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1 **Title:** Identifying priority conservation areas for a recovering brown bear population in
2 Greece using citizen science data

3

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19

20 **Running head:** Identifying priority conservation areas for bears

21 **Abstract:** Understanding the processes related to wildlife recoveries is not only essential in
22 solving human–wildlife conflicts, but also for identifying priority conservation areas and in
23 turn, for effective conservation planning. We used data from a citizen science program to
24 study spatial aspects related to the demographic and genetic recovery of brown bears in
25 Greece and to identify new areas for their conservation. We visually compared our data with
26 an estimation of the past distribution of brown bears in Greece and used a point process
27 approach to model habitat suitability, and then compared our results with the current
28 distribution of brown bear records and with that of protected areas. Our results indicate that
29 in the last 15 years bears have increased their range by as much as 100%, by occupying

1 mainly anthropogenic landscapes and areas with suitable habitat that are currently not
2 legally protected, thus creating a new conservation reality for the species in Greece. This
3 development dictates the re-evaluation of the national management and conservation
4 priorities for brown bears in Greece by focusing in establishing new protected areas that will
5 safeguard their recovery. Our conservation approach is a swift and cheap way of identifying
6 priority conservation areas, while gaining important insights on spatial aspects of population
7 recovery. It will help prioritize conservation actions for brown bears in Greece and may serve
8 as a model conservation approach to countries facing similar financial and logistic constraints
9 in the monitoring of local biodiversity or facing challenges in managing rapid population
10 recoveries. Our conservation approach appeared also to be better suited to identifying
11 priority areas for conservation in areas with recovering wildlife populations and may
12 therefore be used as an “early-warning” conservation system.

13

14 **Keywords:** Greece, large carnivores, Poisson point process, presence-only data, *Ursus arctos*

1 Introduction

2 Large carnivores have been celebrating significant population comebacks in Europe (Chapron
3 *et al.*, 2014), sparking an increased interest in identifying the preconditions, factors and
4 processes that have facilitated these comebacks (e.g. López-Bao *et al.*, 2015). A thorough
5 understanding of the processes related to large carnivore recoveries is not only essential in
6 solving the increasing number of human–large carnivore conflicts (Bautista *et al.*, 2016), but
7 also for predicting potential habitat in areas of large carnivore population recovery and in
8 turn, for effective conservation planning in the European context of human-dominated
9 landscapes (Linnell *et al.*, 2008). At the same time, the vulnerability to human threats (Ripple
10 *et al.*, 2014), the socio-cultural and financial implications of human–wildlife conflicts (Treves
11 & Karanth, 2003) and the often large spatial requirements (Ripple *et al.*, 2014, Newsome &
12 Ripple, 2015) and long dispersal abilities (Kojola *et al.*, 2006) of large carnivores dictate a
13 management and conservation approach that is based on the swift collection and evaluation
14 of accurate data on their status. This ensures their recovery and survival through their
15 adequate representation inside and outside protected areas (Di Minin *et al.*, 2016).

16 As new technologies emerge that make it easier to collect and transmit information on
17 one’s location, volunteer participation in data collection is becoming increasingly more
18 important as an ecological research tool (Dickinson *et al.*, 2012). Volunteers participating in
19 citizen science programs can collect more data and cover wider areas, faster than
20 researchers alone would, all of this at a lower cost (Dickinson *et al.*, 2010, Dickinson *et al.*,
21 2012). If analysed properly, opportunistic, presence-only data of citizen science projects can
22 produce reliable estimates of wildlife distribution trends (van Strien *et al.*, 2013); however,
23 such data may suffer from *observer bias* [*sensu* Warton *et al.* (2013), also commonly referred
24 to as *sampling bias*], when the sampling effort is not evenly distributed in the entire study
25 area. Thus, if a species is present, it is more likely to be recorded when more people are
26 present to see it, i.e. in areas more densely populated by humans and/or more accessible,
27 such as those close to roads, research centres and cities (Geldmann *et al.*, 2016, Daru *et al.*,
28 2018). If no correction is made for observer bias, the risk is to model the observer
29 distribution instead of the species distribution (Hortal *et al.*, 2008, Warton *et al.*, 2013). To
30 address this issue, Warton *et al.* (2013) extended standard Species Distribution Models
31 (SDMs; Guisan *et al.*, 2017) and developed a method that corrects for observer bias by
32 relating the records of species presence to variables that are split into two categories:

1 *ecological variables* are variables that are likely to influence a species' occurrence, whereas
2 *observer bias variables* are variables that are likely to influence the detection of a species
3 (the observer's occurrence mainly). When making predictions, only the ecological variables
4 are used, and a common value for the observer bias variables (e.g. the average, or the
5 minimum/maximum value) is set, making the predictions as if the distribution of observers
6 was spatially homogeneous. This method has been successfully applied to model the
7 distribution of plant data (Warton *et al.*, 2013), but is yet to be applied to animals.

8 Presence-only data obtained from citizen science programs are particularly relevant to
9 large carnivores, such as brown bears (*Ursus arctos*), because bears are difficult to monitor,
10 due to their cryptic and solitary nature and due to their relatively low density of occurrence
11 over large areas (Kindberg *et al.*, 2009). At the same time however, bears are also highly
12 charismatic species attracting public attention, increasing the chances that observations
13 would be reported, thus making them particularly suitable for citizen science programs.

