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## **Science communication is needed to inform risk perception and action of stakeholders**

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# 1 **Science communication is needed to inform risk perception and** 2 **action of stakeholders**

3

## 4 **Abstract**

5 Stakeholders are critical environmental managers in human-dominated landscapes.  
6 In some contexts, stakeholders can be forced to personally act following their own  
7 observations and risk perception instead of science recommendation. In particular,  
8 biological invasions need rapid control actions to reduce potential socio-ecological  
9 impacts, while science-based risk assessments are rather complex and time-  
10 delayed. Although they can lead to important detrimental effects on biodiversity,  
11 potential time-delayed disconnections between stakeholders' action and science  
12 recommendations are rarely studied. Using the case study of western European  
13 beekeepers controlling the invasive Asian hornet *Vespa velutina nigrithorax* for its  
14 suspected impact on honey bee colonies, we analysed mechanisms underlying  
15 personal actions of stakeholders and how they evolved in science disconnection.  
16 Personal actions of stakeholders were causal-effect linked with their risk observation  
17 but disconnected to time-delayed science predictions and recommendations.  
18 Unfortunately, these science-disconnected actions also led to dramatic impacts on  
19 numerous species of the local entomofauna. These results highlight the need to  
20 improve mutual risk communication between science and action in the early-stages  
21 of management plans to improve the sustainability of stakeholders' practices.

22

23 **Keywords:** Biological invasion; Citizen science; Honey bee mortality; Invasive  
24 species; Yellow-legged hornet

25

## 26 **1. Introduction**

27 The management of human-dominated landscapes involves the critical role of  
28 environmental managers, which represent a strong action and observation force  
29 (Shackleton et al., 2019a). Stakeholders can be defined as environmental managers  
30 who are affected by the decisions and actions they take, and who have the power to  
31 change their actions (Reed et al., 2009). Ideally, management plans should be  
32 established by environmental policies, following scientific risk assessment  
33 recommendations, and prior to stakeholders' opinion-based actions (Genovesi and  
34 Shine, 2004). However, the current rate of global changes can lead to time lags  
35 between the provided scientific recommendations and the emergency to act in the  
36 field. One common example implies biological invasions (Courchamp et al., 2017).  
37 Biological invasions have negative effects worldwide such as biodiversity loss and  
38 species extinctions and can threaten economy and public health (Bellard et al., 2017;  
39 Courchamp et al., 2017; Cole et al., 2019). Invasive alien species management  
40 implies three types of action: preventing the invasion from occurring (e.g. public  
41 awareness and border control of global market), reducing the impact magnitude (e.g.  
42 by controlling the expansion range through individual trapping or population  
43 eradication programs), or repairing the damages (e.g. restoration programs)  
44 (Bradshaw et al., 2016). The choice of the management plan depends on the  
45 invasion stage and the results from risk assessment studies (Campbell et al., 2015).  
46 Nevertheless, assessing the potential risk of a newly introduced alien species is  
47 extremely complex and time consuming; it depends on a combination of co-  
48 evolutionary processes, population dynamics, complex interspecific relationships,  
49 abiotic changes, and anthropogenic impacts (Liu et al., 2007; Heger et al., 2013;  
50 Shackleton et al., 2019b). Consequently, some studies have showed that risk

51 assessment estimations can be time-shifted in regard to the rapid need –real or  
52 perceived– of stakeholders to take actions and control alien species (e.g. Matzek et  
53 al., 2015). Although stakeholders’ risk perception and actions should be related to  
54 previously emitted science recommendations (Genovesi and Shine, 2004), the time  
55 gap without established scientific risk assessment can force stakeholders to  
56 personally make decision and act following their own observations and risk  
57 perception.

58 Risk perception consists in the importance that individuals give to an at-risk  
59 situation (Lamarque et al., 2011; Dewitt et al., 2015; Shackleton et al., 2019b). It is  
60 known that risk perception is determined by different social and environmental factors  
61 affecting individuals, such as the degree of knowledge they have and/or the  
62 environment in which they evolve (Martín-López et al., 2012). In the case of humans,  
63 someone’s perception of an environmental risk will vary according to their relation to  
64 nature (i.e. hobby and/or professional activity dependent on nature) and the amount  
65 of knowledge obtained through communication networks (Martín-López et al., 2012;  
66 Shackleton et al., 2019b). Accordingly, risk perception of biological invasions can be  
67 radically different between citizens or even cause conflicts among them (Estévez et  
68 al., 2015; Tassin and Kull, 2015). This is the case, for example, of many tree species  
69 introduced massively around the world for forest production or aesthetic reasons.  
70 These introductions, which have sometimes led to invasions, crystalize sharp  
71 conflicts of interest between naturalists –aware of the environmental impacts of these  
72 exotic tree species– and forest managers (Dickie et al., 2014). Although the drivers of  
73 stakeholders’ risk perception have been studied, the ways in which they decide to  
74 personally act in a science-disconnected context is still an open question.

75           In this study, we analysed the mechanisms underlying personal actions of  
76 stakeholders and how they evolved in a science-disconnected context. We used the  
77 case study of western European beekeepers controlling the invasive Asian hornet  
78 *Vespa velutina nigrithorax* (also called the Yellow-legged hornet) for its suspected  
79 impacts to their professional activity. First observed in 2004 in Southwest France, this  
80 species has rapidly spread across most of the French territory (Villemant et al., 2011;  
81 Robinet et al., 2017), and it has then established successively in several  
82 neighbouring countries, e.g. Belgium, Germany, Italy, the Netherlands, Portugal,  
83 Spain and the United Kingdom (Robinet et al., 2018; Rome and Villemant, 2019).  
84 The Asian hornet captures foraging western honey bees (*Apis mellifera*) at the  
85 beehive entrances during the critical pre-wintering season for honey bee colonies,  
86 and therefore may represent an additional risk factor involved in the winter mortality  
87 of currently declining bee colonies (Leza et al., 2019; Requier et al., 2019a). Western  
88 honey bees are currently declining (Potts et al., 2010; Goulson et al., 2015; Requier  
89 et al., 2018), a phenomenon manifested by high bee colony mortality rates during  
90 winter (Neumann and Carreck, 2010), and likely due to a combination of multiple  
91 stresses including parasites, pesticides, and lack of flowers (Potts et al., 2010;  
92 Goulson et al., 2015; Henry et al., 2017).

