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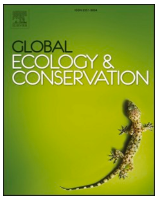

# Identifying human-caused mortality hotspots to inform human-wildlife conflict mitigation

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ABSTRACT

Humans are responsible for over a quarter of all wildlife mortality events across the globe. The pressure this puts on wildlife populations contributes to the decline of many at-risk species. To minimize human-caused mortality and reverse population declines in species across the world, we first need to know where these events are happening or likely to occur since managers and public agencies often have limited resources to devote to a problem. As such, our objective was to develop a modeling approach to delineate human-caused wildlife mortality hotspots in regions with limited data. We used internet search engines and national media to collect data on brown bear (*Ursus arctos*) mortality events in Iran from 2004 to 2019. We then developed a spatially-explicit Maximum Entropy (MaxEnt) model using anthropogenic and environmental variables to predict the probability of human-caused brown bear mortality. We were able to delineate 7000 km$^2$ as human-caused mortality hotspots, along with the geographical locations of those hotspots. This provides information that can help identify where critical conflict mitigation efforts need to be implemented to reduce the potential for human-caused wildlife mortality. However, more targeted studies such as surveys of local people will be needed inside hotspots identified with this methodology to assess the attitudes of humans toward different wildlife species, informing the specific mitigation actions that will need to be made. Finally, we suggest that media data can be used to identify these hotspots in regions where systematic data is lacking.

## 1. Introduction

Global biodiversity conservation relies heavily on resolving widespread human-wildlife conflicts (Redpath et al., 2013; Frank et al., 2019; Su et al., 2022). Due in part to human population expansion into undisturbed land, more humans and wildlife are living side by side, leading to an increase in conflict events (Carter and Linnell, 2016; Chapron and López-Bao, 2016; Mohammadi et al., 2021a). Resolving these conflicts are often challenging as they cover a wide range of scenarios with complex interactions between humans, wildlife, and their environment, which vary widely with the specific taxa and region in question (Zimmerman et al., 2021; Mohammadi

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et al., 2022). Some of the most common conflict instances take place between humans and large carnivores (Treves and Karanth, 2003; Carter and Linnell, 2016), often taking the form of vehicle collisions (Mohammadi et al., 2018), heavy livestock depredation (van Eeden et al., 2017) and even threats to human safety (Bombieri et al., 2019). This can threaten the lives and livelihoods of people and contribute to negative attitudes towards carnivores (Bruskotter and Wilson, 2014; Miller et al., 2016). As a result, it is common to see humans preemptively striking and retaliating against carnivores to either deter or kill individuals that pose a perceived risk (Treves and Bruskotter, 2014; Can et al., 2014; Adhikari et al., 2022).

Humans are responsible for a large proportion of carnivore mortality events around the world (Hill et al., 2020). This proportion varies by region and species, with humans directly or indirectly accounting for over 60 % of wolf (*Canis lupus*) mortality events in Wisconsin, USA from 1979 to 2012 (Treves et al., 2017), 44 % of African wild dog (*Lycaon pictus*) mortality events in sub Saharan Africa from 2001 to 2016 (Rabaiotti et al., 2021), and 65 % of leopard (*Panthera pardus*) mortality events in Nepal from 2006 to 2013 (Thapa, 2015). These events can happen unintentionally (e.g., vehicle collisions) or intentionally (e.g., poaching and retaliation) (Soofi et al., 2022). In highly rural or agricultural regions, intentional killings are among the most frequent types of human-caused mortality among large carnivores (Liberg et al., 2012; Gantchoff et al., 2020). Humans intentionally kill carnivores using a variety of methods and tools, including stoning (Farrington and Tsering, 2019; Parchizadeh and Belant, 2021), trapping (Carter et al., 2017), poison (St.