14 Brown bears are globally considered by the IUCN as species of Least Concern. They are
15 the only Ursid in Europe, where several populations are small, isolated and threatened by
16 habitat loss and fragmentation and by human-bear conflicts (Swenson & Sandegren, 2000,
17 Bautista *et al.*, 2016, Piédallu *et al.*, 2017). This is particularly the case for brown bears in
18 Greece where the species reaches its southernmost European distribution and is considered
19 to be endangered, numbering fewer than 500 individuals (Karamanlidis *et al.*, 2015). Despite
20 increasing human-wildlife conflicts (Karamanlidis *et al.*, 2011), bears have been recovering in
21 recent years (i.e. after approximately the year 2000) in Greece, both demographically
22 (Karamanlidis *et al.*, 2015) and genetically (Karamanlidis *et al.*, 2018). At the same time,
23 circumstantial evidence suggests that the species has also been expanding its range
24 (Karamanlidis *et al.*, 2008); however, no thorough, nation-wide study has been conducted so
25 far to substantiate this fact, partially because of the logistic and financial constraints that
26 have befallen the country since the onset in 2009 of a financial crisis. This incomplete
27 understanding of the current distribution of brown bears in Greece is hindering their
28 effective conservation, which in turn may compromise the ongoing demographic and genetic
29 recovery of the species in the country.

30 The aims of this study were to take advantage of a large citizen science data set to study
31 the presence of brown bears in Greece during the recovery of their population in the country

1 and to identify new priority areas for their conservation. The first aim was achieved by
2 visually comparing our citizen science data with an estimation of the past distribution of the
3 species in the country. The latter aim was achieved by applying Warton et al.'s (2013)
4 approach to our citizen science data to model habitat suitability, and then comparing the
5 predictions of our model with the current distribution of brown bear records in Greece and
6 with that of protected areas in the country. This comparison allowed us to assess the
7 distribution of highly suitable bear habitat in relation to the distribution of bears and
8 protected areas and obtain new, valuable insights on the spatial recovery and conservation
9 priorities of brown bears in Greece.

10 **Materials and methods**

11 **Data collection**

12 Data on bear presence were collected from 2004–2016 within the framework of a citizen
13 science program, the “Hellenic Brown Bear Rescue and Information Network” (HBBRIN),
14 established by the non-governmental organization ARCTUROS. Information on bear presence
15 (i.e. opportunistic observations, damage to human property, attacks to humans, approaches
16 to inhabited areas) was received from throughout the range of the species in the country
17 (i.e. the Pindos Mountains in the western part and the Rodopi Mountains in the eastern part
18 of Greece) through the post, telephone or email and was verified either on site by a field
19 team or through the evaluation of the information provided (e.g. photographs and videos).

20 **Studying brown bear presence in Greece**

21 To gain insights on spatial aspects of the demographic and genetic recovery of brown bears
22 in Greece, we mapped bear records from the HBBRIN using QGIS v2.14 (QGIS Development
23 Team, 2016) and visually compared them with the past distribution of the species in the
24 country. We considered as a reference the distribution of brown bears in Greece (Fig. 1)
25 published in the assessment of the species for the Red Book of Endangered Species of
26 Greece (Mertzanis *et al.*, 2009). In this assessment the total area of continuous brown bear
27 range in Greece was estimated at approximately 13,500 km², which consisted of two
28 geographically distinct population nuclei in the northeastern and northwestern part of the
29 country. Although no information is available on how this map has been produced and
30 whether it represents only core areas of the species or also areas of temporal re-occurrence,
31 it is evident, from the references therein and its publication date, that the map is the best

1 available account on the distribution of brown bears in Greece prior to their demographic
2 and genetic recovery (i.e. estimated to have started at the beginning of the century) and the
3 beginning of our study.

4 To compare the habitat characteristics between the past distribution of brown bears in
5 Greece and the new areas where the species was documented through the HBBRIN, we
6 calculated the percentage of coverage of different habitat types [extracted from Corine Land
7 Cover 2006 (CLC) seamless vector data, Version 16 (European Commission, 04/2012)], road
8 density (OpenStreetMap, 2016) and human population density (Center for International
9 Earth Science Information Network (CIESIN) & Centro Internacional de Agricultura Tropical
10 (CIAT), 2005). The size of the area where the species was documented through the HBBRIN
11 was calculated by Local Convex Hulls (LoCoHs) using a fixed radius of 50 km and the five
12 nearest neighbors of each point [R package “rhr”; (Signer, 2016)], excluding however 5% of
13 the outermost records in order to reduce the impact of extreme observations.

14 **Identifying new priority areas for brown bear conservation in Greece**

15 *Modelling framework*

16 We modelled the intensity of observations per space unit as our response variable in an
17 inhomogeneous Point Process Model (PPM), a common tool for modelling the occurrence of
18 species based on a set of explanatory factors using presence-only data (Renner *et al.*, 2015;
19 Appendix 1). Inhomogeneous PPMs take as input the observed point locations and a set of
20 spatially-indexed predictors, and produce as output an intensity of point locations per unit
21 area. This is achieved by introducing a set of quadrature points (often spaced along a
22 rectangular grid) at which the predictors are also measured. We divided these spatial
23 predictors into two categories: (1) *ecological* variables, or variables that affect the
24 probability of presence of the species in the area, and (2) *observer bias* variables, affecting
25 the probability of the species to be detected given that it is present in the area. Here we
26 compared two approaches: (1) a simple approach, where only *ecological* variables were
27 taken into account, and (2) the method by Warton *et al.* (2013), where both *ecological* and
28 *observer bias* variables were taken into account when building the model, and predictions
29 were made by setting the *observer bias* variables to a common value for the whole study
30 region (a process thereafter called “correction for observer bias”; Appendix 1). By correcting
31 for observer bias, the output is detrended and hence can be interpreted as an intensity of

1 bear observations per square kilometre, if all locations in the study area had equal sampling
2 effort as quantified by the observer bias variables (Warton *et al.*, 2013). If we can accept that
3 the realised distribution of brown bears in Greece is compatible with preferred habitat, then
4 such maps of corrected intensity are proportional to habitat suitability.