93           The Asian hornet, an additional risk factor for honey bees, has alarmed  
94 western European beekeepers and has motivated the rapid development of control  
95 methods over the past years (Turchi and Derijard, 2018). The use of passive traps  
96 with homemade syrup or poisoned (with insecticide) baits was the most common  
97 method used for the control of the Asian hornet (Rome et al., 2011; Rojas-Nossa et  
98 al., 2018). However, the risk from Asian hornet predation on honey bees has only  
99 recently been assessed (Requier et al., 2019a). This delayed estimation has

100 postponed the spread of the science recommendations to control this risk (Requier et  
101 al., 2019a; but see also some general recommendations of management delivered  
102 before: French ministry of Agriculture, 2013). Therefore, western European  
103 beekeepers have mainly followed their own observations and perception of Asian  
104 hornet-related risk to assess the necessity to put into place management actions for  
105 the last 15 years. This time delay between beekeepers' action and scientific  
106 recommendations represents a great opportunity to analyse how risk perception and  
107 personal action of beekeepers (so-called stakeholders thereafter) evolved in a  
108 science-disconnected context.

109         We performed a national-wide stakeholder-based survey to record beekeepers  
110 risk observation, perception and personal actions taken against the Asian hornet over  
111 the French territory and prior to the first Asian hornet scientific risk assessment  
112 publication (Requier et al., 2019a). We then estimated the risk of honey bee colony  
113 mortality and the associated management action recommendations, based on a  
114 combination of science-based citizen science programs recording the presence of  
115 the risk factor (based on Rome and Villemant, 2019) and predicting colony mortality  
116 (based on Requier et al., 2019a). This information was then compiled to: (i) evaluate  
117 the causal links underlying drivers of stakeholder risk perception and action in a  
118 science-disconnected context, and (ii) analyse whether risk observation, perception  
119 and personal action of stakeholders are connected to post-assessed science  
120 predictions and recommendations. Moreover, given that accumulated evidences  
121 showed that trapping the Asian hornet does not represent a biodiversity-friendly  
122 control method and leads to the catch of non-targeted insect species (Rome et al.,  
123 2011; Rojas-Nossa et al., 2018; Turchi and Derijard, 2018; Requier et al., 2019b), we



124 finally discussed how biodiversity (i.e. the local entomofauna) can be affected by the  
125 potential science-disconnected personal actions.

126

## 127 **2. Methods**

128

### 129 ***2.1. Long-term citizen science program of Asian hornet nest record***

130 Since the introduction of the Asian hornet in France in 2004, a citizen science  
131 program has been implemented at a national scale to record its invasion range. For  
132 that, a web-platform was designed by the French National Museum of Natural History  
133 (Rome and Villemant, 2019), inviting people to register observations (i.e. nests and  
134 individuals), associated with a picture to proof the identity of the Asian hornet and the  
135 location of the observation. A taxonomist carefully approved all of the valid  
136 observations and excluded those without supporting proofs or based on other  
137 species (e.g. *Vespa crabro*, the native European hornet) (Rome and Villemant,  
138 2017). The location of Asian hornet nests were then recorded in the French national  
139 biodiversity database (INPN) over the 2004 to 2019 years (Rome and Villemant,  
140 2019), however, we restricted the dataset to the 2004 to 2013 period for the aim of  
141 this study, in order to match the other datasets (see below). This database provided  
142 10,379 records of Asian hornet nests. We finally computed the sum of nests detected  
143 per township to get a single data at the municipality area scale, which is the spatial  
144 resolution of the study.

145

### 146 ***2.2. Estimating the Asian hornet risk for managed honey bees***

147 We defined the Asian hornet risk as density dependant in both the predator  
148 abundance (i.e. the number of nests recorded) and the prey abundance (i.e. the

149 number of honey bee colonies). Whilst the predator abundance was previously  
150 recorded through the citizen science program (see above), we used the national-wide  
151 dataset of honey bee livestock from the French ministry of agriculture (French  
152 ministry of Agriculture, 2017) to calculate prey abundance. This database is based on  
153 mandatory beekeeper declarations of the number of honey bee colonies per  
154 township across the whole French territory. We obtained and therefore used the data  
155 from the year 2013. Overall, the dataset ranged from 0 to 2,377 honey bee colonies  
156 per township. We then computed a dilution factor of Asian hornet predation load  
157 according to the number of beehives per township. For that, we first converted the  
158 number of Asian hornet nests per township as a number of predating hornets (the  
159 risk factor *per se*). No information is yet available on the exact number of predating  
160 hornets per nest, however, we know that a nest of Asian hornets reaches in average  
161 3,000 individuals during the season of honey bee predation –from September to  
162 November– (Rome et al., 2015). We chose a conservative value of 1% of the Asian  
163 hornet nest population (i.e. 30 hornets) likely to predate simultaneously from a single  
164 nest on the beehives stock of the township. We then divided the number of predating  
165 hornets in a township by the number of managed colonies in the same area to  
166 estimate the Asian hornet load per beehive. This simple estimate is based on the  
167 hypothesis that hornets could reach any hive located in the same township from their  
168 nest. The flight range of hornets varies basically from 2 to 3 km (Rome and Villemant,  
169 2017; Kennedy et al., 2018) and could physiologically reach until 30 km (based on  
170 laboratory tests, Sauvard et al., 2018), while the mean size of a French townships is  
171 a 3.87 km side length square (varying from 3 to 75,780 hectares, with a mean area is  
172 1,500 hectares).