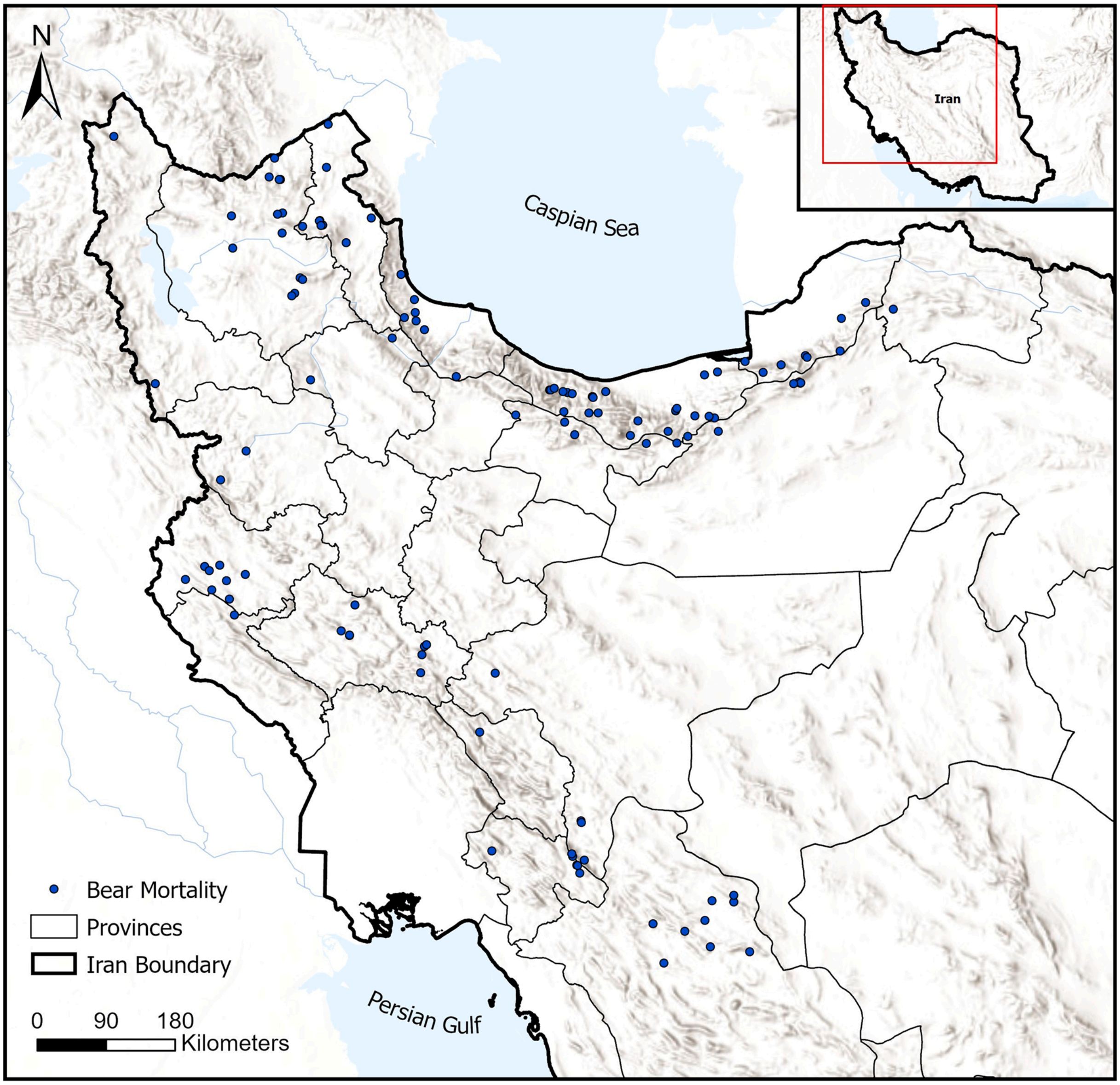

**Fig. 1.** The elevation map of Iran with brown bear mortality points across Alborz and Zagros mountains collected from the internet search using specialized

**Table 1**
Uncorrelated variables were employed to develop the model of brown bear mortality in Iran.

| Category | Variables | Description | Unit | Source |
|---|---|---|---|---|
| Topography | Elevation | Altitude | Meter | https://glovis.usgs.gov |
| Cover | *Land-cover*: Density of orchards, forests, rangelands |  | Class | FRWMO, 2010 |
|  | NDVI | Normalized difference of vegetation index | Percentage | MODIS data (MOD13A1 V6 map at 500-m cell size; http://earth explorer.usgs.gov) |
| Human Disturbance | Human Footprint | Integrated index of population density, land transformation, human access, and presence of infrastructure | Percent Relative Human Influence | Sanderson et al. (2002) |
| Climate | BIO1 | Annual Mean Temperature | C * 10 | Worldclim |
|  | BIO12 | Annual Precipitation | mm |  |

John et al., 2012; Carter et al., 2017), herding dogs (Nayeri et al., 2022), or most commonly, firearms (Thorn et al., 2013; Parchizadeh and Belant, 2021). Since humans are capable of efficiently killing wildlife using these tools, human-caused mortality represents a primary conservation concern for many species linked to conflicts (Liberg et al., 2012; Gantchoff et al., 2020; Parchizadeh and Belant, 2021).

Human-caused mortality events can be especially devastating when the species has a small population size and low reproductive rate as in large mammals (Hill et al., 2020). These events lead to fewer breeding individuals, can lead to a decrease in the gene pool, and cause entire populations to become more vulnerable to biotic and abiotic factors (Woodroffe and Ginsberg, 1998). This is especially pronounced in many large, at-risk carnivore species (Cardillo et al., 2004). Reducing the frequency of human-caused mortality events might be the most important measure to prevent population collapse for some of these species (Bleyhl et al., 2021).

However, sufficient reductions in mortality cannot be achieved without first knowing where these events are occurring or likely to occur since managers and public agencies often have limited resources to devote to a problem. To identify areas of a landscape where a particular phenomenon might occur, and thus assign those areas priority for investment like establishment of a protected area (Mohammadi et al., 2021b) or education (Dickman et al., 2013), researchers often use spatially explicit models like habitat models (Farhadinia et al., 2015; Wan et al., 2019; Mohammadi et al., 2021c). Developing these models typically relies on environmental or anthropogenic predictor variables and occurrence data for the target species. Sometimes, the need to manage a particular species may be pressing, but data of the species might be incomplete or unavailable. Researchers with insufficient funding to systematically collect these data in the field must rely on unconventional data sources, such as data extracted from media sources, to identify known records for a species (Nayeri et al., 2022). Media sources, either social or traditional, can provide researchers with data on a variety of topics including observations of wildlife-related events (Eid and Handal, 2017; Parchizadeh and Belant, 2021; Sardari et al., 2022). We propose that a methodology similar to habitat modeling coupled with data on human-caused carnivore mortality events collected from media sources can be applied to build a spatial model to identify areas in which human-caused mortality in carnivore species is likely to occur.