5 To account for spatial dependence among point locations, we fitted a special type of
6 PPM called an “area-interaction model”, which assumes interactions among all points within
7 a 2km radius (see Appendix 1). Fitting an area-interaction model can be thought of as being
8 analogous to accounting for over-dispersion in Poisson count data. The area-interaction
9 model introduces a point interaction covariate which captures additional spatial patterns not
10 explained by the other predictors, the same way that an over-dispersion parameter captures
11 excessive variance not accounted for by the other predictors in a Poisson regression. We
12 considered the fitted area-interaction model as our best model and therefore only present
13 parameter estimates for this model – a comparison with other considered models is
14 presented in Appendix 1.

15 *Explanatory variable selection*

16 A grid of 1x1 km² was laid over the study area, which corresponds to the resolution of the
17 coarsest explanatory variable. The mean value of a set of explanatory variables expected to
18 influence either bear or observer presence was calculated for each grid cell. Explanatory
19 variables were chosen following previous brown bear studies in Europe (Naves *et al.*, 2003,
20 Martin *et al.*, 2013). We used topography (i.e. maximum altitude and mean slope), distance
21 to forest edge and distance to shrubland edge, density of rivers (i.e. accumulated length of
22 rivers in the pixel), and percentage of agricultural land as ecological variables, and distance
23 to human settlements, as well as distance to the closest primary or secondary road as
24 observer bias variables (Appendix 1, Table S1). The construction of the grid and the
25 calculation and extraction of the ecological variables were done in the R software (R
26 Development Core Team, 2011) and in QGIS (Quantum GIS Development Team, 2013).

27 Variable selection was done using a LASSO regularization path (Appendix 1). A model
28 fitted with a LASSO penalty can shrink some parameter estimates to be exactly zero,
29 effectively reducing the number of corresponding explanatory variables in the model. We
30 fitted an entire regularization path of models with increasing penalties and chose the model
31 which minimized BIC. We first assessed the effect of each covariate on the intensity of brown

1 bears per square kilometre as estimated in the PPM. To visualise these effects, we produced
2 scatterplots of the predicted intensities vs. standardised covariates, and then fitted a
3 smoothed generalized additive model to produce a response curve.

4 *Comparison of habitat suitability predictions with bear records and protected area* 5 *distribution in Greece*

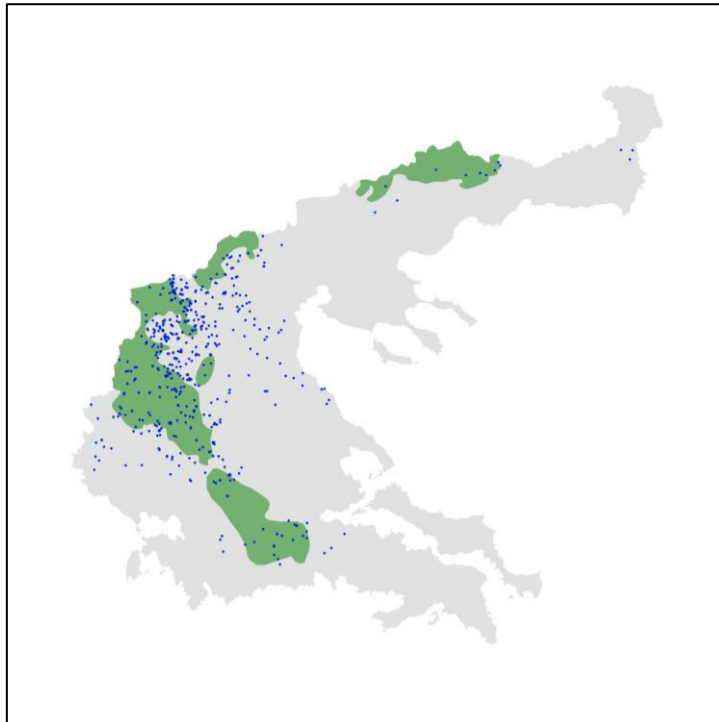
6 The Natura 2000 (N2K) network is a European network of protected areas for birds and
7 habitats (http://ec.europa.eu/environment/nature/natura2000/db_gis/index_en.htm).

8 Some of the sites in the N2K network (33 out of 419) comprise a dedicated network for the
9 protection of bears in Greece [as reported in their Standard Data Forms (SDFs)]. To compare
10 our habitat suitability predictions with the presence of bears and the distribution of
11 protected areas in Greece, we mapped all the N2K sites in Greece
12 (http://www.ekby.gr/ekby/en/Natura2000_main_en.html; last updated in 2012), identified
13 the sites included in the dedicated network for the protection of bears in Greece and those
14 which were not. For this, we mapped only areas of highly suitable habitat, defined as those
15 grid cells with predicted intensities above the 80% quantile. Only N2K sites with more than
16 5% of their total area classified as highly suitable habitat were retained. Areas containing
17 highly suitable habitat, but not included in the N2K network of protected areas, were also
18 identified.

19 **Results**

20 **Studying brown bear presence in Greece**

21 From 2004 – 2016 the HBBRIN recorded the presence of bears (Appendix S2, Table
22 Bear_spxy2017) on 632 occasions: 40% of these cases (i.e. 251 data points) were located
23 within the past distribution of the species, 60% beyond (Fig. 1). The new distribution area of
24 brown bears in Greece that was not included in the map of Mertzanis et al. (2009) covered a
25 total of 16,661 km² and was, compared to the past distribution of the species, characterized
26 by lower elevations, higher coverage by primary and secondary roads and agricultural areas
27 and lower coverage by mature forests (Table 1).



1

2 **Figure 1** Map of a part of continental Greece indicating the distribution of brown bears in the
 3 country according to Mertzanis *et al.* 2009 (shaded green area) and the locations of 632
 4 brown bear occurrences recorded through the HBBRIN (2004 – 2016).