173

174 **2.3. Predicting the hornet-related risk of bee colony mortality**

175 We used the mechanistic BEEHAVE model (Becher et al., 2014) to assess the risk  
176 probability of honey bee colony mortality related to Asian hornet predation. We  
177 performed 1,000 simulations to predict the daily colony growth of a bee colony  
178 population from the beginning of January to the end of May of the following year. This  
179 time period was chosen to include a complete winter season. The model was  
180 calibrated following Becher et al.'s (2014) initial colony settings, for which four key  
181 colony parameters were modified to increase stochasticity in the predictions and to  
182 improve representativeness of real field-condition variability (Requier et al., 2019a).  
183 We followed Requier et al. (2019a) method to simulate hornet impacts in BEEHAVE,  
184 consisting in altering the two parameters "forager mortality" and "the maximal  
185 foraging distance allowed for the colony" during the day 240 (August 28<sup>th</sup>) to the day  
186 310 (November 6<sup>th</sup>). Along the 1,000 computed simulations, we gradually decreased  
187 the maximal foraging distance allowed for the colony from the default value of  
188 7,299 km per day down to 0 (no foraging activity), and we increased the forager  
189 mortality rate from the default value of 1.00e-05 to 2.00e-05. Thus, each simulation  
190 involved a level of hornet impact ranging from low (0 hornets predating) to high  
191 impact (more than 20 hornets predating at the beehive entrance). Simulations were  
192 further classified based on whether they predict colony collapse during winter.  
193 Collapse events were defined following the two thresholds from Becher et al. (2014):  
194 (i) simulations that predict a population size smaller than 4,000 adult bees during  
195 winter, and (ii) simulations that predict a total depletion of honey stock during winter.  
196 We then estimated the colony mortality probability related to Asian hornet predation  
197 in each township. This last step consisted in inferring the corresponding modelled

198 mortality risk to the estimated number of Asian hornets predated on the beehives for  
199 each township of the French territory.

200

#### 201 ***2.4. Estimating management recommendation***

202 We followed Requier et al.'s (2019a) recommendations suggesting the application of  
203 control methods only in case of high hornet loads (i.e. more than 13.3 hornets  
204 predated at the beehive entrance). Low hornet loads do not lead to foraging  
205 paralysis (i.e. the most important factor of hornet-related colony mortality), while the  
206 hornet-based risk only concerns previously weakened colonies. At high hornet loads,  
207 the hornet-based risk of bee colony collapse results in a foraging paralysis of the bee  
208 colony and subsequently an over-consumption of honey stocks reserved for  
209 overwintering (Requier et al., 2019a). Requier et al.'s (2019a) suggested that in such  
210 conditions, controlling the hornet loads around the beehives could decrease the  
211 number of hornets overflying and help bee colonies to conserve their foraging  
212 activity. Thus, science-based recommendations of control were provided in the  
213 townships where the estimated hornet loads exceeded 13.3. Otherwise  
214 recommendations deter stakeholders from control action.

215

#### 216 ***2.5. Stakeholder-based survey of risk observation, perception and personal*** 217 ***action***

218 We performed a stakeholder-based survey in 2013 (i.e. six years before the  
219 publication of the Asian hornet risk assessment including management  
220 recommendation, Requier et al., 2019a) to record the risk observation, perception  
221 and personal action of beekeepers against the Asian hornet over the French territory.

222 We first designed a standardized questionnaire to invite beekeepers to notify their  
223 activities, including 11 questions designed to record:

224 (1) *Site of the operation* – the names and zip code of the municipality where more  
225 than 50% of the colonies are placed.

226 (2) *Operation size* – the total number of honey bee colonies managed at the date  
227 of the survey.

228 (3) *Education* – The starting year of beekeeping activity was asked. Education was  
229 then estimated as the number of years of beekeeping practiced, which  
230 corresponds to the amount of time elapsed between the date of the survey  
231 and the start of this activity.

232 (4) *Risk factor observation* – Observation of Asian hornet nests in the landscape  
233 surrounding the operation (i.e. in a range of 500 m around the apiary; two  
234 categories: yes or no)

235 (5) *Risk observation* – Observation of Asian hornet predating honey bees at the  
236 beehive entrance (two categories: yes or no)

237 (6) *Total winter mortality* – the total number of colonies dead during the winter  
238 season of 2009-2010, 2010-2011 and 2011-2012

239 (7) *Presumed hornet-related winter mortality* – The number of colonies dead,  
240 presumably due to the predatory behaviour of the Asian hornet during the  
241 winters of season of 2009-2010, 2010-2011 and 2011-2012. The risk  
242 perception was then estimated as the proportion of colonies lost due to the  
243 Asian hornet relatively to the total number of colonies lost, and then yearly  
244 averaged (**Figure 1**).

245 (8) *Personal action* – The setting up of control method of the Asian hornet using  
246 traps (two categories: yes or no).

247 (9) *Trap number* – If (8) is yes, the number of traps established in the whole  
248 operation.

249 (10) *Trap design* – If (8) is yes, the type of trap used. Then summarized in two  
250 categories: commercial or home-made trap.

251 (11) *Bait composition* – If (8) is yes, the type of bait used. Then summarized in two  
252 categories: commercial or home-made-bait.

253 The questionnaire was then distributed in June of 2013 over the French territory  
254 through beekeeping social networks and national beekeeping journals. In particular, it  
255 was published in four national journals of beekeeping and entomology and was also  
256 available online across various web-platforms (e.g. the Asian hornet dedicated  
257 website of Tours university and beekeeping websites from provinces of Gironde,  
258 Dordogne and Indre et Loire). The beekeepers had until December of 2013 to send  
259 their answers, date of end of the survey. After a post-validation procedure was set (to  
260 exclude incomplete answers: 18 respondents), the responses of the 401 remaining  
261 respondents were used to analyse the drivers of beekeepers' action against the  
262 Asian hornet, and the relationship with science predictions. The responses came  
263 from beekeepers who were distributed throughout the whole country (**Figure 1**).

264

## 265 ***2.6. Testing the role of social, environmental and economic contexts***

266 Social, environmental and economic contexts can affect perception and actions of  
267 stakeholders (Martín-López et al., 2012). Such factors can also affect scientific  
268 predictions, given their role in biological invasion, in particular in the case of the  
269 Asian hornet (e.g. Robinet et al., 2017). We used the CORINE (Coordination of  
270 Information on the Environment) Land Cover 2012 dataset to record the  
271 environmental context for each township (European Environment Agency, 2010).