We demonstrated a spatially-explicit modeling approach to help identify human-caused mortality hotspots from media-sourced data by using the holarctic brown bear (*Ursus arctos*), a widespread species known to interact with humans frequently (Can et al., 2014; Krofel et al., 2020; Zarzo-Arias et al., 2021), as a case study species. By identifying areas that are more prone to human-caused brown bear mortality events, we can provide recommendations that pinpoint locations for future research and where pilot implementations of conflict mitigation efforts are most needed. Further, we suggest the same approach be used to advance our understanding of human-caused mortality for other species as a step to help smooth the relationship between humans and wildlife and prevent unnecessary killing of wildlife.

## 2. Materials and methods

### 2.1. Study area

Our study covers an area of 1,648,000 km$^2$ in Iran and is located at the intersection of three Palearctic, Saharo-Arabian, and Oriental biogeographic realms (Yusefi et al., 2019). It contains two main mountainous regions - Alborz (from northeast to northwest) and Zagros (from northwest to southwest). It contains a diverse array of vegetation from Hyrcanian forest to arid shrublands (Yusefi et al., 2019). The elevation ranges from 28 m below sea level to 5610 m above sea level (Heshmati, 2007). Due to its location, climatic and topographic diversity, Iran has a high diversity of animal species, so 192 mammal species from 34 families live in this country (Yusefi et al., 2019). Indeed, Iran has the most biological diversity among Asia's southwestern countries (Makhdoum, 2008). Protected areas in Iran are composed of four IUCN categories: National parks, Natural monuments, Wildlife refuges, and Protected areas (PAs). (Darvishsefat, 2006). Currently, 11 % (Number of PAs = 284, Department of Environment of Iran) of the Iran lands is protected. Fig. 1.

### 2.2. Data collection

We collected brown bear mortality locality data in Iran, which was available within the time period of 2004–2019 by using keyword searches in Google search engine and national media outlets (e.g., IEW, IRNA). Keywords were in Persian and consisted of "Brown bear mortality", "Brown bear death", "Bear death", "Brown bear carcass", "brown bear slaughter", and "arresting bear poacher". All results were in Persian and were read by native Persian speakers on the team. Afterward, we further filtered the data using names of counties and provinces that are known to encompass the range of brown bears in Iran and then recorded the information necessary to pinpoint the location of each event if it was present (Yusefi et al., 2015). We verified the independence of each mortality event by cross-checking the respective media articles. We also checked each Iranian Department of Environment (DoE) provincial news portal within the known range of brown bears for mortality records.

### 2.3. Environmental layers

Based on existing ecological knowledge of brown bears in Iran (Ansari and Ghoddousi, 2018; Almasieh et al., 2019; Mohammadi et al., 2021b), we selected a set of anthropogenic and environmental variables that are most relevant to brown bear habitat selection and obtained relevant GIS layers for our spatial statistical modeling (Table 1). We acquired a 30-m digital elevation model (DEM) raster layer from the Shuttle Radar Topography Mission (SRTM; http://earthexplorer.usgs.gov). In addition to using elevation as a predictor variable, we used the DEM to calculate ruggedness, which is a measure of how different the elevation is between adjacent cells in a DEM (Riley et al., 1999). We then obtained the national land cover map of Iran to extract three land use predictor variables: forest, orchard, and rangeland (FRWMO, 2010). We used 16-day composite MODIS data (MOD13A1 V6 map at 500-meter cell size; http://earthexplorer.usgs.gov) to calculate mean annual normalized difference vegetation index (NDVI). We included two Worldclim climatic variables including BIO1 (Annual Mean Temperature) and BIO12 (Annual Precipitation) in the model to understand the impact of temperature and precipitation on mortality (Fick and Hijmans, 2017). To represent human-related predictor variables, we obtained a human footprint dataset, which consists of road networks, human population density, and human infrastructure (Sanderson et al., 2002).

Before building the human-caused mortality model, we determined the degree of multicollinearity between the predictor variables to avoid covariance. To do this, we calculated the Pearson correlation coefficient between each pair of variables. If any pair of predictor variables were correlated with a coefficient of $r > |0.7|$, we evaluated the correlation of each variable in the pair with every other included predictor variable. We then removed the variable in the pair that was more highly correlated with other predictor variables, keeping the other variable to build the human-caused mortality model. We did not assess autocorrelation because we ensured the independence of all the data points.

### *2.4. Human-caused mortality model*

We converted all layers to ASCII format in ArcMap 10.7 to use them in MaxEnt 3.3.3k (Phillips et. al, 2006) for modeling the probability of bear mortality. We used 75 % of our mortality points for training the model, and the other 25 % for testing model performance. We also performed 10 model replications for more precise results (Phillips et al., 2006). To determine the contribution of each variable to the model, we used jackknife analysis of regularized training gain, Area Under the Curve (AUC), and test gain (Yang et al., 2013). We also assessed the Receiver Operating Characteristic (ROC) plot for model validation (Phillips and Dudik, 2008). We used AUC for assessing the model fitness (Baldwin, 2009). To produce the final mortality model surface, we clipped the results based on

