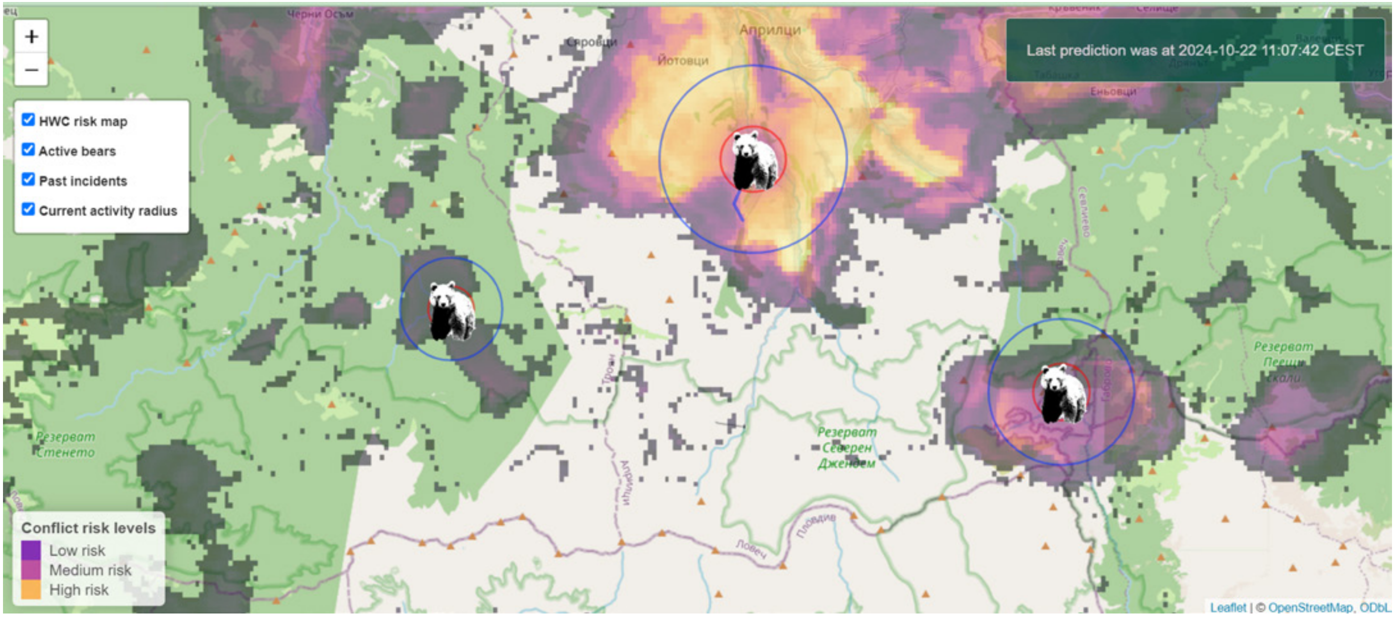


*Fig. 1. Example screenshot of the Human–Bear Conflict Radar.*

near real-time data with more complex analyses and models to create, for example, forecasts of human–carnivore conflict risk similar to local weather forecast apps [11]. These higher maturity versions of DTs are at the cutting edge and we are aware of only two which are currently at the stage of being run on a server and available to end-users: the Crane Radar [12] and the Human–Bear Conflict Radar, which is the focus of this article. Furthermore, the near real-time data necessary for the functioning of DTs is not just limited to expensive devices with data transfer capabilities. Observations made by experts or citizen scientists in the field can also be used to inform a DT if these observations are entered into a data entry app or online platform such as the Sensing Clues Platform, EarthRanger, ObsIdentify, eBird or iNaturalist [12].

## Case study: the Human–Bear Conflict Radar

In order to realise the potential of this technology, prototypes need to be developed and tested in the field. The first prototype DT in the sphere of human–wildlife conflict was developed within the project Forensic Intelligence and Remote Sensing Technologies for nature conservation (Nature-FIRST)[1], the first working version of which premiered in 2024 at the TusnadEcoBear Conference[2]. Named the Human–Bear Conflict (HBC) Radar, it was developed for use in monitoring and forecasting conflicts involving brown bears (*Ursus arctos*) in the Central Balkans, Bulgaria[3]. Unlike static models based on events in the past, the HBC Radar continually updates predictions of conflict risk and bear movement using conflict reports recorded in real-time (Fig. 1).