272 This dataset is characterized by a high spatial resolution (i.e. 100 m<sup>2</sup>) and is  
273 composed of 44 different land cover classes (hereafter habitat), each belonging to  
274 one of the four following broad categories: artificial surfaces (urban, roads, industrial  
275 units, etc.), agricultural areas (non-irrigated arable land, pastures, fruit trees, etc.),  
276 natural areas (coniferous forest, bare rocks, etc.) and wetlands and marine areas  
277 (estuaries, salines, etc.). Based on Fournier et al. (2017), we only retained the  
278 categories identified as suitable habitat to the Asian hornet, and computed the  
279 proportion of these habitats per township. We used the national-wide dataset of  
280 human population from the French ministry of agriculture (French ministry of  
281 Agriculture, 2017) to record the number of people living in each township as an  
282 indicator of the social context. Indeed, the number of people living in an area could  
283 positively affect the probability to detect a nest, but could also influence stakeholder's  
284 personal actions through social interaction and group making decision (Traves et al.,  
285 2004; Behdarvand et al., 2014). Finally, we used the number of managed honey bee  
286 colonies per township (see above, French ministry of Agriculture, 2017) as an  
287 estimate of economic beekeeping level.

288

## 289 ***2.7. Statistical analyses***

290 All statistical analyses were performed using the R Project for Statistical Computing  
291 version 3.3.3 (R Development Core Team, 2018).

292 *Identifying causal links underlying drivers of stakeholder risk perception and*  
293 *personal action.* We used path analyses (Shipley, 2009) to disentangle direct and  
294 indirect effects along the chains from risk observation to control action. Path analysis  
295 helps to disentangle the most plausible direct and indirect links in multivariate  
296 datasets by assessing conditional independence among indirectly linked variables.

297 We applied the path analysis using the *PiecewiseSEM* R-package (Lefcheck, 2016).  
298 We first selected scientific predictions for all townships where we had collected  
299 beekeeper answers from the survey (n = 401, **Figure 1**). We then built a basic path  
300 model that reproduced the mechanistic structure underlying stakeholder's action,  
301 linking risk factor observation (i.e. Asian hornet nest), risk observation (i.e. Asian  
302 hornet predating at the beehive entrance), risk perception (i.e. the proportion of  
303 colonies lost due to the Asian hornet) and personal action of stakeholders  
304 (application of control methods).

305 *Analysing the link between risk observation, perception and personal action of*  
306 *stakeholders and post-assessed science predictions and recommendations.* We built  
307 a similar basic path model that reproduced the mechanistic structure underlying  
308 science-predicted action recommendations, linking the risk factor (Asian hornet nest  
309 inventory), risk identification (predicted number of hornets predating at beehive  
310 entrance), risk estimation (predicted hornet-related colony mortality) and the science-  
311 based recommendations of management (recommendation of control). We then  
312 analysed the relationship between stakeholder data and science prediction (e.g. risk  
313 factor observation and risk factor inventory, respectively) to test for potential  
314 correlations. Each causal link in the path model was depicted as a linear model (LM)  
315 or a generalized linear model (GLM), using *lm* and *glm* function in the *base* R-  
316 package respectively, depending on the nature of the involved variables. We used  
317 GLMs with a binomial error structure for risk factor observation, the risk observation,  
318 the personal action of stakeholders, and the science-based recommendation. We  
319 used LMs with Gaussian error structure for other variables. All variables were  
320 standardized using *Z* scores, and the normal distribution of residuals of each model  
321 was checked. We then identified the simplest path model structure that did not



322 deviate from the conditional independence expectations while including only  
323 significant links. The path analysis showed consistent causal links along and  
324 between the two chains from risk observation to control action, with indirect links that  
325 did not significantly deviate from conditional independency requirements (Fisher's  $C$   
326 = 35.27,  $P = 0.823$ ; **Figure 2**). Coefficients and detailed  $P$  values underlying the path  
327 analysis are presented in the online Supplementary Materials (**Appendix S1**).

328

329 *Effect of stakeholder actions on biodiversity.* We first evaluated the efficiency  
330 of trapping (i.e. the control action from stakeholders) on the targeted trapping of  
331 Asian hornet. For that we fit a GLM with a binomial error structure to test the logistic  
332 link between the number of traps established (log-transformed) and the collection of  
333 Asian hornets as a binary variable (yes = 1 or no = 0). We then evaluated the effect  
334 of trapping on the collection of non-targeted entomofauna (e.g. European hornet,  
335 other Vespidae, the Western honey bee *Apis mellifera*, Diptera, Lepidoptera, other  
336 insects). Thus, we fit a second GLM with a binomial error structure to test the logistic  
337 link between the number of traps established (log-transformed) and the collection of  
338 other insects than the Asian hornet as a binary variable (yes = 1 or no = 0). The  
339 model residuals were extracted and inspected against fitted values (residuals vs.  
340 fitted plot and normal Q-Q plot) to ensure the residual normality and the  
341 homoscedasticity assumptions were fulfilled.

342

### 343 **3. Results**

344

#### 345 **3.1. Drivers of stakeholder risk perception and personal action**

346 Among the chain from risk observation to control action of stakeholders, the most  
347 notable links were between risk factor observation, risk observation and personal  
348 action (**Figure 2**). Following the causal links, the personal action of stakeholders (the  
349 carried out of trapping) was positively affected by the risk observation (i.e. the  
350 observation of Asian hornet predating at the beehive entrance), and the risk factor  
351 observation (i.e. the observation of Asian hornet nests in the surrounding landscape  
352 of the apiary). The risk perception (i.e. the predicted hornet-related colony mortality)  
353 was positively affected by the risk observation but was not linked with the personal  
354 action. Finally, the social context (i.e. the number of people in the township) had a  
355 direct negative effect on the risk factor observation, and an indirect negative effect on  
356 the risk observation (**Figure 2**).

357

### 358 ***3.2. Links between risk observation, perception and personal action of*** 359 ***stakeholders and post-assessed science predictions and recommendations***

360 On the other hand, the causal links showed that the science-based recommendation  
361 of control action was positively affected in cascade by the risk estimation (i.e. the  
362 predicted hornet-related colony mortality), the risk identification (i.e. the predicted  
363 number of hornets predating at beehive entrance), and the risk factor inventory (i.e.  
364 the inventory of Asian hornet nests). The environmental context (the suitable habitat  
365 for the Asian hornet) had a direct positive effect on the risk factor inventory, and an  
366 indirect positive effect on the risk observation (**Figure 2**). In turn, the economic  
367 context (the number of managed beehives per township) had an indirect negative  
368 effect on the risk estimation. Such effects underlying the chain from risk factor  
369 inventory to control action recommendation confirm the integration of the science-  
370 based estimate processes in the path analysis.