5

6 **Table 1** Habitat characteristics of the past and new distribution of brown bears in Greece (for
 7 more information, see the “Studying brown bear presence in Greece” in the Materials and
 8 methods section).

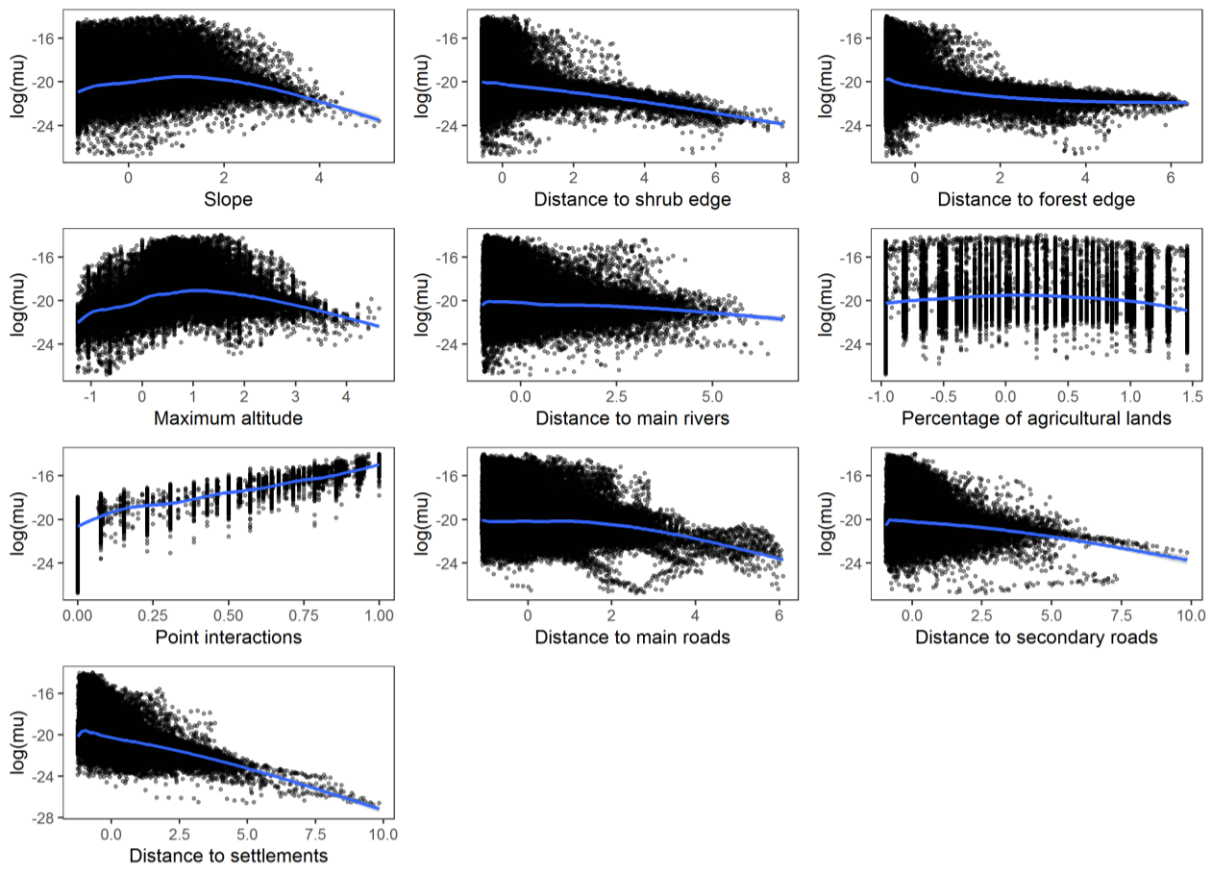
	Past distribution	New distribution*
Total area (km ²)	13,903	16,661
Elevation (m.a.s.l.)	1134.3	726.8
Population density (persons/km ²)	32.7	39.2
Primary roads (km/100 km ²)	3.4	9.7
Secondary roads (km/100 km ²)	41.4	87.7
Mature forest (%)	51.4%	23.8%
Transitional woodland and shrubs (%)	25.6%	25.5%
Grasslands and pastures (%)	10.3%	12.8%
Agricultural areas (%)	10.9%	33.4%