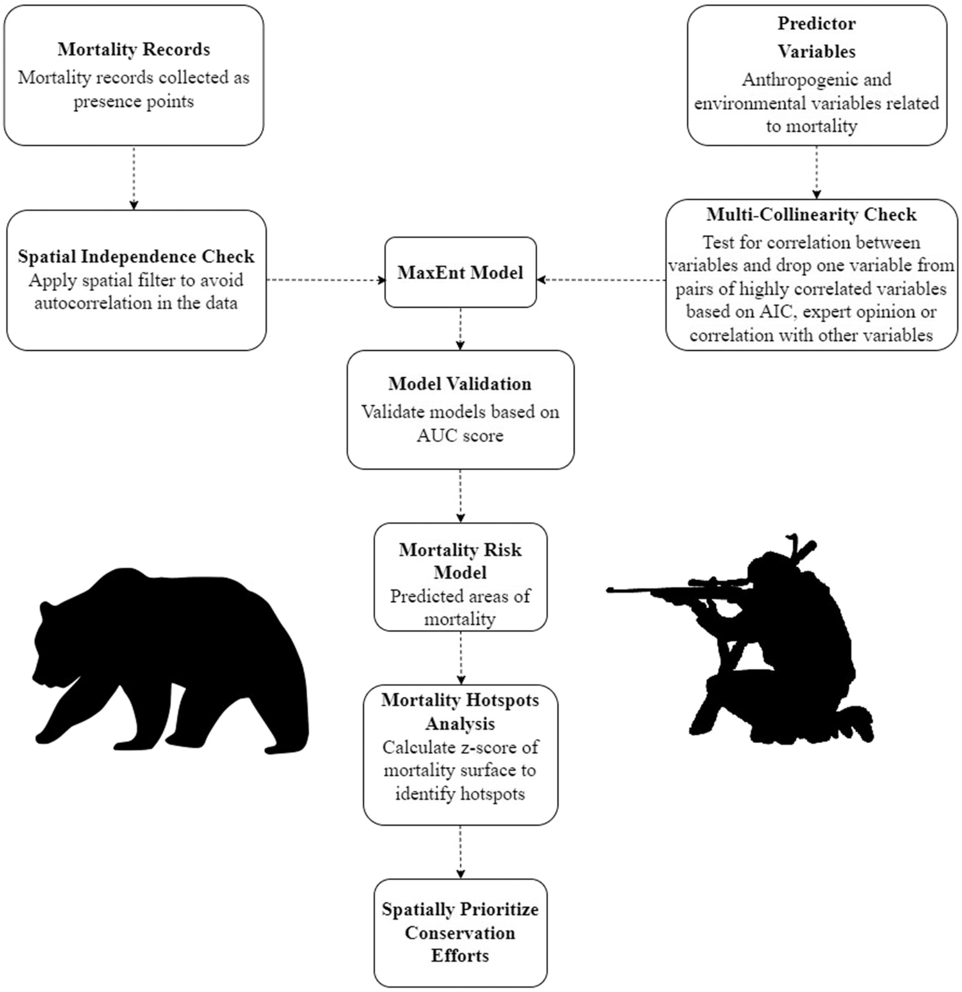

**Fig. 2.** Analytical framework for modeling mortality risk. Silhouette by: © Tracy A. Heath.

all provinces in Iran with at least one known brown bear occurrence. All procedures of the modeling are shown in Fig. 2.

### 2.5. Hotspot analysis

To identify areas of highest probability of human-caused brown bear mortality, we first standardized the final output generated by MaxEnt by calculating the z-score for each pixel of the model surface. We then used a z-score of 3 (i.e., 3 standard deviations above the mean) as the threshold to determine whether a pixel qualified as a human-caused mortality hotspot.

### 2.6. Prioritization for conflict mitigation efforts

We quantified the total hotspot area within each of Iran's provinces and protected areas. Protected area polygons were obtained from UNEP-WCMC (2022). Data of Iran's provinces were also obtained from MapCruzin (https://mapcruzin.com/free-iran-arcgis-maps-shapefiles.htm).