371 Interestingly, the two chains (stakeholder and science) were linked between  
372 risk factor observation and risk factor inventory, and between risk observation and  
373 risk identification (**Figure 2**), suggesting that stakeholder's observation are in  
374 accordance to science-based inventories and estimates (**Appendix S1**). However,  
375 the risk perception and the personal action of the stakeholders were disconnected to  
376 time-delayed science prediction (**Figure 1**), suggesting that beekeepers had  
377 inaccurate perceptions of the Asian hornet risk and carried out trapping action when  
378 it was not needed, and vice versa (**Appendix S1**).

379

### 380 **3.3. Effect of stakeholder actions on biodiversity**

381 A total of 63.3% of the respondents (n = 274) carried out trapping of the Asian  
382 hornets. Based on stakeholder responses, the frequency of occurrence of trapped  
383 Asian hornets varied from 80% to 100% depending on the trap design and bait  
384 composition (**Figure 3**). The most efficient combination was the home-made trap  
385 (based on plastic bottle) with commercial bait (Vétopharma® bait). However, this  
386 combination was also highly performing to trap the native European hornet *Vespa*  
387 *crabro* (*i.e.* with the same catch efficiency than that of the Asian hornet (**Figure 3**)).  
388 Unfortunately, all combinations of trap designs and bait compositions led to  
389 detrimental effects on the non-targeted entomofauna, including honey bees in the  
390 cases of home-made traps filled with home-made bait (e.g. with wine, sugar, beer)  
391 and commercial trap (Vetopharma® bait) filled with commercial bait (**Figure 3**). In  
392 average, the beekeepers used 7.4 traps on their operation, ranging from 1 to 180  
393 traps. Although the establishment of a single trap led to less than 50% chances to  
394 catch the targeted Asian hornet, setting up more traps led to a strong increase of this  
395 probability (n = 274,  $Z = 5.530$ ,  $P < 0.001$ ; **Figure 4a**). However, also based on

396 stakeholder response, the number of traps did not affect the probability to catch other  
397 non-targeted insect species ( $n = 274$ ,  $Z = 0.478$ ,  $P = 0.632$ ; **Figure 4b**), with a  
398 significant high probability ( $> 90\%$ ) to trap non-targeted entomofauna (model  
399 intercept:  $Z = 5.126$ ,  $P < 0.001$ , **Figure 4b**).

400

#### 401 **4. Discussion**

402 Stakeholders manage the environment in human-dominated landscapes, ideally  
403 following management plans that were previously established by science-based  
404 environmental policies. Here, we showed that beekeepers had to personally act  
405 following their own observations and risk perception (the risk of bee predation by the  
406 Asian hornet) instead of following scientific recommendations that were time delayed.  
407 Their personal actions were related to their observations of the risk, but not related to  
408 their risk perception (i.e. the presumed hornet-related colony mortality). The result  
409 suggests that they practiced control action as preventive measures even in contexts  
410 where they did not perceive any direct risk for their production. While the risk  
411 observations were in accordance with science-based estimates, their risk perception  
412 and personal actions were disconnected to time-delayed science predictions and  
413 recommendations. These results suggest that beekeepers perceive a risk when there  
414 is none and vice versa, and act when it is not necessary in contexts of science  
415 disconnection (e.g. trapping action in absence of hornet nests in the surrounding  
416 landscape). Unfortunately, these science-disconnected actions also lead to important  
417 impacts on local biodiversity. Trapping actions lead to the catch of non-targeted local  
418 entomofauna, already threaten by many factors and critically declining (Sánchez-  
419 Bayo and Wyckhuys, 2019).

420 This work highlights that stakeholders' risk perception and personal action did  
421 not follow a biodiversity-friendly approach in a science-disconnected context. The  
422 general recommendations made before any formal risk assessment study were not  
423 sufficient to inform or to raise stakeholders' awareness concerning the detrimental  
424 effects on biodiversity to trap Asian hornets. A potential explanation could be that  
425 stakeholders applied control methods for the purposes of risk prevention. Indeed, the  
426 Asian hornet was rapidly predicted as likely to expand all over the French territory as  
427 well as to eventually spread further in Western Europe (Villemant et al., 2011). Yearly  
428 records of the expansion range of the Asian hornet have confirmed the rapid spread  
429 of this invasive species over the French territory (Rome and Villemant, 2019) and  
430 further in the neighbouring European countries (Rome and Villemant, 2019). This  
431 could affect stakeholder's risk perception towards the requirement of control actions  
432 even if the risk factor is not yet present in an area, and even with methods that may  
433 be detrimental for biodiversity. Indeed, the common use of simple passive traps with  
434 homemade syrup or poisoned baits are known to fail to sustainably reduce the  
435 populations of Asian hornets (Beggs et al., 2011; Turchi and Derijard, 2018) and  
436 represent a low-efficiency method to control Asian hornet-related impacts on honey  
437 bees (Monceau et al., 2012 ; Requier et al., 2019a,b). Although the environmental  
438 impacts of common trapping on the numerous species of the local entomofauna was  
439 established before the risk assessment study (e.g. Dauphin and Thomas, 2009;  
440 Beggs et al., 2011; Rome et al., 2011), more biodiversity-friendly methods are now  
441 tested and/or available for beekeepers. For instance, more species-specific trapping  
442 systems based on sex pheromone attraction are currently in process of development  
443 and could allow the specific catch of the Asian hornet without trapping other insects  
444 (Couto et al., 2014; Cheng et al., 2017; Gévar et al., 2017; Wen et al., 2017; Turchi

445 and Derijard 2018). Moreover, the use of beehive muzzle –a mesh placed around the  
446 beehive’s flight board allows bee workers to continue foraging even in the presence  
447 of hovering hornets– can reduce the foraging paralysis and thus positively affects the  
448 survival of hornet-stressed colonies (Requier et al., 2019b). Given the multiple  
449 evidences of negative effects in the use of common trapping methods on the local  
450 entomofauna (Rome et al., 2011; Rojas-Nossa et al., 2018; Turchi and Derijard,  
451 2018; Requier et al., 2019b) that the present study confirms, we recommend that  
452 beekeepers prioritize the use of biodiversity-friendly methods such as species-  
453 specific trapping systems and beehive muzzles for the control of the Asian hornet.