*Calculations excluding past distribution area

9 **Habitat suitability for brown bears in Greece**

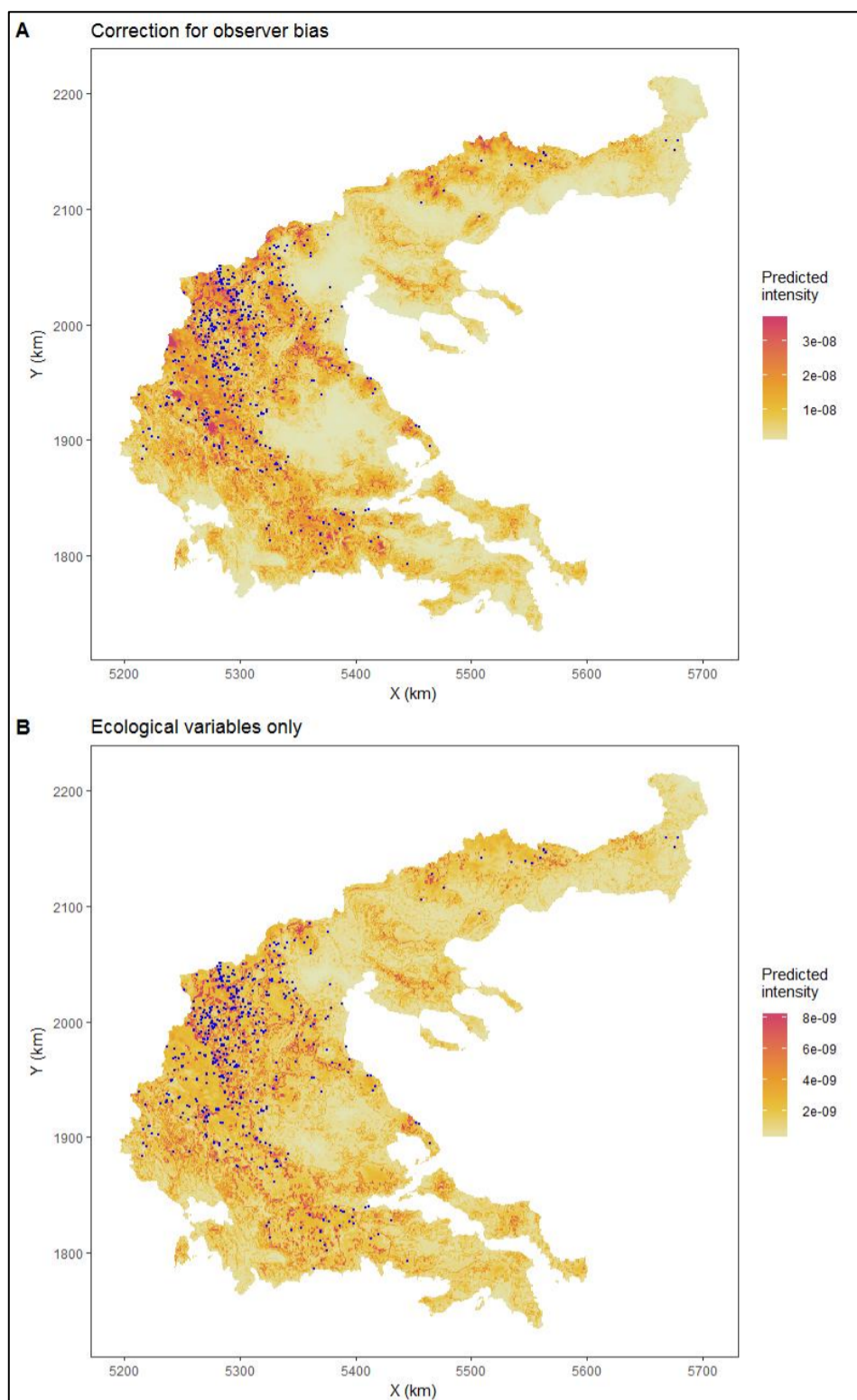
10 The intensity of the PPM was the highest for intermediate altitudes, slopes and percentage
 11 of agricultural land (Fig. 2; Appendix 1, Table S2). The intensity of the PPM decreased for

- 1 greater distance to shrubland and forest edges and to both types of roads and human
- 2 settlements (Fig. 2; Appendix 1, Table S2).



- 3
- 4 **Figure 2** Response curves for each variable in the model. Points: scatterplot of predicted
- 5 intensity ($\log(\mu)$) against standardised covariate values (mean 0, variance 1). Blue line:
- 6 fitted smooths (using generalised additive models).

- 7
- 8 When examining the predictions from the model (Fig. 3), habitat suitability was patchier
- 9 when correcting for observer bias (Fig. 3A: best model, correcting for observer bias) than
- 10 when observer bias was ignored (Fig. 3B: only ecological variables were used).