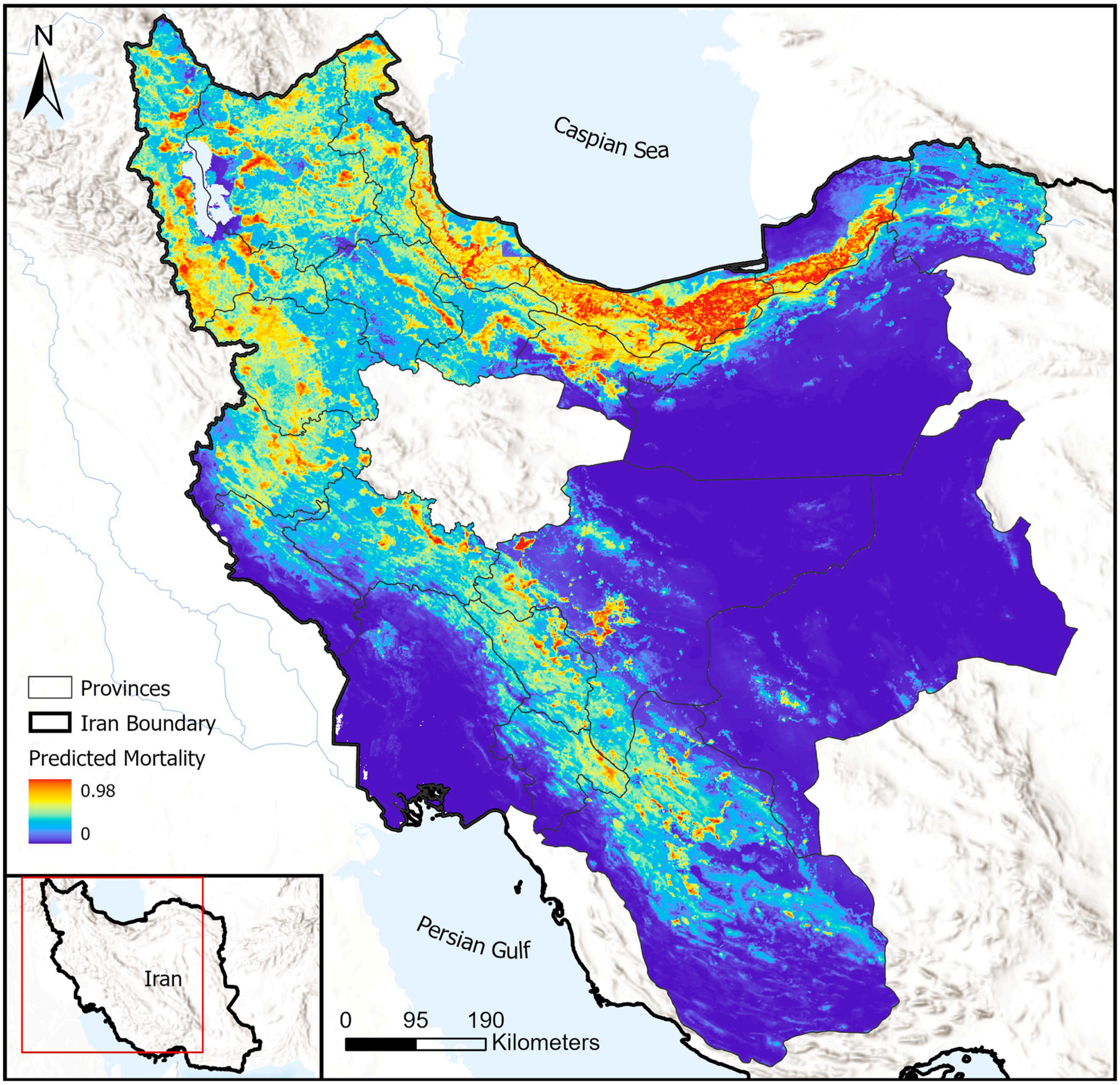

**Fig. 3.** Probability of brown bear mortality overlaid with Iranian provinces known to contain brown bears. Red color represents a greater probability of human-caused brown bear mortality.

## 3. Results

We collected 116 human-caused mortality points across Iran from a variety of media sources, including the internet portals of 22 provincial offices of the environment and news portals (n = 13). We removed two variables, distance to roads and villages and ruggedness, from the modeling due to their high correlation ($r > 0.7$) with human footprint and elevation, respectively.

### *3.1. Model output*

Our brown bear mortality model fits our training data well, with an average AUC value of 0.888 across the ten model replicates. The prediction surface derived from the average model, showing the relative hotspots of human-caused brown bear mortality, is shown in Fig. 3. Areas showing the highest risk of human-caused brown bear mortality were primarily located in the Alborz Mountains in northern Iran. Of the environmental and anthropogenic variables in the MaxEnt model, NDVI contributed the most, contributing 67.6 % to the model's response; annual mean temperature and human footprint contributed 17.7 % and 6.4 % respectively. Collectively, these three variables accounted for > 91 % of model contribution. The remaining variables, elevation, annual precipitation, forest,

