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► To cite this version:

Gaël Le Roux, Michaël Guillon, Lise Bernard, Luc de Haro, Olivier Lourdais, et al.. What drives the risk of being bitten by a viper? A fine spatial scale study in western France. *Toxicon*, 2023, 228, pp.107130. 10.1016/j.toxicon.2023.107130 . hal-04099855

HAL Id: hal-04099855

<https://hal.science/hal-04099855>

Submitted on 23 May 2023

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1 **What drives the risk of being bitten by a viper? A fine spatial scale study in western**
2 **France**

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14 Declaration of conflicts of interest: The authors declare they have nothing to disclose.

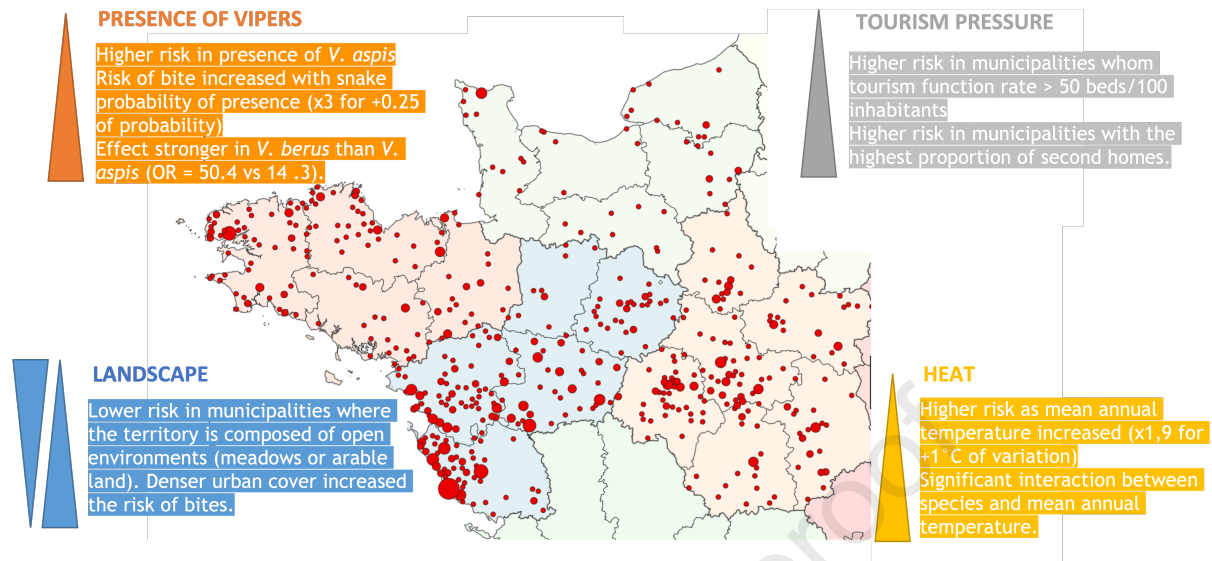
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CRedit Author statement

Gaël Le Roux: Conceptualization, Methodology, Investigation, Writing – Original draft preparation. **Mickaël Guillon:** Software, Methodology. **Lise Bernard:** Investigation, Data curation. **Luc de Haro:** Writing – Review & Editing. **Olivier Lourdais:** Conceptualization, Methodology, Validation, Writing – Review & Editing. **Alexis Descatha:** Writing – Review & Editing, Supervision.

Journal Pre-proof

What drives the risk of being bitten by Vipers in France?



16 **Abstract**

17 Previous studies on viper bites in France have focused on clinical consequences of
18 envenomation, efficacy of antivenom and epidemiology of bites. Herein, we
19 wanted to clarify temporal and spatial patterns in bite incidence using a fine spatial
20 scale (municipality level). We focused on viper bites recorded over the last 10
21 years in 4 regions of western France. We addressed the determinants of bite
22 occurrence and number of bites considering the following variables: predicted
23 probability of viper presence, species (*V. aspis* or *V. berus*), climatic data, tourism
24 function rate, soil transformation and landscape use. 703 bite cases were retained
25 with significant disparities between areas. Bites occurred either during a garden-
26 related activity (339 cases, 51.2%) or during an activity in the countryside (300
27 cases, 45.3%). The probability of presence of a viper at the municipality level
28 positively influenced the risk of being bitten (multiplied by 3 for a variation in
29 probability of 0.25 from 0.5) but varied between species (lower in *V. berus* than *V.*
30 *aspis*). Artificial land development had a positive effect on bite risks. Finally, a
31 tourism function rate above 50 beds/100 inhabitants was strongly associated with
32 an increase in the risk of occurrence and frequency of bites. Overall, viper bites
33 recorded in our study were concentrated on the south coastline of Pays de la Loire
34 region. The coastal towns are significant areas of tourist attraction and are located
35 close to preserved semi-natural landscapes that provide favorable habitats for
36 vipers. This convergence may favor human/wildlife encounters.

37 **Keywords:** european viper; asp viper; snakebite; risk evaluation; tourism pressure

38 **1. Introduction**

39 Viper bites in Europe are rare events with an overall incidence of 1.06 per 100,000 inhabitants
40 (Chippaux, 2012). The associated burden and economic cost are much lower than in rural areas
41 of developing countries (Africa, South East Asia, South America) (*Global snakebite burden*,
42 2018; Patikorn et al., 2020). According to a 2012 literature review, in Europe, rural activity was
43 also a source of bites until the beginning of the 20th century, as illustrated by the number of viper
44 hunters in the French, British and Italian countryside (Bronckers, 2020; Chippaux, 2012; Fabien,
45 1947). After the WWII in France, the shift in farming practices involving mechanization, pesticide
46 intrans and single-crop production, have fundamentally altered natural habitats, contributed to
47 the loss of biodiversity and led to the rarefaction of human/animal encounters (European
48 Commission, 2001). Today, the development of nature-related activities (hiking, fishing, etc.) and
49 tourism in rural areas has changed the circumstances in which people are bitten, the age groups
50 concerned (children), as well as the seasonality of bites (late spring and summer) (Chippaux,
51 2012).