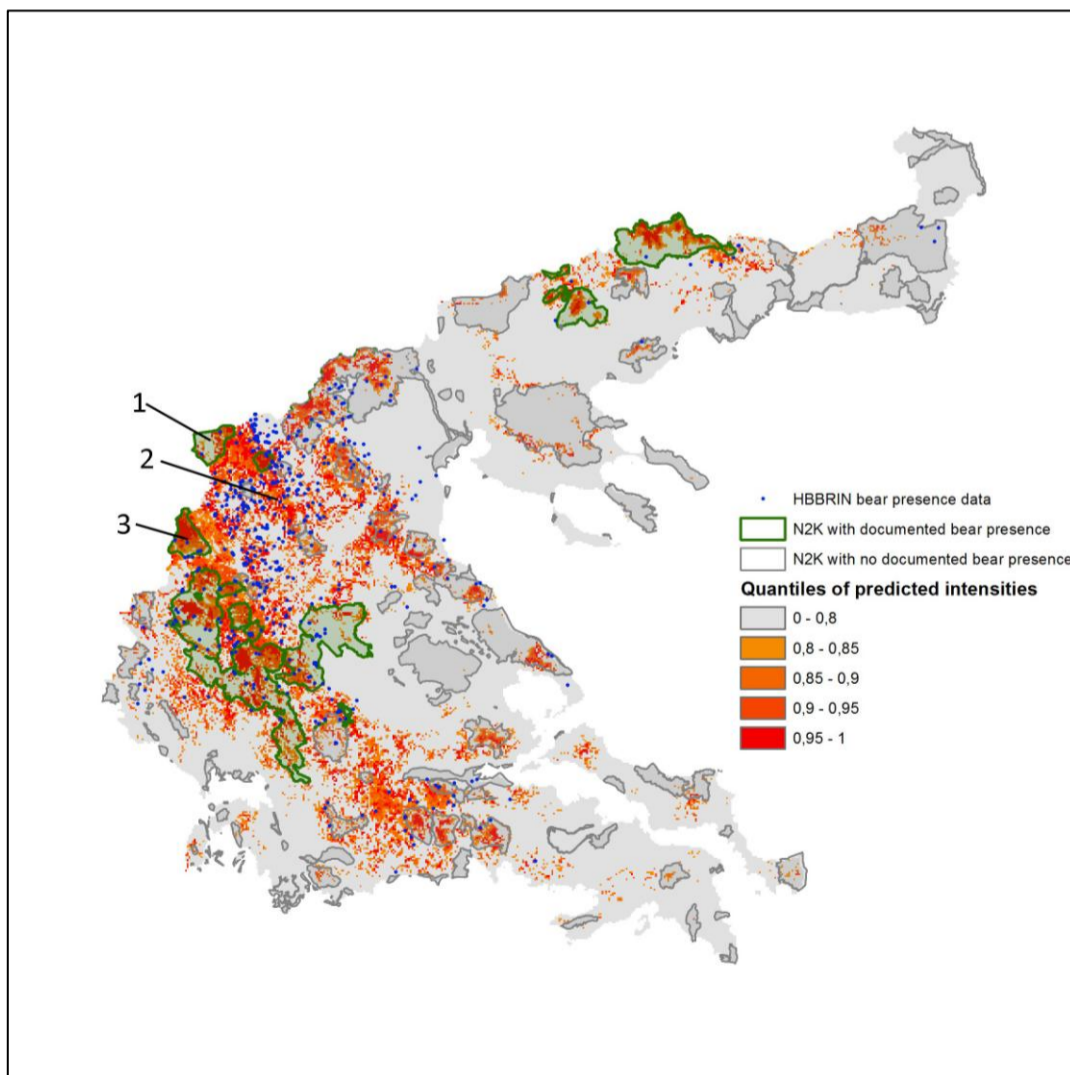


1
 2 **Figure 3** Habitat suitability map from the model with point interaction, A: from the model
 3 with both ecological and observer bias variables, where predictions were conditioned on a
 4 common level of bias; B: from the model that did not correct for observer bias (i.e. with the
 5 ecological variables only); blue points are the opportunistic observations. For visualisation
 6 purposes, values above the 0.95 percentile of the global map are set to the 0.95 percentile
 7 value.

8
 9 **Identifying new priority areas for brown bear conservation in Greece**

10 Our habitat suitability analysis identified 99 N2K sites with highly suitable brown bear habitat
 11 in Greece (i.e. predicted intensities higher than the 80% quantile covering more than 5% of
 12 the total area of an N2K site) (Fig. 4). Eleven N2K sites contained > 80% of highly suitable

1 habitat, 25 contained > 60%, 53 contained > 40%, while the remaining N2K sites contained <
 2 40% of suitable brown bear habitat respectively (Appendix S2, Table N2K). Out of the N2K
 3 sites with suitable bear habitat in Greece, 33 had bears included in their SDFs, 66 did not.
 4 N2K sites with bears in their SDFs were associated with high-quality bear habitat (88% of
 5 these sites had > 40% suitable bear habitat) and actual bear presence (in 64% of these sites,
 6 81 cases of bear presence were recorded). N2K areas without bears in their SDFs were
 7 associated with low-quality bear habitat (36% of these sites had > 40% suitable bear habitat)
 8 and low bear presence (in 45% of these sites, 104 cases of bear presence were recorded).
 9 There were however notable exceptions, including 7 areas (10.6%) with high quality bear
 10 habitat (i.e. > 60%) and bear presence, as well as 5 areas (7.6%) with low quality bear habitat
 11 (i.e. < 20%) and bear presence (Appendix S2, Table N2K). In addition, bear presence was
 12 recorded 485 times in areas not included at all in the N2K network (Fig. 4), mainly in the
 13 western population nucleus of the species in the country. High-suitability habitat in this part
 14 of the range of the species was located mainly in the area enclosed by the Grammos, Vitsi-
 15 Varnoundas and Askio mountains (Fig. 4).



16
 17 **Figure 4** Map of a part of continental Greece indicating the opportunistic data (blue), the
 18 predicted highly suitable habitat (red gradient) and the Natura 2000 (N2K) coverage, with

1 (green) and without presence of bears (gray) in SDFs. Habitat suitability predictions were
2 obtained with the model with point interactions, built with both ecological and observer bias
3 variables, and projected conditioning on a common level of bias. All grid cells for which
4 predicted intensity was above the 0.80 percentile of the global map qualified as highly
5 suitable habitat. Numbers indicate the Mountains: 1) Vitsi-Varnoundas, 2) Askio, and 3)
6 Grammos, respectively.

7 **Discussion**

8 Understanding the processes associated with population recoveries and identifying areas
9 that are suitable for recolonization by endangered species is essential to support effective
10 conservation policies (Cianfrani *et al.*, 2010). We used data from a citizen science project and
11 habitat suitability modelling to understand the spatial aspects associated with the
12 demographic and genetic recovery of an endangered brown bear population at the southern
13 edge of its European distribution and to identify priority areas for conservation.

14 Brown bear presence during the demographic and genetic recovery of the species in
15 Greece was recorded in both the northeastern and northwestern nuclei of the species in the
16 country. However, a significant percentage of the bear records of the study fell outside of
17 the past distribution of the species in Greece, confirming previous circumstantial evidence
18 (Karamanlidis *et al.*, 2008) and providing for the first time a clear indication of the spatial
19 recovery of the species and the recolonization of new areas. This spatial recovery has been
20 associated primarily with the recolonization of anthropogenic/cultural landscapes (Table 1)
21 and is consistent with the increase in human–bear conflicts (Karamanlidis *et al.*, 2011) and in
22 bear–vehicle collisions (Karamanlidis *et al.*, 2012) recorded in Greece during this time. It is
23 also consistent with our understanding of the genetic recovery of the species in the country
24 (Karamanlidis *et al.*, 2018) and our understanding of the effects of human activity on the
25 activity and habitat selection patterns of brown bears in Greece (de Gabriel Hernando *et al.*
26 In Review). Although distribution data from the HBBRIN should be viewed with caution, as
27 this is a citizen science project based in the western part of Greece (and therefore more
28 popular in this part of the country), mainly related to the provision of expertise assistance in
29 human–bear conflicts and cases of bears in distress, evidence suggests that bears in Greece
30 in the last 15 years may have increased their range by as much as 100%. Further research is

1 necessary to substantiate this fact and complete our understanding of the spatial recovery of
2 this large carnivore in Greece.