454 Reconnecting science and action is one of the 21st century priorities (Nisbet  
455 and Scheufele, 2009; Groffman et al., 2010; Shackleton et al., 2019a). Generally,  
456 biological invasions is a very complex topic when it comes to risk communication, as  
457 it is marked with strong duality of opinions among the need of control actions –to  
458 reduce the threat on the native biodiversity due to an invasive species– and the  
459 recommendation of no action due to direct risk of impact of control methods on native  
460 biodiversity (Courchamp et al., 2017). The results of this study highlight the need to  
461 improve the quality and quantity of risk communications between science and action  
462 in the early-stages of management plans, in order to improve the sustainability of  
463 stakeholders’ practices. Over the last years, there has been an increase in the  
464 practice of citizen science programs and other community-based projects in  
465 conservation biology (Bryce et al., 2011; Follett and Strezov, 2015; Requier et al., in  
466 press). These allow, in socio-ecological systems, to connect researchers, citizens  
467 and stakeholders around common environmental issues. For instance, a recent  
468 citizen science study in the United States has shown broad public interest in  
469 pollinator conservation issues (Wilson et al., 2017). This study showed that

470 conservation efforts require significant public support and that any program aimed at  
471 stopping or mitigating the decline of pollinators should include awareness and  
472 education measures. Citizen science programs and other community-based projects  
473 could also facilitate human interactions and education concerning other topic of  
474 biodiversity conservation and environmental management, such as risk  
475 communication on invasive species issues. Overall, scientists have to communicate  
476 with stakeholders and vice versa, sharing explicit information on the risk, the  
477 hypothesis made, the methodological framework used, and the uncertainty that  
478 comes with the risk predictions, in order to ensure co-constructed, coherent and  
479 acceptable management recommendations (Schmolke et al., 2010; Voinov and  
480 Bousquet, 2010; Shackleton et al., 2019a).

481         Our results help to fill a knowledge gap regarding how personal actions of  
482 stakeholders evolve in a science-disconnected context. In particular, our results  
483 provide evidence that mutual communication between stakeholders and researchers  
484 though, before, during and after the risk assessment process, is one component that  
485 needs to be reinforced to ensure its usefulness for biological invasion management  
486 and policies (Theobald et al., 2000; Jönsson et al., 2015; Shackleton et al., 2019a).  
487 Moreover, involving stakeholders in invasions management programs is central to  
488 not only ensure their success, but also enhance their acceptability and avoid  
489 situations where such programs result from a single actor involved (Liu et al., 2011;  
490 Verbrugge et al., 2013). This requires interacting works between stakeholders and  
491 researchers in the drafting, conduction and final evaluation of co-managed programs  
492 (Crowley et al., 2017; Novoa et al., 2018; Shackleton et al., 2019a). For instance,  
493 web-based forums and round-table discussions could promote such a mutual  
494 communication. New ways of communication are also needed, to (1) establish a two-

495 ways link between researchers and all stakeholders involved in the invasions  
496 management process and (2) to address this disjunction between science and action,  
497 for which citizen science programs and other community-based projects can help.  
498 Beyond risk communication, considering the knowledge, the experience and the  
499 perception that people and stakeholders have of a situation, a risk, or a system, in  
500 the scientific process of risk assessment can ensure the usefulness and acceptability  
501 of biological invasion management.

502

### 503 **Research data**

504 The data presented in this manuscript are available through the Dryad Digital  
505 Repository (doi: xx.xxxx/dryad.xxxx [to be complete at final acceptance]).

506

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729

### 730 **Figure Captions**

731 **Figure 1.** Spatial distribution of two hornet-related risk evaluations: (1) Science-  
732 based predicted risk, obtained at the town scale, corresponding to the predicted  
733 number of hornets that can predate on beehives (colour gradient). This estimation  
734 was obtained based on online citizen declarations checked by a specialist. (2)  
735 Stakeholder-based perceived risk (black open circles). This estimation was obtained  
736 by inviting beekeepers (i.e. stakeholders) to declare on a standardized questionnaire  
737 their observation, perception and management of the Asian hornet. See methods for  
738 more details on the estimates.

739

740 **Figure 2.** Path analysis revealing the causal links identified between the observation,  
741 perception and management of the Asian hornet risk by beekeepers, and their  
742 relationship with science recommendation. Only significant links are shown. See  
743 online Supplementary Materials (**Appendix S1**) for detailed statistical properties of  
744 the path model and links. Total explained variance ( $R^2$ ) is indicated in the box for

745 each response variable. The thickness of an arrow represents the magnitude of the  
746 (standardized) effect and the colour shows the correlation sign (positive or negative).  
747

748 **Figure 3.** Frequency of occurrence of the trapped insects in two different trap  
749 designs (home-made trap on the left and commercial trap on the right) and two  
750 different bait compositions (home-made bait and commercial bait). The probability to  
751 catch the targeted insect *Vespa velutina* is showed in red while the probability to  
752 catch different non-targeted groups of entomofauna (e.g. European hornet, other  
753 Vespidae, the Western honey bee *Apis mellifera*, Diptera, Lepidoptera, other insects)  
754 is presented within the grey gradient.