52 Heretofore, most epidemiological studies focus only on identifying individual risk factors
53 without addressing other relevant aspects related to snake ecology or anthropic pressure on natural
54 habitats (Murray et al., 2020). Patterns of spatial variation in bite incidence at a fine scale are, by
55 contrast, rare and relatively new. There are a few examples, notably in Sri Lanka (Ediriweera et
56 al., 2018; Goldstein et al., 2021), in Costa Rica (Bravo-Vega et al., 2019), in Bangladesh (Rahman
57 et al., 2010) or in Iran (Yousefi et al., 2020). Most of them assume that the distribution of bites is
58 mainly related to the overlap of snake and human activities. Some studies have successfully
59 developed a mechanistic approach applying to snakebites methods used in determining the risk
60 of zoonotic spread (Martín et al., 2022). For example, snake distribution and abundance models
61 and human population density maps could be used to represent the human-snake spatial alignment
62 that underlies human-snake contact (Martín et al., 2022). Species distribution (SDM) modeling
63 permit to clarify environmental determinant of species presence (Sillero et al., 2021) and their
64 spatial output can provide relevant tools in spatially explicit epidemiological studies.

65 Metropolitan France is home to four species of viper: *Vipera aspis* (asp viper), *Vipera*
66 *berus* (common European adder or adder), *Vipera seoanei* (Seoane's viper) and *Vipera ursinii*
67 (Orsini's viper, meadow viper). The latter two have an extremely limited range in France and
68 hardly aggressive (no significant envenomation has been reported with *V. ursinii* (Orsini et al.,
69 1998)). Western Palearctic vipers (Genus *Vipera*) typically have a parapatric distribution with
70 reduced contact zone. Broadly speaking, the Loire valley is the limit of distribution for *Vipera*
71 *aspis* in the north-west and for *Vipera berus* in the south. A very narrow contact zone occurs
72 notably in Loire Atlantique (Guiller et al., n.d.). While hybridization is possible, the phenomenon
73 is very rare with limited gene flow between the species (Guiller et al., 2017; Zwahlen et al., 2022).

74 These two main species are responsible for 200 to 300 bites each year in France, with large
75 disparities between regions. The studies carried out on vipers in France have focused on the
76 clinical consequences of envenomation, the efficacy of antivenom and the epidemiology of bites
77 (Boels et al., 2009; de Haro, 2012; De Haro et al., 2002; Jollivet et al., 2015).

78 The aim of the present study is to apply this reasoning to venomous snake bites in the
79 north-western quarter of France, a region particularly exposed to viper envenomation. We
80 examined the following hypothesis: (1) First, we posit that bite risks should be driven by
81 environmental factors including seasons, with higher occurrence in summer (which correspond
82 to viper activity period); (2) Second, bite risks should be increased by human activities and
83 notably summer tourism that should favor the probability of encounters; (3) Third, we also
84 hypothesized that land transformation should influence snake bite leading to an overlap between
85 the high probability of presence of vipers and the perimeter of human activity.

86 **2. Methods**

87 **2.1. Study area and species occurrence**

88 The study area includes four regions (Normandy, Brittany, Pays de la Loire, Centre-Val de Loire
89 regions) that correspond to the area of competence of the Grand Ouest Poison Control Center
90 (PCC). This study area is ecologically relevant since it encompasses the distribution limits of the
91 two most widespread vipers in France, the adder (*V. berus*) and the aspic viper (*V. aspis*). The
92 ecology of the species has been intensely studied in Western France and notably their
93 ecophysiology, reproduction, and conservation (Dezetter et al., 2021; Guiller et al., 2012; Guillon
94 et al., 2014; Lourdais et al., 2013). Both species are facing important decline because of habitat
95 degradation (Guiller et al., 2022; Reading et al., 2010).

96 **2.2. Case selection and information**

97 All cases were extracted from the French National Poisoning Cases Database, which is fed by the
98 daily calls received by the 8 French PCCs. All cases of bites in the area of competence of the
99 Grand Ouest PCC (Normandy, Brittany, Pays de la Loire, Centre-Val de Loire regions) were
100 included, whenever the imputability of a viper was considered very probable or probable,
101 according to the following criteria:

102 (a) Very probable: presence of one or two points of skin puncture compatible with a viper bite
103 (hand up to the wrist, foot up to the ankle) with signs of envenomation such as local oedema,
104 pain, bleeding from the skin puncture.

105 (b) Probable: in case of lesions of doubtful aspect, observation of a viper (identified as such by
106 the toxicologist) in the immediate vicinity of the victim.

107 This selective approach was important since other type of bites or small wounds can be mistakenly
108 attributed to vipers by the public because of a lack of knowledge. The species involved in the bite
109 is only accessible in very rare cases (sufficiently clear photo of the animal, the killing of the
110 animal, etc.).

111 The date and location of bites and the activity at the time of the bite were the only data
112 collected for the study. When known, the municipality where the bite occurred was the elementary
113 unit of space. Failing that, it was the commune where the nearest distributing post office
114 (identified by its postal code) was located. If no bite location was indicated, the commune of the
115 hospital where the patient was treated was considered. Because bite data are retrospective they
116 may be overclouded by approximations, particularly regarding their exact location. The
117 communal unit is the most detailed information that can legitimately be expected from a telephone
118 response to an emergency.

119 The activity at the time of the bite was categorized into four types:

- 120 (1) activity in a wilderness area (hiking, climbing, swimming, etc.),
- 121 (2) activity in a private or public garden (gardening, mowing the lawn, etc.),
- 122 (3) activity on the public path (on the street, on the roadside, etc.),
- 123 (4) activity in another type of place or unknown.

124 The biting circumstance was considered with three categories:

- 125 (1) voluntary when it resulted from a voluntary interaction with the animal (attempt to catch,
126 kill, handle),
- 127 (2) professional when it occurred during the victim's professional activity.
- 128 (3) accidental (all other cases).