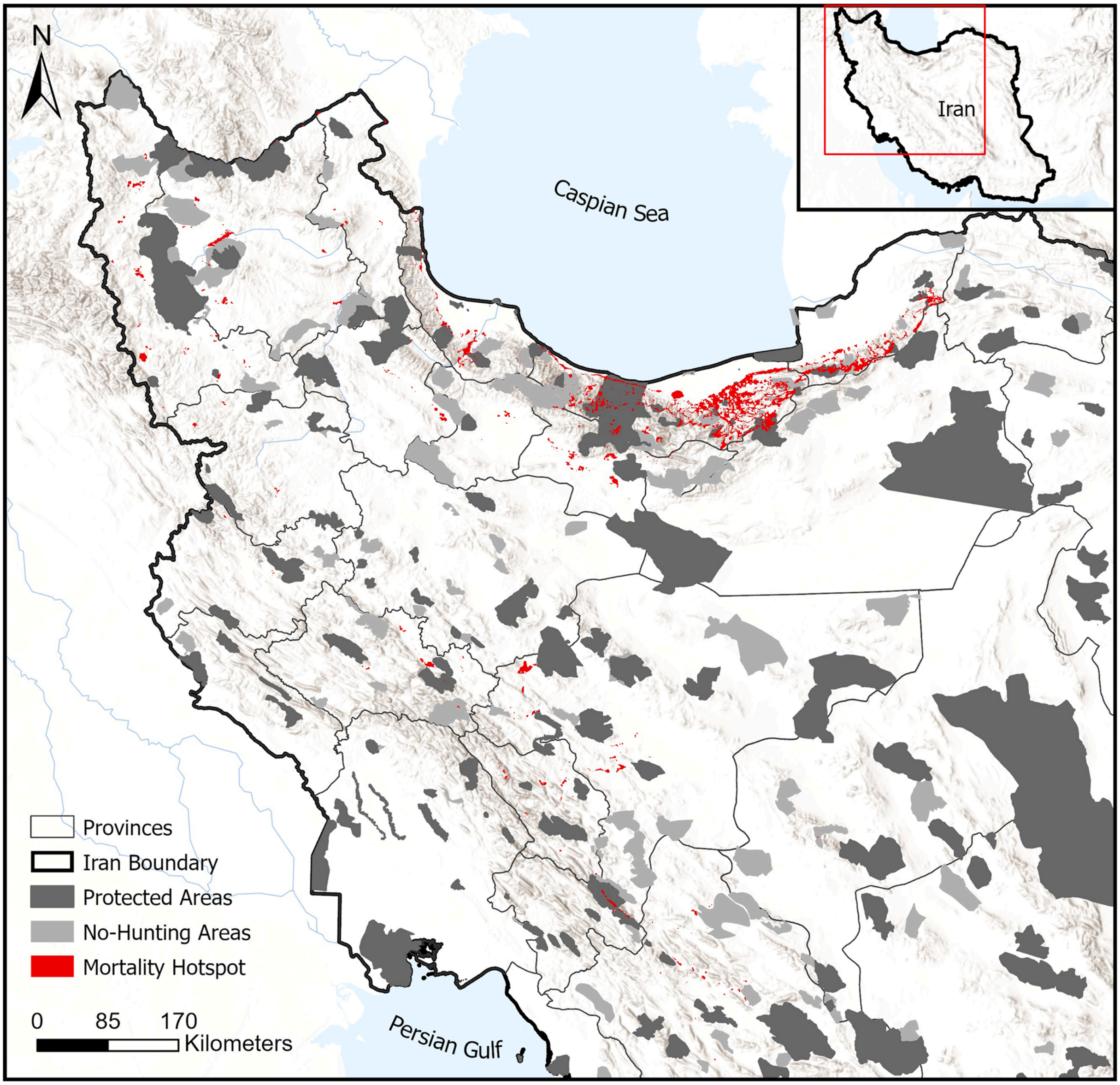

**Fig. 4.** Map showing the locations of brown bear mortality hotspots calculated based on a z-score threshold value of greater than 3 standard deviations above the mean.

orchard, and range, contributed 4.8 %, 2.6 %, 0.6 %, 0.3 %, and 0.0 %, respectively. Response curves (Fig. S1) show how each variable responded to predicted mortality. In this mortality model, the probability of brown bear mortality increases sharply with NDVI and human footprint. It also increases with mean annual temperature up to a point but then decreases above 15 °C.

Fig. S1. Response curves of the highest-contributing predictors, (a) mean annual temperature in degrees Celsius x10, (b) human footprint in percent of footprint, and (c) NDVI, for brown bear mortality in Iran, derived from the Maximum Entropy model developed on the media-sourced data of brown bear human-caused mortality from 2004 to 2019.

### 3.2. *Human-caused mortality hotspots*

We determined that the total area of mortality hotspots in Iran is 7002.74 km$^2$, with 80.4 % of that area located outside of the protected area network (Fig. 4). One protected area, the Central Alborz protected area located in the northern part of the country, accounted for nearly 5 % (312.23 km$^2$) of the total area of human-caused mortality hotspots. We also found that 67 % of predicted mortality hotspots were within two provinces in Northern Iran: Mazandaran (52 %) and Golestan (15 %) (Fig. 4).

## 4. Discussion

Humans are directly responsible for over a quarter of all wildlife mortality events across the globe (Hill et al., 2019), and the frequency and location of human-caused mortality events represents a primary conservation concern for many species and requires proper attention (Steyaert et al., 2016; Gantchoff et al., 2020; Parchizadeh and Belant, 2021). This is the first study to model areas of high human-caused wildlife mortality risk, or "mortality hotspots", using media data. This novel approach provides critical information to help prioritize conservation and human-wildlife conflict mitigation efforts. For example, our model was able to identify two provinces, Mazandaran and Golestan, that contain a large area of human-caused brown bear mortality hotspots (>67 %) in Iran. These two provinces are made up of rural and urban human communities with high population densities (Soofi et al., 2018), making them prime candidates for further study and future investment in conflict mitigation to reduce the risk of human-caused brown bear mortalities. Furthermore, the mortality hotspots map also provides spatially-explicit information that pinpoints specific locations where mitigation efforts are most needed within the two provinces. The same kind of information is currently lacking for many species with conservation concerns across the globe. Our approach can be applied broadly for other species and in other regions to fill these knowledge gaps.

### 4.1. *Effectiveness of protected area in preventing conflicts and wildlife mortality*

Our approach was able to evaluate the spatial relationship between protected areas and human-caused mortality hotspots. For example, we were surprised to see that nearly 20 % of the human-caused mortality hotspots were located within protected areas in Iran. Also, while most mortality hotspots occurred outside of Iran's network of protected areas, they were never more than 50 kilometers away from the nearest protected area. A similar study on different carnivores also found that most of the mortalities occurred in non-protected areas (Adhikari et al., 2022). Previous studies have suggested that instances of human-wildlife conflict are more common around protected areas (Broekhuis et al., 2017; Hipólito et al., 2020), and these findings independently suggest this to be the case. Our model also helps with more effectively designating new protected areas and law enforcement within them by providing information on the locality of mortality hotspots. Moreover, corridors that allow for wildlife movement between protected areas should be identified and preserved by incorporating both social and ecological knowledge (Ghoddousi et al., 2021; Ghoddousi et al., 2022).