755

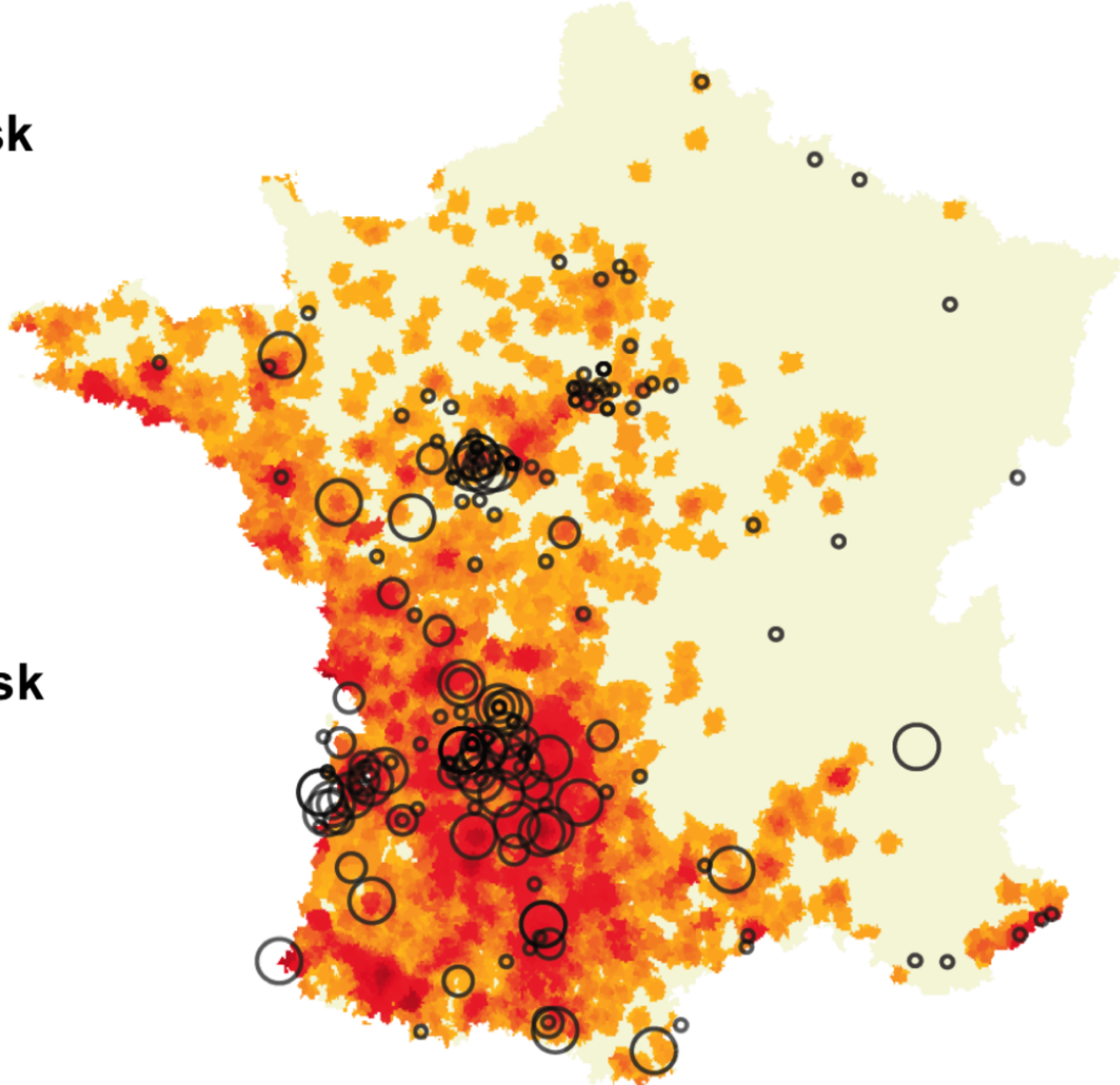
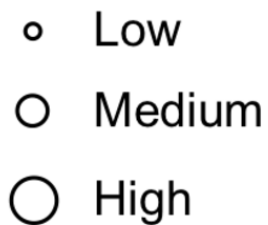
756 **Figure 4.** Effect of the number of established traps on the probability to catch **(a)** the  
757 targeted Asian hornet or **(b)** other non-targeted insects. The number of established  
758 traps increased the probability to catch the targeted Asian hornet, but did not affect  
759 the high probability to catch other non-targeted insects. The dotted line shows non-  
760 significant relationship. Thick line shows the model predictions with shaded areas  
761 (presented if the model is significant) indicating the 95% confidence interval.

762

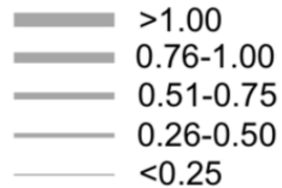
## Predicted risk



## Perceived risk



Estimate of selected path



— Positive effect  
— Negative effect

**Stakeholder**

Personal action  
( $R^2=0.34$ )

Risk perception  
( $R^2=0.15$ )

**Context**

Social

Risk factor obs.  
( $R^2=0.10$ )

Risk observation  
( $R^2=0.33$ )

Environment

Risk factor inv.  
( $R^2=0.29$ )

Risk identification  
( $R^2=0.62$ )