129 ***2.3. Explanatory variables considered***

130 *2.3.1. Viper occurrence*

131 The probability of occurrence of vipers was determined in a previous work, based on correlative
132 models of species distribution (Guillon, 2012) using occurrence data at the municipality level
133 gathered over the last 30 years by the French herpetological society (SHF) from regional
134 conservation organizations and herpetologists' observations . The correlative models use
135 relationships between field observations (occurrence), and climatic variables to project the
136 realized niche. Environmental variable used included temperature and precipitation data
137 (AURELHY, METEO-FRANCE corresponding to the 1971-2000 period) and monthly
138 interpolated solar irradiation database (PVGIS © European Communities). Spatial projections
139 were obtained for the probability of the presence of *V. berus* (the adder) and *V. aspis* (the asp

140 viper). The accurate determination of the species involved in the bite is difficult to obtain notably
141 because the two species are quite similar. Therefore, we determined the species involved at the
142 site from the highest probability of presence. In the Pays de la Loire and Centre-Val de Loire
143 regions *V. aspis* was the most frequent species (76.1% and 86.3% of communes respectively) and
144 the average presence probability of *V. aspis* was 0.55 and 0.46 respectively. In turn *V. berus* was
145 dominant in Normandy and Brittany (in 99.7% and 97% of the municipalities respectively). Its
146 probability of presence was 0.51 and 0.63, respectively.

147 2.3.2. Climatic conditions

148 The meteorological data were extracted from the International Surface Synoptic Observations
149 (SYNOP) circulating on the World Meteorological Organisation (WMO) Global
150 Telecommunication System (GTS) (Météo-France, n.d.). The data extracted were daily minimum,
151 maximum and mean temperatures, and daily sunshine duration in hours. Sunshine's duration is
152 the time during which a location is subject to effective insolation, i.e. sufficient solar radiation to
153 produce distinct shadows. A total of 27 SYNOP stations were used. The data was not available
154 for all the municipalities in the area. Therefore, each municipality was assigned the climate data
155 of the nearest SYNOP station. The average distance between a municipality and the nearest
156 station was 31.52 km.

157 2.3.3. Landscape attributes

158 As a first approach, the artificial modification of land variable was used. This is a public data
159 produced by the French Observatory for Soil Artificialization which reflects the transformation
160 of natural, agricultural and forestry areas by urban or industrial development operations (Cerema,
161 n.d.).

162 The land cover at the local level was obtained from CORINE Land Cover
163 (CLC) ("CORINE Land Cover," 2018). This is a biophysical inventory of land cover and its
164 evolution according to a 44-item nomenclature. This inventory is produced by visual
165 interpretation of satellite images. The production scale is 1:100,000. CLC is used to map
166 homogeneous land use units with a minimum surface area of 25 ha. The latest version (2018) was
167 used with the following land-use items: 111, continuous urban fabric; 112, discontinuous urban
168 fabric; 12, industrial, commercial and transport units; 13, mine, dump and construction sites; 14,
169 artificial, non-agricultural vegetated areas; 21, arable land; 22, permanent crops; 23, pastures; 24,
170 heterogeneous agricultural areas; 32, scrub or herbaceous vegetation associations; 33, open spaces
171 with little or no vegetation; 4, wetlands; 5, waters. The amount of each item was related to the
172 area of the municipality.

173 2.3.4. *Demographic data*

174 The data on resident population and communal area are taken from the National Institute of
175 Statistics and Economic Studies (INSEE), the public agency responsible for the production,
176 analysis, and publication of official statistics in France (Institut National de la Statistique et des
177 Etudes Economiques, 2021).

178 The communal density grid is a variable that characterizes municipalities according to
179 the distribution of their population in their territory. Thus, the more concentrated and numerous
180 the population is, the denser the municipality is considered to be. In addition to the three levels
181 of density defined at European level (densely populated municipalities, intermediary density
182 municipalities and rural municipalities), France has divided the so-called rural municipalities into
183 sparsely populated and very sparsely populated municipalities, in order to refine the description
184 of sparsely populated territories (Institut National de la Statistique et des Etudes Economiques,
185 2022).

186 2.3.5. *Tourism intensity*

187 The tourism variables are calculated based on the number of tourist beds offered by each
188 municipality, which is public data produced by INSEE.

189 The tourist function rate is the ratio between the tourist accommodation capacity of
190 municipalities (number of tourist beds) and their year-round resident population. It is an indicator
191 of tourist pressure that makes it possible to quantify the theoretical multiplication of the
192 population in periods of tourist influx. For example, a municipality with a tourist function rate of
193 100 beds per 100 inhabitants will be able to welcome as many visitors as it has permanent
194 inhabitants. The tourist density is a complementary variable, expressed as the number of tourist
195 beds per km². We also considered the share of second homes in the housing stock of each
196 commune. This is also public data produced by INSEE.

197 2.4. *Statistics*

198 The statistics were carried out using R software (R version 4.0.3). We first considered the
199 occurrence, per municipality, of at least one bite (0/1) in 10 years. We also considered the total
200 number of bites per municipality over the same period

201 2.4.1. *Univariate Analysis*

202 Quantitative variables are reported as mean (SD). We performed Fisher's exact test or Pearson's
203 Chi-squared test as allowed by the conditions of application. Qualitative data (activity and
204 circumstances, location and date of bite, viper species) and categorical variables were expressed
205 as n (%). We analysed them using Welch Two Sample t-test.

206 2.4.2. *Bite occurrence models*

207 We used a logistic regression to determine the variables influencing the occurrence of at
208 least one bite in each municipality. The variables defined a priori according to the literature data
209 (probability of viper presence, viper species, average annual temperature, tourism function rate
210 and soil transformation) were introduced in the first model.

211 The search for other potential adjustment variables involved a second penalized
212 regression model of the LASSO (Least About Shrinkage and Selection Operation) (R-package
213 ‘glmnet’). The penalty coefficient (λ) was chosen to provide an estimation error of less than
214 one standard deviation from the minimum error obtained by 10-fold cross-validation, while being
215 as parsimonious as possible. We kept the variables that had a coefficient different from 0 with
216 this λ coefficient. Finally, an approach using a backward and forward stepwise algorithm
217 was also used, based on a full logistic model, and after deleting multicollinear variables (variance
218 inflation factor > 5). The quality of the models was assessed by their AIC and BIC index, the
219 deviance, estimated by the pseudo-R² (rate of variance explained by the model), the error rate of
220 the model after performing a confusion matrix (threshold of probability of bite at 0.5), as well as
221 the AUC of the corresponding ROC curve.