Reports of HBC can be registered in the field using the Cluey data-entry app from the Sensing Clues Platform[4]. For the Central Balkans, these reports are made by bear experts from the Bulgarian Academy of Sciences and the Vitosha Nature Park Directorate, who are routinely contacted by local people in the event of a conflict incident such as damage to beehives (Fig. 2) or predation on livestock. (There is no recent history of bear attacks on humans in the Central Balkans, so this dynamic is not included in the model.) The reporting of HBC involves entering the location (GPS point) together with the type of event (e.g. 'plundered wastebin', 'killed animal'), any action taken (e.g. 'relocated') and optional data entry fields for further information. Once made, this new report shows up on the Radar in real-time as an 'active bear'. Using a dispersal model created from open-source GPS

[1] https://www.naturefirst.info/news/digital-twins-for-ecology-and-nature-conservation-an-interview-with-anna-davison
[2] https://www.naturefirst.info/news/human-bear-conflict-radar-to-be-presented-for-the-first-time-at-the-tusnad-ecobear-conference
[3] https://www.wur.nl/en/newsarticle/the-bear-truth-conflict-can-be-prevented-with-brand-new-radar.htm
[4] https://www.sensingclues.org/data-collection

data from Slovenian bears [13], the mean and maximum distance a bear is predicted to have travelled since the report is also added to the Radar as radii around the active bear which are periodically updated as time passes. New HBC reports added to the radar are analysed against this movement information to determine whether these reports are likely to constitute new active bears or are caused by an existing (known) active bear, in the latter case updating the map with a line from the previous conflict report(s) to the new one. If 10 days pass with no new reports, the bear is deemed 'inactive' and removed from the map.

For the conflict risk element of the Radar, further historical data were required to create a habitat suitability model for the brown bear in the Central Balkans. This was done using (indirect) bear observations and associated survey tracks obtained during the Nature-FIRST project in 2022–2024 using the Cluey app, combined with CORINE land cover maps of the area and prior knowledge on bear habitat preference provided by experts from Salviamo l'Orso. Alongside the resulting habitat suitability score raster, this model was also used to create rasters containing distance from the core bear area and habitat patchiness. These three variables were then used alongside historical conflict reports (from 2022–2024, made the same way as real-time reports) to train a random forest model. The resulting conflict risk prediction is displayed as a heatmap and shows the likelihood of a conflict event across the Central Balkans area (Fig. 1). In the current version, 'risk' constitutes the risk of any conflict event type known to be recorded in the region (e.g. damage to beehives or livestock) represented as a probability. If there are active bears on the map, then the conflict risk map is used alongside the dispersal model to create a localised forecast of conflict for the coming week.

The Radar is still being tested, so users are currently the scientists and rangers who also collect the data (HBC reports). However, in the process of developing and improving the HBC Radar, we are also looking to enable local communities to enter their own real-time conflict reports and, potentially, access a version of the Radar showing conflict risk without sensitive information on precise bear locations. Other potential users of the HBC Radar include bear response teams, local rangers, local administrations and conservation NGOs. Envisioned uses of the HBC Radar include enabling bear-smart, adaptive decision-making by local users including quick and targeted deployment of bear response teams, prioritising distribution of more permanent intervention measures such as electric fencing or keeping livestock away from conflict hotspots.

## Future prospects

Work is already underway to improve predictions, apply the system to other sites and adapt it for other species. The HBC Radar is under iterative development which constitutes a cycle of feedback from users in the field and

*Fig. 2. Beehives damaged by a bear in Bulgaria (Photo: Vladimir Todorov).*

improvements to the model in order to produce more informative predictions [11]. Core bear areas as originally defined using the habitat suitability model were refined during a workshop with bear experts from the Bulgarian Academy of Sciences and the changes will be integrated into the next version of the Radar. When new conflict events are recorded, we will also evaluate the predictions made by the Radar to better determine their limitations and inform the next round of improvements. In the meantime, current work includes improving the conflict risk map so it forecasts conflict risk a month ahead, which can then be displayed even when there are no 'active' bears and will reflect seasonal variation in HBC. Furthermore, the possibility of applying and testing the system at two additional sites (in Romania and Ukraine) is being explored while our experience with the HBC Radar is informing development of a DT for managing crop-raiding elephants in Mozambique.

Within the next year, open-source code for the HBC Radar will be made available, alongside an associated scientific paper, via GitHub to enable others to build on the work. Interested parties will still need to have sufficient technical knowledge to be able to link their own (real-time) data to the HBC Radar code and to get the tool live or, for those without such expertise, this can be achieved through the Sensing Clues Foundation with the integration of their Cluey app.

DTs have great promise as decision-support tools for managing conflict with large carnivores. The HBC Radar provides a first proof of concept for this, although the accuracy of the predictions still needs to be evaluated to determine its efficacy. As digital twinning is still such a new concept for ecology, developing and testing prototypes such as the HBC Radar is key for determining their limitations and their potential. This process requires close collaboration between carnivore experts, IT specialists, data analysts and modellers, data providers and end-users.

For those interested in developing DTs of their own, there are some key requirements which need to be met for successful implementation. Firstly, the problem to be addressed should be well-defined at the outset and end-users of the DT identified along with their needs. Second, there must be an informative source of (near) real-time data which is accessible to be integrated into the DT. Thirdly, there must be sufficient expert knowledge and historical data to accurately model the issue so as to provide the required output information. Finally, technical experts are required to create and maintain applications which allow data to enter the DT and/or the output to be accessed. To lower the thresholds of time, expertise and funding needed to achieve this, existing data collection methodologies and digital infrastructures should be harnessed where available.

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