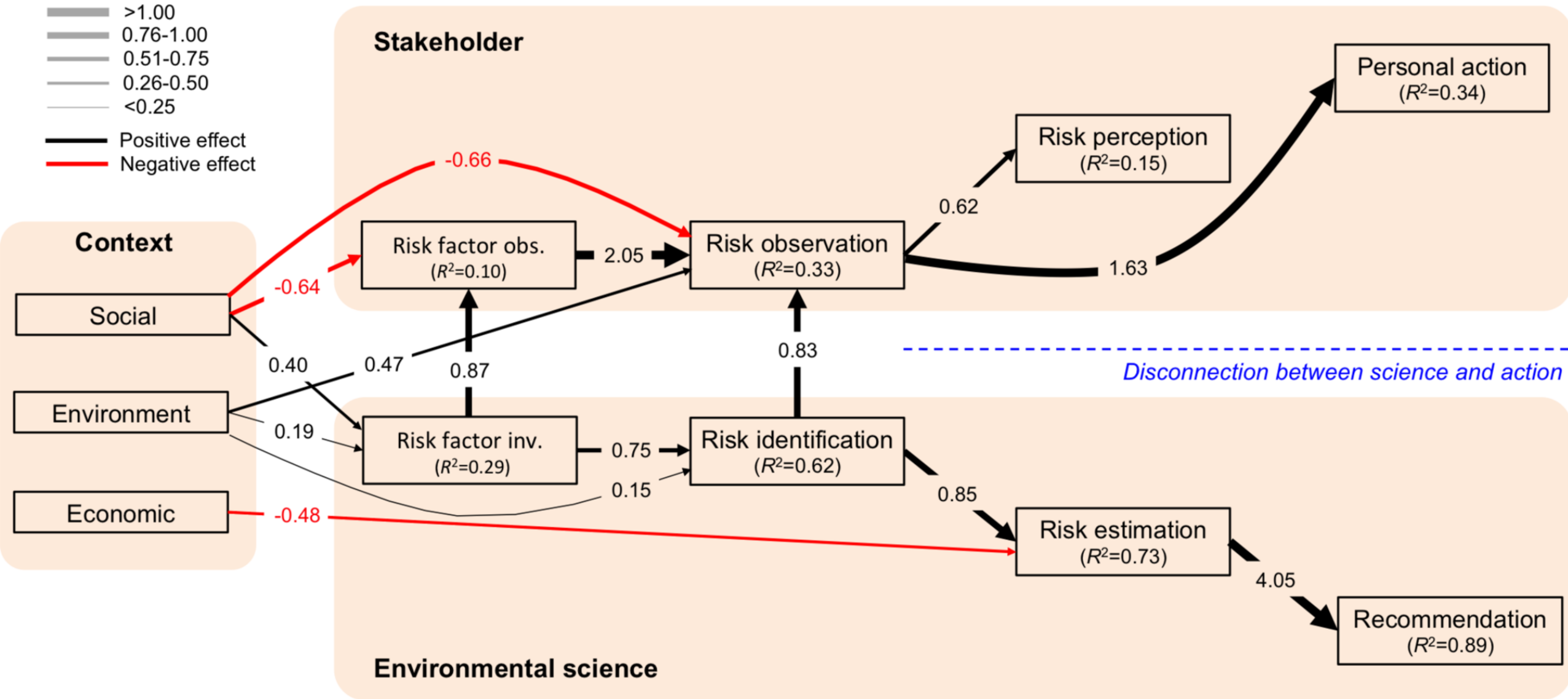
Economic

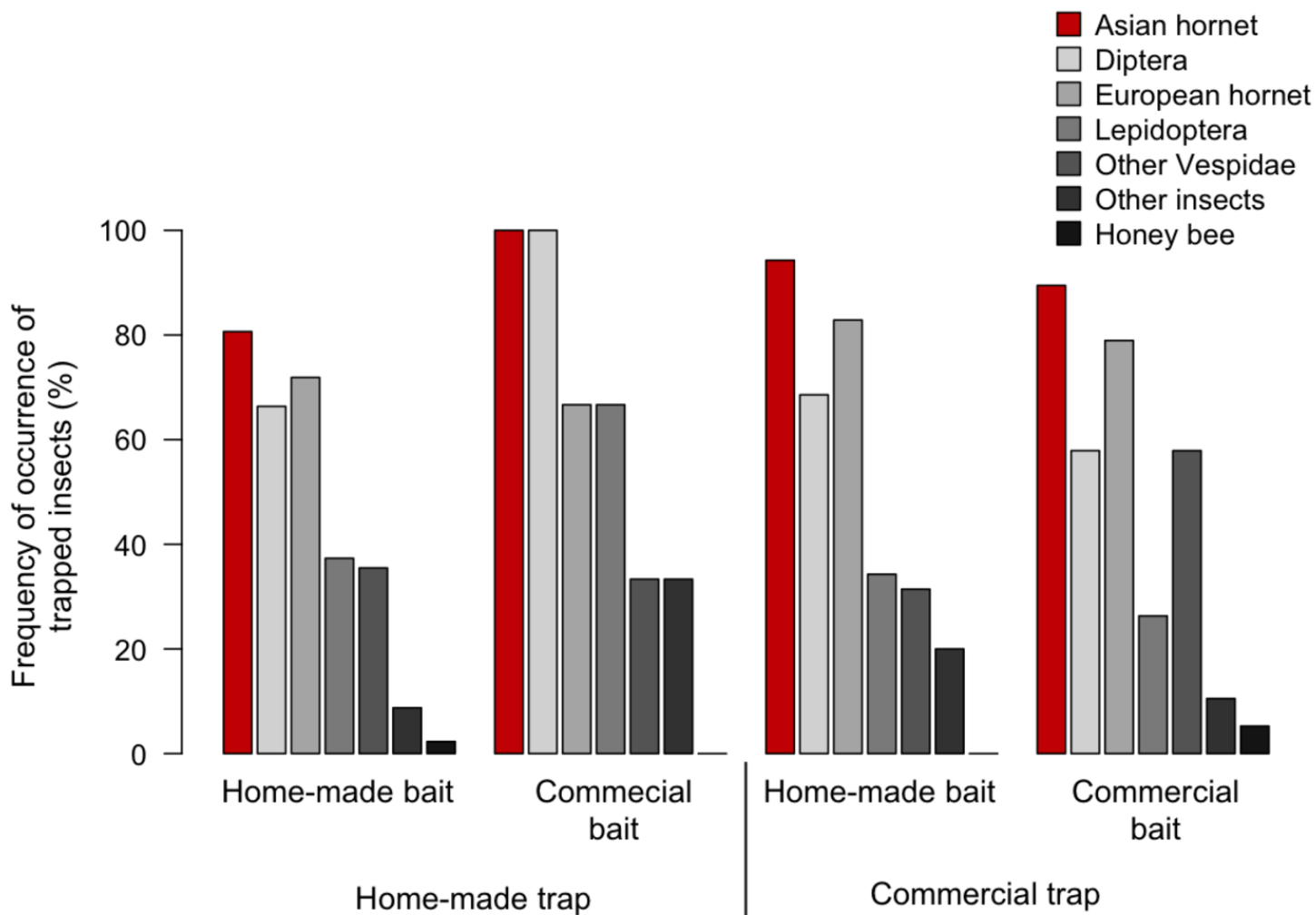
Risk estimation  
( $R^2=0.73$ )

Recommendation  
( $R^2=0.89$ )

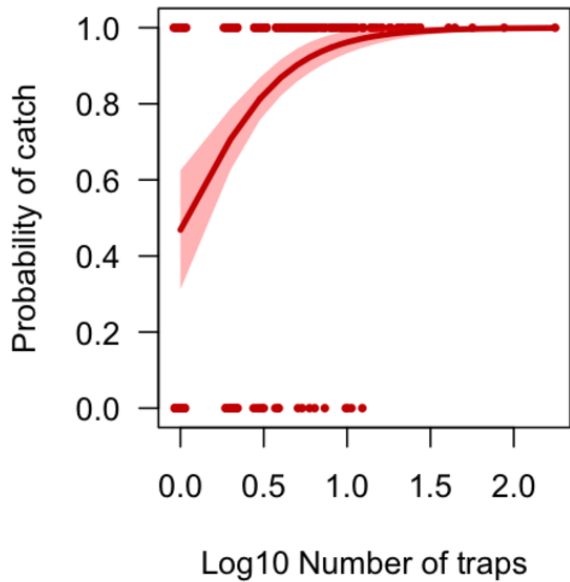
**Environmental science**

*Disconnection between science and action*





**(a) Asian hornet**



**(b) Other insects**