222 2.4.3. *Bite number models*

223 As bites are rare events but for which regional disparities exist, it is necessary to check the absence
224 of overdispersion of the data and to take into account a number of zero observations that is much
225 higher than what the Poisson distribution would suggest. We used Zero-inflated Negative
226 binomial and Negative binomial hurdle models were each fit to the data with general linear
227 regression (R-packages ‘AER’, ‘MASS’ and ‘pscl’). The dependent variable was the count of
228 bites in 10 years. Independent variables were those that have been used for the binomial logistic
229 regression. We used the same predictors both in the count part and the logit part of the zero-
230 inflated models.

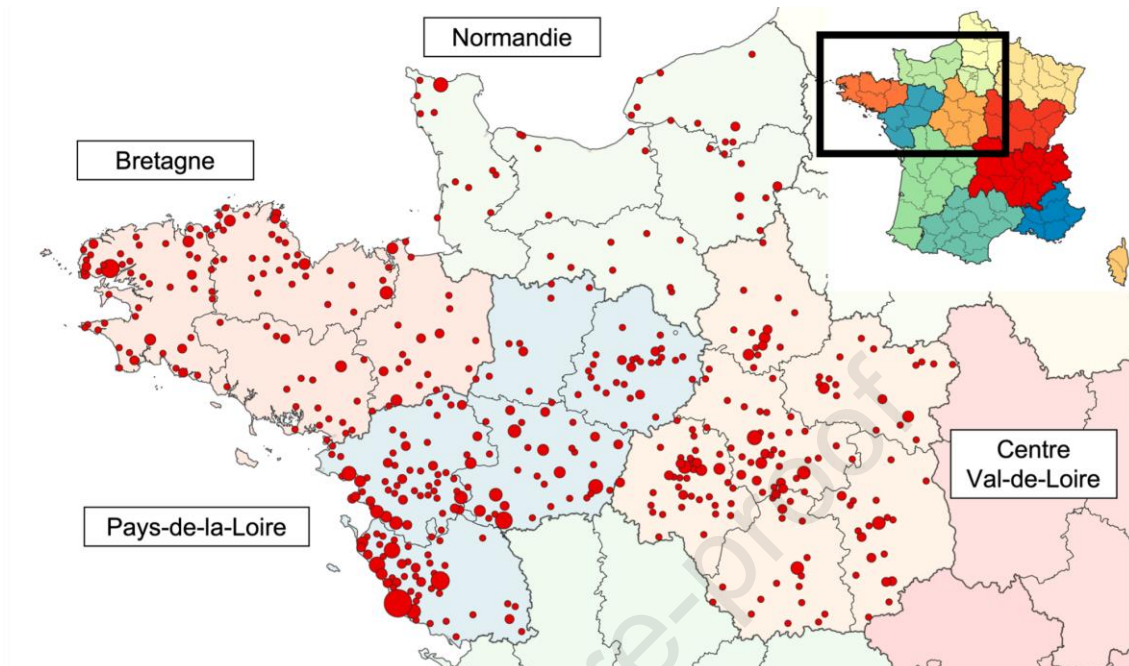
231 Various statistical tests were applied to evaluate over-dispersion and compare model fit.
232 For negative binomial models, the dispersion parameters were tested for difference from zero
233 with t-statistics. To assess the goodness-of-fit of models, likelihood and AIC were determined.

234 3. Results

235 3.1. *Descriptive analysis*

236 Over the study period (January 2012 to May 2021), 703 bite cases were recorded in 488
237 municipalities of the four regions covered (Figure 1). The Pays de la Loire region was the region
238 with the highest number of bites (41.8%, 294 cases), followed by the Centre-Val de Loire region

239 (28.0%, 197 cases), Brittany (22.9%, 161 cases) and finally, Normandy (7.3%, 51 cases). This
 240 change was significant ($p < 0.001$).



241

242 Figure 1. Study area and location of bite cases. Each circle corresponds to a municipality where at least
 243 one bite was observed. The area of the circle corresponds to the number of bites observed.

244 An important disparity was observed in the number of bites, which reached 18 in one
 245 municipality of the Vendée coast. The observed mean of the number of bites was 0.102, while the
 246 observed variance was 0.240, indicating an overdispersion of the data, confirmed by a dispersion
 247 test ($z = 3.6332$, $p\text{-value} < 0.0001$). To explore the excess of null observations, we visually
 248 examined the data. The Poisson distribution underestimates the null observations and
 249 overestimates the number of communes with a single bite.

250 **3.2. Bite circumstances**

251 Bites occurred mainly in the second and third quarters (660 cases, 93.9%, $p = 0.0016$), with a
 252 maximum in July (162 cases). During the day, 92.7% of bites (652 cases) occurred between 8:00
 253 a.m. and 9:00 p.m., with 41.4% (270 cases) occurring between 3:00 p.m. and 6:00 p.m.

254 The bites either occurred during a garden-related activity (339 cases, 51.2%) or during
 255 an activity in the countryside (300 cases, 45.3%). Seven cases occurred on the public road. For
 256 the other cases (57 cases, 8.1%), the location or activity was unknown.

257 The majority of bites (502 cases, 75.8%) were the result of a fortuitous encounter with the animal.
 258 Only fifty-one patients (7.7%) were bitten while attempting to interact with the animal (e.g., to
 259 catch it, to photograph it). There was no significant difference between the two species regarding

260 the circumstances of bites ($p < 0.9$). However, bites in the countryside were significantly more
 261 frequently associated with *V. berus* than with *V. aspis* (55.4% vs. 42.7%, $p = 0.0314$).