3 The results of the study indicate that bear habitat suitability decreased with distance from
4 forest and shrubland edge (Fig. 2). We interpret the first effect as forest and shrubland edges
5 providing an interface between potential resources outside and refuges inside. Forest cover
6 in itself (which can be interpreted as providing refuge) has already been shown to be an
7 important variable influencing bear presence (Naves *et al.*, 2003, Martin *et al.*, 2012). The
8 quadratic effects found for altitude (consistent with G uthlin *et al.*, 2011), slope and
9 percentage of agricultural land could be also due to the interface between refuge (i.e. higher
10 altitude, steeper slopes and fewer open spaces) and potential resources (i.e. lower altitudes,
11 smooth terrain and existence of crop fields).

12 Although previous studies have tried to correct for some of the spatial sampling bias
13 inherent to citizen science data (e.g. Phillips *et al.*, 2009), these approaches would not have
14 been suitable for our case study. For example, volunteers often record within a given study
15 area several other species, usually more common than the focus species, providing
16 information that can be used to infer observer bias and correct for it (e.g. Phillips *et al.*,
17 2009). However, this approach merely replaces observer bias with species richness bias
18 (Warton *et al.*, 2013), because there might be spatial patterns in the distribution of species
19 richness. Also, this approach would not be applicable to our data collection scheme, as
20 observers spontaneously report bear presence and are unlikely to record the presence of
21 other species. Finally, in cases where, like in our study, citizens spontaneously report
22 opportunistic data, it is almost impossible to rely on any type of information other than the
23 location of the observations. By relying on independently collected data to model observer
24 bias, the method proposed by Warton *et al.* (2013) has the advantage to provide a flexible
25 and generic way of correcting for observer bias.

26 However, several issues arise when trying to model observer bias using this approach.
27 First, one needs to select variables that capture observer bias. In doing so, some variables
28 seem intuitive, like those related to human population density or to accessibility of the area.
29 But others can be harder to classify, like, for example, distance to human settlements, which
30 may have a negative effect on species detection with the less people in remote areas, the
31 less likely that someone will detect the species if it is present. Therefore, it seems plausible

1 to consider distance from human settlements as an observer bias variable. This is likely to be
2 the case for plants, but for free-ranging mammals with large home ranges, the same variable
3 can also have two opposite ecological effects, with bears either avoiding populated areas
4 (e.g. Naves *et al.*, 2003, Martin *et al.*, 2012, Piédallu *et al.*, 2017) because they are perceived
5 as risky, or being attracted to them, as they can provide shelter and/or resources (Elfström *et*
6 *al.*, 2014). Such difficulty of classifying variables can create limitations because if some
7 features appear both in the ecological and in the observation process, the model is non-
8 identifiable (Fithian & Hastie, 2013). Similar problems of joint effects on presence and
9 detectability can arise with roads, which can provide access for observers to the sites where
10 bears are present (observer bias variable), but can also be related to disturbance (habitat
11 fragmentation, road mortality) and thus negatively influence the presence of bears (Graves
12 *et al.*, 2011, Martin *et al.*, 2012). We chose to consider the distance to roads as an observer
13 bias variable. Although its negative effect on bear detection (i.e. the further away from a
14 road, the less likely a bear observation will be made) is consistent with that choice, the
15 difficulty to decide *a priori* whether a variable should be considered as observer or ecological
16 bias emphasizes the need for future research.

17 Ideally, one should validate the approach – at least for a subset of the study area – using
18 data collected by standardised protocols (hence not suffering from observer bias). This
19 would allow concluding whether the correction for observer bias improved the predictions
20 or not, and would also allow for a model which includes both presence-only and presence-
21 absence data. However, in this study we did not have access to such good-quality validation
22 data. We had access to telemetry data [Very High Frequency (VHF) and Global Positioning
23 System (GPS) data] – which are commonly available for a subset of the study area in many
24 projects), but using these for validation would not have been appropriate for several
25 reasons. First, telemetry data are biased towards the capture locations – it is impossible to
26 assign areas with no records to areas without the species or to areas with the species but
27 where no tracked individual occurred. Similarly, areas with a lot of telemetry locations could
28 correspond to areas that are preferred by the bears or simply to areas where the home
29 range of multiple tracked individuals overlap. A solution to this problem would be to model
30 habitat selection within each individual's home range. However, the habitat selection that
31 would be modelled using this approach is at a scale that does not match the habitat
32 selection modelled using Warton *et al.*'s method (2013) for opportunistic data. Warton *et*

1 al.'s method (2013) models Johnson's *first order selection* ("the selection of physical or
2 geographical range of a species"), while using telemetry data would allow us to model *third*
3 *order selection* ("the usage made of various habitat components within the home range";
4 Johnson, 1980). In particular, modelling selection within the range does not inform on which
5 environmental conditions are highly unsuitable for the species (by definition, no telemetry
6 data will come from these areas), whereas this distinction between suitable and unsuitable
7 conditions is what is the most important for conservation. This distinction is also where the
8 strength of our predictions lies (i.e. identifying areas that are highly suitable vs. areas that
9 are not – whereas areas with mixed predictions are less useful). Overall, despite the fact that
10 it was not possible to formally validate our correction for observer bias, studies that have
11 had access to good validation datasets have already demonstrated the added value of
12 correcting for observer bias using the approach we used here (e.g. Warton *et al.*, 2013). This
13 is supported in our study also by the findings presented in Fig. 4 (i.e. comparison between
14 our predictions and N2K sites with known bear presence), which indicate that most sites
15 with known presence of bears are predicted as containing highly suitable habitat. Apart from
16 being generally applicable to species that are rare and sampled by citizen science and for
17 which there are only presence-only data, our use of Warton *et al.*'s method (2013), is of
18 important, practical relevance for (endangered) species conservation in general and brown
19 bear conservation in Greece in particular.