### 4.2. *Environmental factors associated with human-caused mortality*

Two factors play a primary role in determining whether human-wildlife conflict will lead to human-caused mortality: the rate at which humans and wildlife come into contact (i.e., the encounter rate) and human attitudes toward wildlife when an encounter happens. The eight variables included in our human-caused brown bear mortality model primarily contribute to the encounter rate between humans and bears. First, our results showed that NDVI was the most important factor in predicting brown bear mortality: as NDVI increases, so does the relative risk of mortality. Bears rely on resources that are usually most abundant in areas of high NDVI such as forests, so they will likely use those areas more frequently than areas with low NDVI (Wiegand et al., 2008). Similarly, as humans continue to expand they are more likely to do so into areas of high NDVI, increasing the rate at which humans and bears might come into contact (Van der Geest et al., 2010; Carter and Linnell, 2016).

Annual mean temperature was the second most important predictor of brown bear mortality, likely due in part to the impact that temperature has on brown bear behavior (Penteriani et al., 2019). For example, one study in the western Cantabrian mountains showed that annual mean temperature had contrasting impacts on brown bear crop and livestock damage in two subpopulations (Zarzo-Arias et al., 2021). As climate change threatens ecosystems that wildlife depend on, bears might be more likely to venture near human settlements to find resources, increasing the likelihood of encounters and subsequent mortality (Delgado et al., 2018; Penteriani et al., 2019; Zahoor et al., 2021).

Human footprint, which consists of population density, human access, and infrastructure (Sanderson et al., 2002), was the third highest contributor to the risk of brown bear mortality. As humans and their infrastructure expand, wildlife are more likely to venture near or across human-dominated landscapes causing interactions between humans and wildlife (Carter and Linnell, 2016). For example, areas with large human or livestock populations can attract large carnivores, and thus put them at risk of mortality when they encounter roads or human settlements (Mohammadi and Kaboli, 2016; Broekhuis et al., 2017; Hipólito et al., 2020). In addition, increasing human-brown bear conflict is associated with access to areas where both bears and humans co-occur at the same time to use the same resources (Yusefi et al., 2015; Kudrenko et al., 2021), and that is where mortalities of either human by bears or human-caused mortality of bears take place (Penteriani et al., 2016; Bombieri et al., 2019; Parchizadeh and Belant, 2021). Different populations, however, might react to each variable differently or not at all (Zarzo-Arias et al., 2021); therefore it is important to consider a priori knowledge of a study system when designing future studies to identify hotspots of human-caused wildlife mortality. Once these areas have been identified, actions to minimize human-caused mortality should be implemented, targeting both humans (human-centered) and wildlife (wildlife-centered) (WSPA. 2009).

While all of our predictor variables were related to the encounter rate between humans and wildlife, we suggest that NDVI provides an indirect indication of the attitudes of humans once an encounter occurs. NDVI, for example, likely encompasses large areas of agricultural land like orchards and rangelands. In these areas, bears might be more likely to raid crops or attack livestock, which has been shown typically to contribute to negative attitudes within communities (Can et al., 2014; Krofel et al., 2020). Similarly, if bears raid orchards or depredate livestock on rangelands this can threaten the livelihoods of people who depend on those assets and contribute to negative attitudes. We suggest that studies should be conducted on the human aspect of mortality both within and outside of mortality hotspots to identify the differences of social factors between them toward a more accurate understanding of mortality hotspots.

### *4.3. Human-centered actions*

Knowing where human-wildlife conflict and associated mortality events are most likely to occur is an important step toward mitigating wildlife mortality risk since resources available for mitigation efforts are often limited and conservationists need to know where to focus their efforts for maximum benefit. Spatial knowledge allows an interdisciplinary coalition of collaborators to prioritize their efforts in areas most at risk of human-caused mortality, such as making investments into local communities in outreach programs, equipment, or economic incentives (Dickman, 2010; Mohammadi et al., 2021c). These investments can take place to discourage intentional killing of wildlife although they should be adapted to the different communities within mortality hotspots according to the needs of those communities, which may vary widely. For example, some communities might benefit from a compensation scheme aimed at mitigating livestock or crop losses to depredation, while another might benefit from training to learn new livestock husbandry techniques including use of protection measures (Nyhus, 2016). However, few studies have investigated the attitudes and perceptions of people living in mortality hotspots in regards to human-wildlife conflict (Rastgoo et al., 2021). Human-wildlife conflict does not have a one-size-fits-all solution (Zimmerman et al., 2021), and more targeted research within mortality hotspots will be needed to determine (1) what are peoples' attitude regarding species involved in conflicts, (2) peoples' tolerance toward damage from those species, and (3) what are their needs that would discourage intentional human-caused wildlife mortality. Then, more effective measures can be undertaken to reduce human-caused mortality one community at a time.