262 3.3. Probability of being bitten at municipal level

263 The occurrence of a bite in the municipalities according to species characteristics, climate,
 264 resident and tourist population and land use is described in Table 1.

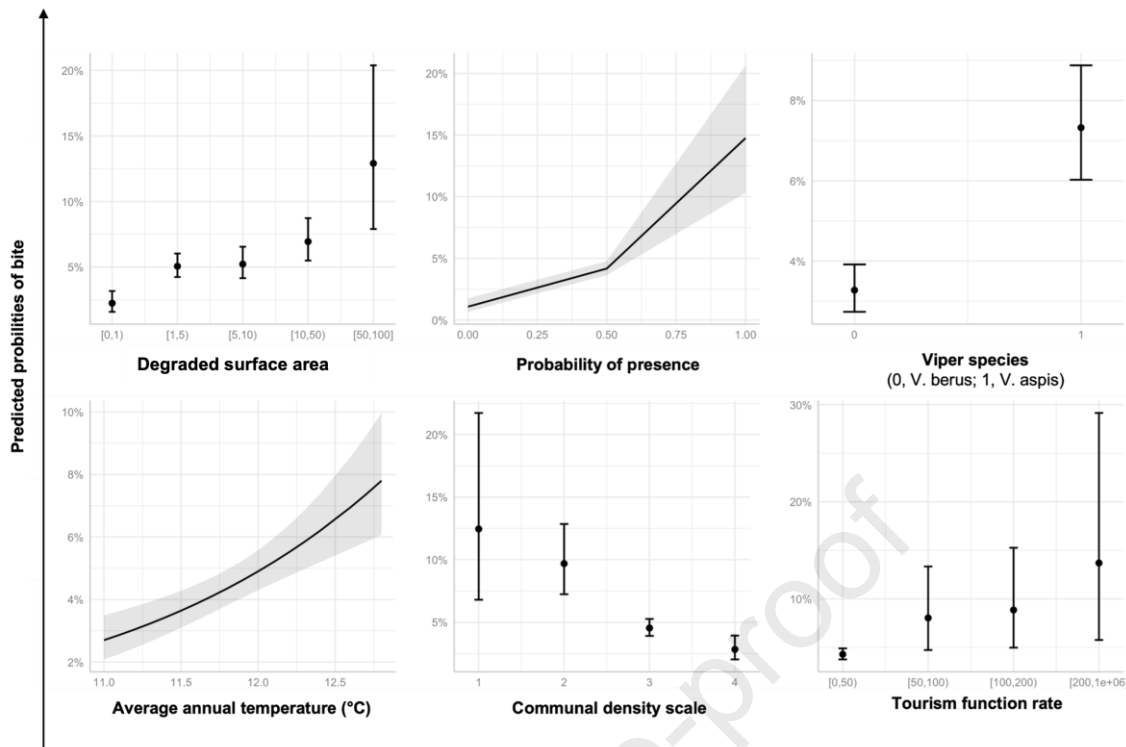
265 Table 1. Features of the municipalities in terms of species data, climate, tourist and resident population
 266 and land use, according to the occurrence or not of at least 1 bite in 10 years (OR: odd ratio, Ref: variable
 267 level take as reference). There are 6852 municipalities in the region of interest, of which 488 had 703
 268 bites.

269

Number of bites in the municipality in 10 years	None, N = 6364	At least one bite, N = 488	OR (95% CI)	p
Viper species				<0.001
<i>Vipera berus</i>	4,166 (65%)	185 (38%)	Ref.	Ref.
<i>Vipera aspis</i>	2,198 (35%)	303 (62%)	3.10 (2.57-3.76)	<0.001
Probability of viper presence	0.52 (0.13)	0.57 (0.13)	21.41 (10.29-44.89)	<0.001
Average daily sunshine duration (h)	5.02 (0.44)	5.25 (0.46)	3.58 (2.84-4.55)	<0.001
Average annual sunshine duration (h)	1,744.92 (150.90)	1,825.38 (154.14)	1.00 (1.00-1.00)	<0.001
Average annual temperature (°C)	11.79 (0.56)	12.21 (0.52)	3.88 (3.26-4.64)	<0.001
Annual average minimum temperature (°C)	7.69 (0.56)	8.01 (0.65)	2.82 (2.37-3.37)	<0.001
Annual average maximum temperature (°C)	16.59 (0.90)	17.11 (0.89)	2.04 (1.81-2.30)	<0.001
Tourist density (number of beds/km²)				<0.001
≤ 10	5,744 (90%)	331 (68%)	Ref.	Ref.
11 – 20	174 (2.7%)	38 (7.8%)	3.79 (2.59-5.42)	<0.001
21 – 50	217 (3.4%)	59 (12%)	4.72 (3.44-6.38)	<0.001
51 – 100	90 (1.4%)	24 (4.9%)	4.63 (2.85-7.24)	<0.001
> 100	137 (2.2%)	36 (7.4%)	4.56 (3.07-6.62)	<0.001
Tourism function rate (number of beds/100 inhabitants)				<0.001
< 50	6,170 (97%)	449 (92%)	Ref.	Ref.
50 – 99	103 (1.6%)	17 (3.5%)	2.27 (1.30-3.72)	0.002
100 – 199	67 (1.1%)	15 (3.1%)	3.08 (1.68-5.28)	<0.001
≥ 200	22 (0.3%)	7 (1.4%)	4.37 (1.72-9.80)	<0.001
Percentage of secondary residences	11.53 (11.39)	11.59 (14.37)	1.00 (0.99-1.01)	>0.9
Communal density scale				<0.001
High density	59 (0.9%)	25 (5.1%)	Ref.	Ref.
Medium density	431 (6.8%)	100 (20%)	0.55 (0.33-0.93)	0.022
Low density	4,434 (70%)	324 (66%)	0.17 (0.11-0.28)	<0.001
Very low density	1,439 (23%)	39 (8.0%)	0.06 (0.04-0.11)	<0.001
Artificial development of land (% of municipal area)				<0.001
< 1%	1,847 (29%)	35 (7.2%)	Ref.	Ref.
1 – 4%	2,176 (34%)	167 (34%)	4.05 (2.84-5.95)	<0.001
5 – 9%	1,186 (19%)	96 (20%)	4.27 (2.91-6.41)	<0.001
10 – 49%	1,055 (17%)	152 (31%)	7.60 (5.29-11.23)	<0.001
≥ 50%	99 (1.6%)	38 (7.8%)	20.26 (12.27-33.58)	<0.001
Continuous urban fabric				<0.001