20 Our habitat suitability modelling produced a map with the predictions of the most
21 suitable bear habitat in the country. The predictions seem less accurate in the northeastern
22 nucleus where a high percentage of observations fall outside areas with high predicted
23 intensities. This could be due to the existence of ecological differences between the Pindos
24 and Rodopi bear populations and the fact that only 2% of the total observations used for
25 modelling came from the latter area, thus predicting less accurately habitat suitability in that
26 nucleus. As evidenced by these predictions, the existing network of protected areas that is
27 formally dedicated to the protection of the species (i.e. N2K sites with bears included in their
28 SDFs) contains critical habitat for the conservation of the brown bear in Greece. This fact is
29 indirectly supported by the high densities of bears (Karamanlidis *et al.*, 2015), the high
30 number of human–bear conflicts (Karamanlidis *et al.*, 2011) and the genetic importance as
31 source populations of these protected areas (Karamanlidis *et al.*, 2018), and therefore these
32 areas should be considered as belonging currently to the core habitat of brown bears in

1 Greece. However, despite the fact that core bear areas in Greece contain critical habitat for
2 the species, our study recorded a relatively low number (12.3%) of bear observations in
3 these areas. This discrepancy is likely explained by the increased experience (Galloway *et al.*,
4 2006) of people living in areas with well-established bear populations, as opposed to people
5 living in areas where bear populations are recovering and bear presence is still an unusual
6 event. This suggests furthermore that our approach might be better suited to identifying
7 priority areas for conservation in areas with recovering wildlife populations, i.e. may be used
8 as an “early-warning” conservation system.

9 The results of our study indicate furthermore that only a portion of highly suitable habitat
10 for bears in Greece is currently included in the dedicated N2K network of protected areas for
11 bears; most records of bears originated either from areas with no legal protection status or
12 from protected areas with no specific management measures for the protection of bears,
13 thus creating a new “conservation reality” for the species in the country. On a practical level,
14 this new conservation reality dictates that protected areas that do not have the brown bear
15 in their SDFs, but do have highly suitable habitat and bear presence at the same time in
16 them, will need to prepare for the possibility of the re-establishment of the species in their
17 management area and adjust their management priorities and actions accordingly. For areas
18 with highly suitable habitat and bear presence that are not legally protected, this
19 conservation reality dictates that the information of this study should be used by the
20 national conservation authorities to re-evaluate their national management and
21 conservation priorities, while focusing at the same time in establishing new protected areas
22 for the species in some of the highly-suitable areas identified in the study. A similar approach
23 has been suggested for the conservation of another recovering large carnivore in Greece, the
24 grey wolf (*Canis lupus*) (Votsi *et al.*, 2016).

25 The main differences in habitat characteristics between the past and new distribution of
26 brown bears in Greece provide insights into the spatial recovery of the species; new
27 distribution areas are more humanized (i.e. denser road network, higher population
28 densities, higher proportion of agricultural areas and lower proportion of mature forest). The
29 ability for bears to re-colonize such areas is most likely explained by multiple factors
30 including: 1) the behavioural plasticity of the brown bear (Ordiz *et al.*, 2014), which in this
31 case has resulted in activity and habitat selection adaptations to human activity of bears in
32 Greece (de Gabriel Hernando *et al.* In Review); and (2) abandonment or decrease in

1 agricultural activities in the less productive areas as a consequence of the general rural
2 abandonment, allowing a progressive naturalization of these areas (Poyatos *et al.*, 2003).

3 **Conclusions**

4 For the past several years Greece has suffered a financial crisis that has had a negative effect
5 on the national environmental management apparatus (Lekakis & Kousis, 2013) that is likely
6 to leave national management authorities in the future struggling to find the necessary funds
7 to effectively monitor and manage biodiversity in the country. Given that the bear
8 population in the country is rapidly recovering (Karamanlidis *et al.*, 2015, Karamanlidis *et al.*,
9 2018) and that at the same time bear densities and conflicts with humans in Greece are
10 increasing (Karamanlidis *et al.*, 2011), our approach of collecting information on bear
11 presence through a citizen science program and using it to produce habitat suitability maps
12 has been a swift and cheap way of identifying potential hot-spots of bear presence, activity
13 and conflicts with humans in the country, while gaining important insights on the spatial
14 aspects associated with the recovery of this large carnivore.

15 Our approach will help prioritize conservation actions in the country towards the areas
16 that need it the most and serve as a model approach to other countries facing similar
17 financial and logistic constraints in the monitoring of local biodiversity or facing similar
18 challenges in managing the rapid recovery of a large carnivore. Acknowledging the previous,
19 we propose the intensification of efforts in Greece to further develop the Hellenic Brown
20 Bear Rescue and Information Network, by carrying out targeted awareness campaigns to the
21 general public and selected stakeholders (e.g. Forestry and Veterinary Departments,
22 Management Authorities of Protected areas) that will increase data input and ultimately the
23 quality of the habitat suitability maps produced using this method. At the same time, it is
24 clear that in the case of the brown bear the current setup of the protected areas network in
25 Greece does not reflect the current conservation reality and that there is a clear need to re-
26 evaluate the existing network of protected areas in Greece so that it effectively supports the
27 recovery of the species in the country.

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7 **Data Accessibility Statement**

8 All data and codes used to carry out the analyses and generate the maps are provided as
9 Supplementary Material (Appendix 3).

10

11 Additional Supporting Information may be found in the online version of this article:

12 **Appendix S1:** Details on the methods

13 **Appendix S2:** Predictors data (Bear_backg_env2017.csv); Observations data
14 (Bear_spxy2017.csv); Habitat data (Table N2K)

15 **Appendix S3:** R Code of the study