### *4.4. Wildlife-centered actions*

Some conflict mitigation measures that focus on wildlife include lethal control (Treves et al., 2019), deterrents (Khorozyan and Waltert, 2019), and establishing well-defined wildlife corridors and protected areas (Mohammadi et al., 2021b). In general, lethal population control often shows a short-term reduction in human-wildlife conflict events, (Chapron and Treves, 2016; Treves et al., 2016), although it can have a negative impact on populations in species with small population sizes and low reproductive rate. Even though lethal control can reduce human-wildlife conflict in the short term, its effectiveness often drops rapidly and cannot serve as a long-lasting mitigation measure (Khorozyan and Waltert, 2020). Alternatively, wildlife deterrents such as livestock guarding dogs, physical barriers, and electric fencing may be effective mitigation strategies for wildlife conflict (Can et al., 2014; Khorozyan and Waltert, 2019; Krofel et al., 2020). However, the downside of some of these methods is their relatively high prices for local communities, especially those that lack access to sufficient funds such as government subsidies or compensation programs. If governments can provide subsidies for wildlife deterrents in predicted human-caused mortality hotspots it could be a reasonable solution for reducing the frequency of livestock or crop loss, which is often cited as a reason for retaliatory killing (Karamanlidis et al., 2011). Our human-caused mortality model provides important spatial information to help identify areas where these deterrents could be implemented to maximize their effectiveness while minimizing the cost. Some studies suggest expanding protected areas as another method to mitigate mortalities or conflicts, although the effectiveness of these protected areas are often poorly understood (Ghoddousi et al., 2020, 2022; Mohammadi et al., 2021b). For these expansions to be effective at reducing human-wildlife conflict, they will likely need to take place in areas that are not near predicted mortality hotspots, since the immediate area surrounding protected areas is often subject to higher rates of human-wildlife conflict when protected areas exist in the vicinity of human populations (Broekhuis et al., 2017). Further, increasing protected area coverage alone might not be enough to substantially reduce human-caused mortality as human populations continue to grow quickly and expand into previously undisturbed land (Mohammadi et al., 2021b). This growth can cause fragmentation of habitat, cutting off wildlife populations from each other and resulting in reduced genetic fitness (Schlaepfter et al., 2018), greater risk of local extinction (Crooks et al., 2017), and more instances of human-caused mortality as wildlife try to move between habitat patches, often across human land (Goswami and Vasudev, 2017). Establishing corridors between protected areas could help reduce the frequency of human-wildlife conflict by providing wildlife with a low-cost, low-risk way to travel, disincentivizing them to venture near human settlements (Cushman et al., 2018). Ultimately, a blend of mitigation measures drawing from both human- and wildlife-focused actions will be necessary to address the issue from multiple angles.

### 4.5. *The potential and limitations of media data*

There is limited information on wildlife mortality in the Middle East and studies regarding wildlife mortality often obtain data opportunistically or using media sources rather than using radio-telemetry tracking and other objective methods (Parchizadeh and Belant, 2021; Nayeri et al., 2022). As a result, areas of high population of humans may be overrepresented in media coverage. In addition, poaching wildlife is illegal, so people who intentionally and illegally kill wildlife may not be forthcoming with government officials or scientists. For example, poachers might conceal the corpse of a poached animal, making it hard to identify mortality by poaching occurrences (Liberg et al., 2012). Local volunteers, however, have the potential to observe the aftermath of an illegal event and alert the media and appropriate authorities, meaning that media sources might be able to provide data that would otherwise be difficult to collect through more traditional methods. As a result, we used media sources, including newspapers and government news portals, to collect data on mortality by incorporating keywords pertaining to brown bear and mortality. However, the data we were able to collect from these sources likely underestimated the problem since there are likely more cases than the media did report (Athreya et al., 2015), but we strongly believe that there were no false reports, i.e. the presented results are the minimum mortality. Nonetheless, we believe that the data gathered are representative samples of the general geographic locations where these mortality incidents typically occur, and the sample size that we had was sufficient to construct a reliable model. Although our data is biased toward the reported cases, we propose that our approach provides an important starting point in regions that lack both rigorously collected data and the appropriate funding to collect such data. Using media sources can help researchers collect invaluable data on sensitive, challenging to monitor incidents such as human-caused wildlife mortality events (Parchizadeh and Belant, 2021; Nayeri et al., 2022). Social media is another option that can also empower scientists to use publicly available information to shed light on different topics such as how animals are perceived in media (Nanni et al., 2020) and illegal wildlife trade (Sardari et al., 2022). One strength of social media is its decentralized mode of engagement: anyone can upload information, making it a potentially vast repository of useful information for conservation scientists. Few studies have used social media to collect data and its potential represents an important avenue for future research. Until such time when more data can be collected in data-poor regions, likely supported by more funding available to scientists in these regions, we suggest that media data should play an important role in conservation science research. In addition, a lot of the currently popular social media platforms have only been popularized in Iran recently, and thus were not ideal in providing the temporal coverage that we need for this study. However, looking forward, we think that social media will become increasingly powerful in collecting the kind of data needed in our study area. We also suggest that scientists encourage their local communities to actively participate in conservation science by uploading observations of wildlife or wildlife-related activities to either social media or popular community science platforms.

### 4.6. *Conservation implications*

Our study has wide implications for estimating mortality risk for a wide array of species across different geographic areas. We suggest three broad takeaways from our study. (1) Media data can be effective at identifying mortality hotspots, especially in regions where both data and funding are limited. (2) Once human-caused mortality hotspots are identified, targeted research is needed to explore the roots and drivers of potential human-wildlife conflicts so as to properly inform conflict mitigation programs. (3) The spatially-explicit information from the hotspot model output should be used to prioritize and target locations for conservation and management efforts. Implementing strategies for large wildlife conservation can be costly because protection must cover vast areas as population distributions can span across multiple-use landscapes (Ahmadi et al., 2020; Mohammadi et al., 2022), and often agencies must work across administrative boundaries (Farhadinia et al., 2020; Bleyhl et al., 2021). Therefore, identifying potential threats and their spatial pattern at both local, national, and international scales is important. In addition, since human-caused wildlife mortality put pressure on wildlife in many regions across the globe. These identified areas require special management attention to minimize human-caused wildlife mortality, reducing a key threat to many wildlife populations. Understanding where mortality hotspots are located is an important step that will allow various collaborators to start prioritizing conflict mitigation strategies that will ultimately reduce the pressure on wildlife populations.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02241.

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