< 1%	6,328 (99%)	440 (90%)	Ref.	Ref.
≥ 1%	36 (0.6%)	48 (9.8%)	19.18 (12.35-30.04)	<0.001
Heterogeneous agricultural areas				<0.001
< 25%	5,078 (80%)	322 (66%)	Ref.	Ref.
25 – 49%	1,078 (17%)	145 (30%)	2.12 (1.72-2.60)	<0.001
≥ 50%	208 (3.3%)	21 (4.3%)	1.59 (0.97-2.47)	0.049
Industrial, commercial and transport units				<0.001
< 5%	6,022 (95%)	396 (81%)	Ref.	Ref.
≥ 5%	342 (5.4%)	92 (19%)	4.09 (3.17-5.24)	
Arable land				<0.001
< 25%	1,645 (26%)	199 (41%)	Ref.	Ref.
25 – 49%	2,014 (32%)	170 (35%)	0.70 (0.56-0.86)	<0.001
≥ 50%	2,705 (43%)	119 (24%)	0.36 (0.29-0.46)	<0.001
Pastures				<0.001
< 25%	4,147 (65%)	389 (80%)	Ref.	Ref.
25 – 49%	1,392 (22%)	75 (15%)	0.57 (0.44-0.74)	<0.001
≥ 50%	825 (13%)	24 (4.9%)	0.31 (0.20-0.46)	<0.001
Discontinuous urban fabric				<0.001
< 10%	5,352 (84%)	304 (62%)	Ref.	Ref.
10 – 24%	772 (12%)	117 (24%)	2.67 (2.12-3.34)	<0.001
25 – 49%	184 (2.9%)	53 (11%)	5.07 (3.63-6.98)	<0.001
≥ 50%	56 (0.9%)	14 (2.9%)	4.40 (2.33-7.77)	<0.001
Artificial, non-agricultural vegetated areas				<0.001
< 5%	6,256 (98%)	466 (95%)	Ref.	Ref.
≥ 5%	108 (1.7%)	22 (4.5%)	2.73 (1.67-4.28)	<0.001
Mine, dump and construction sites				0.035
< 1%	6,090 (96%)	457 (94%)	Ref.	Ref.
≥ 1%	274 (4.3%)	31 (6.4%)	1.51 (1.01-2.18)	0.035
Permanent crops				<0.001
< 5%	6,206 (98%)	450 (92%)	Ref.	Ref.
≥ 5%	158 (2.5%)	38 (7.8%)	3.32 (2.27-4.73)	<0.001
Scrub and/or herbaceous vegetation associations				<0.001
< 5%	6,123 (96%)	454 (93%)	Ref.	Ref.
≥ 5%	241 (3.8%)	34 (7.0%)	1.90 (1.29-2.72)	<0.001
Open spaces with little or no vegetation				>0.9
< 0.5%	6,357 (100%)	488 (100%)		
≥ 0.5%	7 (0.1%)	0 (0%)		
Wetlands				<0.001
< 5%	6,159 (97%)	445 (91%)	Ref.	Ref.
≥ 5%	205 (3.2%)	43 (8.8%)	2.90 (2.04-4.05)	<0.001
Waters				0.002
< 5%	6,148 (97%)	458 (94%)	Ref.	Ref.
≥ 5%	216 (3.4%)	30 (6.1%)	1.86 (1.23-2.72)	0.002

270 A first a priori model (model 0) was run to determine the variables that significantly affect the
271 risk of at least one bite occurring in the period considered (see Supplementary Material 1). We
272 also introduced a first notion of land use represented by the artificial transformation of the soils.
273 It was found significantly ($p < 0.001$) that as the proportion of degraded land in the municipality
274 increased, so did the risk of at least one bite occurring there. The effect of the model 0 variables
275 on the predicted probability of bite is summarized in Figure 2.



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Figure 2. Effect of model 0 variables (a priori) on the predicted probability of bite, in 10 years.

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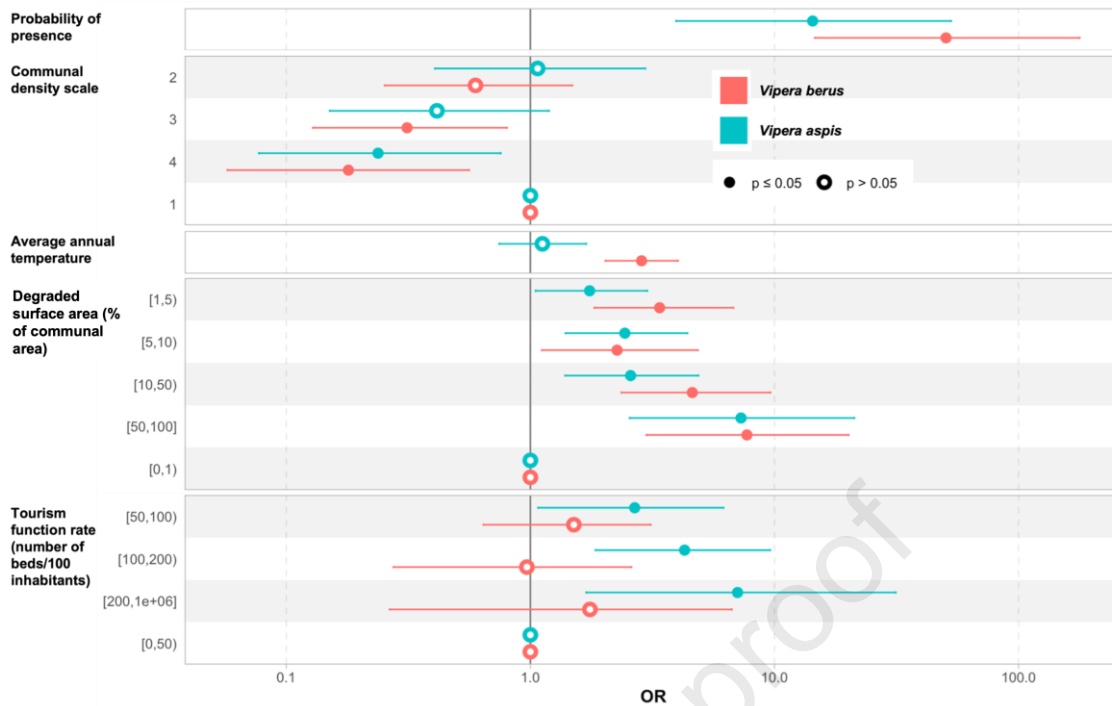
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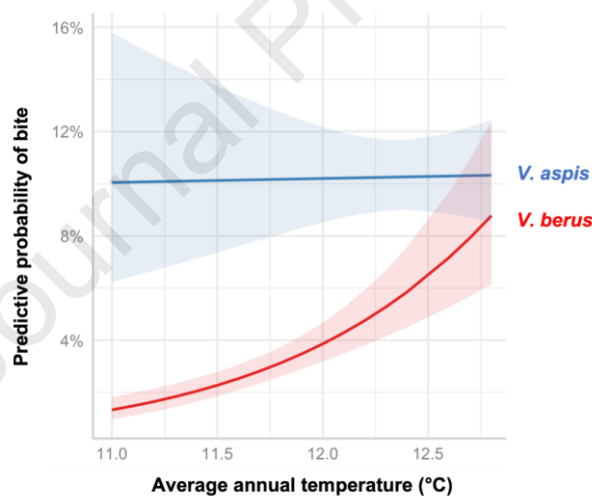
An a priori model (model 1) with the detailed land-use items (according to CLC) and the search for complementary explanatory variables by a LASSO type model (model 2) and a model based on a selection algorithm (model 3) were carried out (see Supplementary Material 1). We also introduced land use variables in model 1, namely the part of continuous urban fabric and the part of heterogeneous agricultural environment. Models 2 and 3 also retained these variables, while identifying others (part of discontinuous urban fabric and arable land).

Given the OR value of the species variable, we analyzed two data subgroups corresponding to the two species. On each of these data subgroups, we applied an a priori model, using the variables of model 0 (Figure 3). The risk of being bitten increased with snake probability of presence but the effect was stronger in *V. berus* than *V. aspis* (OR = 50.4 vs 14.3). The ORs are similar for the communal density grid and artificial development of land variables. However, there was a difference between the two species for the mean annual temperature variable, with the OR being significantly different from 1 (2.86) only for *V. berus*. We confirmed that by demonstrating a significant interaction ($p < 0.001$) between the species variable and annual mean temperature in model 0 (OR=0.34) (Figure 4). Finally, the tourist function rate does not seem to significantly influence the risk of being bitten by *V. berus*, whereas its increase is a favourable factor in the case of *V. aspis*.



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Figure 3. Comparison of the odd ratios (OR) of the variables used in model 0 according to the most likely species in each commune.



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Figure 4. Effect of the interaction between mean annual temperature and viper species on bite probability.

300 3.4. Determinant of bite numbers

301 Model 4 (Zero-Inflated Negative Binomial) indicates that none of the independent variables tested
 302 appear to affect the number of structural zeros, i.e. whether or not zero bite observations are part
 303 of the counting pattern. In contrast, according to Model 5 (Hurdle Negative Binomial), in the
 304 presence of *V. aspis*, when the probability of viper presence is high and when the mean annual
 305 temperature increases, it becomes more likely that at least one bite is observed (see
 306 Supplementary Material 2). In both models, the risk of a higher number of bites increases
 307 significantly with an increase in the degraded surface area (from more than 10% in model 5, and

308 even 1% in model 4), and decreases when the communal density decreases (low-density and very
309 low-density communes). In model 4, the increase in the probability of the presence of vipers as
310 well as the increase in the tourist function rate above 100 beds/100 inhabitants positively
311 influences the number of bites.

312 **4. Discussion**

313 Snake bites resulting from human-animal encounters vary both seasonally and geographically. To
314 our knowledge, this study is the only one to develop a spatially informed approach to the risk of
315 viper bites, in four regions where the risk seems to be the highest in France (Jollivet et al., 2015).
316 As expected, viper's probability of presence extracted from correlative modelling at the
317 municipality level positively influenced the risk of being bitten (multiplied by 3 for a variation in
318 probability of 0.25 from 0.5). This variable also explained the variation in the number of bites as
319 shown by the counting statistic models. Bites were more frequent in Pays de la Loire than in
320 Centre region and more frequent in Bretagne than in Normandie.

321 The period of highest activity for vipers in the summer, especially for males and breeding
322 females. Accordingly, the peak of bites occurs in June and July. Winter bites are exceptional and
323 are most likely the result of animals being disturbed in their winter retreat. Regarding climatic
324 conditions, it has already been shown that temperature and solar radiation parameters have a
325 strong influence on the probability of presence of vipers in the region, with a strong contrast
326 between the two species. The adder is able to withstand relatively cold weather conditions when
327 compared to the asp viper (Lourdais et al., 2013). Our logistic regressions show that the mean
328 annual temperature played a significant role in the bite risk (a variation of +1°C multiplies the
329 risk by 1.83 to 1.92 depending on the model). There was a significant interaction between species
330 and mean annual temperature. Interpreting the interaction with reference to how temperature
331 affected the species variable, the risk of biting by *V. aspis* appeared to be constant while it
332 gradually increased for *V. berus*. This result must be tempered with our own observations of bites,
333 which occurred at rather milder temperatures, and on average lower in municipalities where *V.*
334 *berus* is predominant. This result likely reflects contrasted thermal ecology between the two
335 species (Lourdais et al., 2013).

336 Habitat is an important variable in explaining the distribution of the asp viper and adder
337 (Gentilli et al., 2011; Guillon, 2012). We therefore expect the risk of bites to follow the same
338 trends. The hedgerow landscape is an important part of the living environments of both species,
339 as they are rich in hedgerows. Snakes appreciate hedgerows for their richness in prey and for their
340 numerous refuges, as well as for the herbaceous margin at the foot of the hedge used for basking
341 activities (Lourdais et al., 2015). In France, a land-use study of *V. aspis* observation stations
342 carried out in Burgundy showed that dry grasslands, but also semi-open environments

343 (corresponding in particular to fallow lands or other bushy areas) have the highest levels, clearly
344 above those of the study sample or their regional share (Varanguin and Sirugue, 2012). Thus,
345 municipalities where associations of hedgerows or edges, but also perennial crops (only in
346 univariate analysis) exceed 5% of the territory have an increased risk of being bitten, as compared
347 to municipalities where the territory is composed of meadows or arable land, which are open
348 environments. In general, *V. berus* prefers herbaceous and more humid microhabitats (Guillon et
349 al., 2014). It is often found in peat bogs, rocky pastures and wet meadows (Dewynter, 2011).

350 In support with our hypothesis, we have also shown that soil transformation had a positive
351 effect on the risk of bites. In the same way, the more the land is artificially modified, the more
352 the number of bites increases. Using a land-use approach, we observed the same trend: denser
353 urban cover increased the risk of bites. Similarly, the lower the municipal density, the lower the
354 bite risk. It has already been shown in northern Italy (Lombardy) that urban areas have a highly
355 positive effect on the presence of the asp viper (compared to the adder). One hypothesis put
356 forward by the authors of this study is that urban areas constitute thermophilic habitats that could
357 be selected by the asp viper (Gentilli et al., 2011). Heat-storing solid and rocky substrates
358 (including asphalt) are good places for thermoregulation (Varanguin and Sirugue, 2012). The
359 presence of traffic routes (streets, car parks, in industrial and commercial areas) and waste dumps
360 or areas under construction (only in the univariate approach) are thus factors that increased the
361 risk of a bite occurring in our series. The 7 cases of bites on the public highway illustrate this.
362 However, dense cities do not represent a habitat of choice for these animals and the positive effect
363 would only be due to similar "ecological preferences" on the part of vipers and humans (Gentilli
364 et al., 2011). We found that more than half of the bites occurred in the individual homes (terrace,
365 lawn) during a garden-related activity (weeding, mowing, playing in the lawn, etc.), which would
366 indicate municipalities with many greenery areas, both individual (private gardens, vegetable
367 gardens) and public.

368 The convergence of habitats selection should favour human/wildlife encounters (König
369 et al., 2020; Soulsbury and White, 2015). The coastal towns of the Pays de la Loire and Brittany
370 and the preserved agricultural landscapes (Vendée bocage in the Pays de la Loire) are areas of
371 tourist attraction. The municipalities with a high tourist function are concentrated on the coast
372 and in the mid-mountain areas. Only 6% of the national population resides year-round in the 6,000
373 French municipalities with a tourist function rate of over 100 beds per 100 inhabitants, even
374 though these municipalities account for 60% of the supply of tourist beds (Gauche, 03/2017). The
375 increase in the tourism function rate above 50 beds/100 inhabitants is strongly associated with an
376 increase in the risk of occurrence and frequency of bites, whatever the statistical approach
377 considered (univariate, binomial or counting). Similarly, but only in the univariate approach, the
378 bites tended to take place in the communes with the highest proportion of second homes. Some
379 tourist activities, which are practiced in the summer, do favour encounters with snakes. Nearly

380 half of the bites were observed during an activity related to nature (hiking, camping) in the period
381 under consideration. When comparing the role of tourism pressure on the risk of bites for each of
382 the two species, it was only significant for *V. aspis*. Importantly, the reasoning we have adopted
383 also make the approximation that any encounter between man and animal results in a bite, which
384 is not necessarily the case. It depends on the behavioural traits of the species or the circumstances
385 of the human/animal encounter (Martín et al., 2022). Simple measure can be applied to minimize
386 bite risk from vipers since these shy animals will first respond to disturbance by feeling or using
387 display behavior. Bite is only the last defensive option, and notably when escape is not possible.
388 Overall, the viper bites recorded in our study are concentrated on the south coastline of Pays de
389 la Loire region, where *V. aspis* is the most likely species but also the area that is subject to the
390 greatest tourist pressure in our area of interest (in terms of the rate of tourist activity).

391 This study was carried out on data collected over a period of more than 10 years. This is a
392 relatively long period of time on the scale of the territory, during which the landscape of western
393 France may have undergone profound local changes, particularly in response to changes in
394 demography, agricultural practices and tourist demand (Godron and Forman, 1983). The same
395 applies to viper populations with both species showing important declines in the area in relation
396 with habitat degradation (Guiller et al., 2022). The adder seems to be much more sensitive than
397 the asp viper to landscape transformations, such as cultivation, pine forestation or the drying up
398 of wetlands (Dewynter, 2011). Even though the asp viper is influenced by human activities that
399 reduce its colonization in some areas, it currently has a higher recolonization dynamic with a
400 greater degree of dispersion than the adder (Ursenbacher, 2005). The impact of climatic changes
401 and extreme weather events on the future distribution of the two species require specific attention.

402 Finally, precise knowledge of the municipalities where the risk of being bitten could be the
403 highest is of great interest because it allows public decision-makers to put in place measures to
404 prevent the public from being bitten and to protect areas where vipers are present. It can also be
405 a tool to better distribute antivenoms, expensive products for which shortages are possible (Boels
406 et al., 2020). However, care should be taken as this is a double-edged sword that could lead to the
407 desertion of tourists or worse to the destruction of vipers or their habitats.

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Key Messages:

- Even at a fine scale, the distribution of viper bites is inhomogeneous.
- The probability of viper presence and human population density are elements of the bite risk
- Tourist pressure and the scarcity of viper habitats condition the risk of bites.

Journal Pre-proof

Declaration of interests

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.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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