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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 28th) to the day
186 310 (November 6th). 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 m²) 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

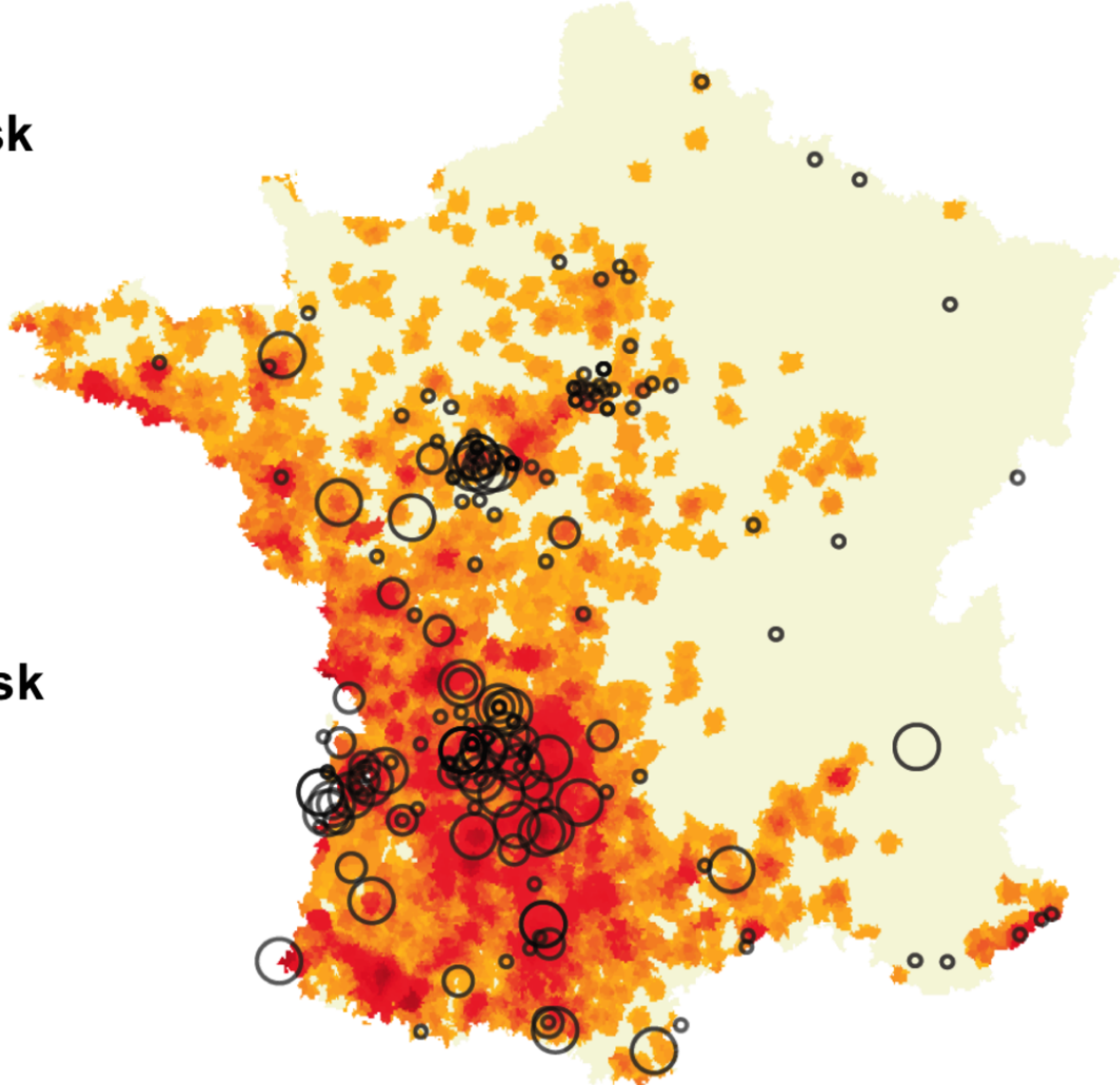
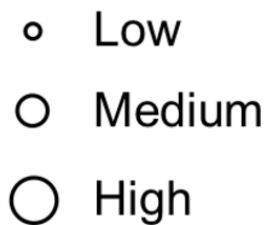
756 **Figure 4.** Effect of the number of established traps on the probability to catch (a) the
757 targeted Asian hornet or (b) other non-targeted insects. The number of established
758 traps increased the probability to catch the targeted Asian hornet, but did not affect
759 the high probability to 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

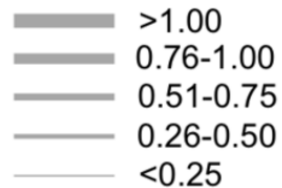
Predicted risk



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
($R^2=0.62$)

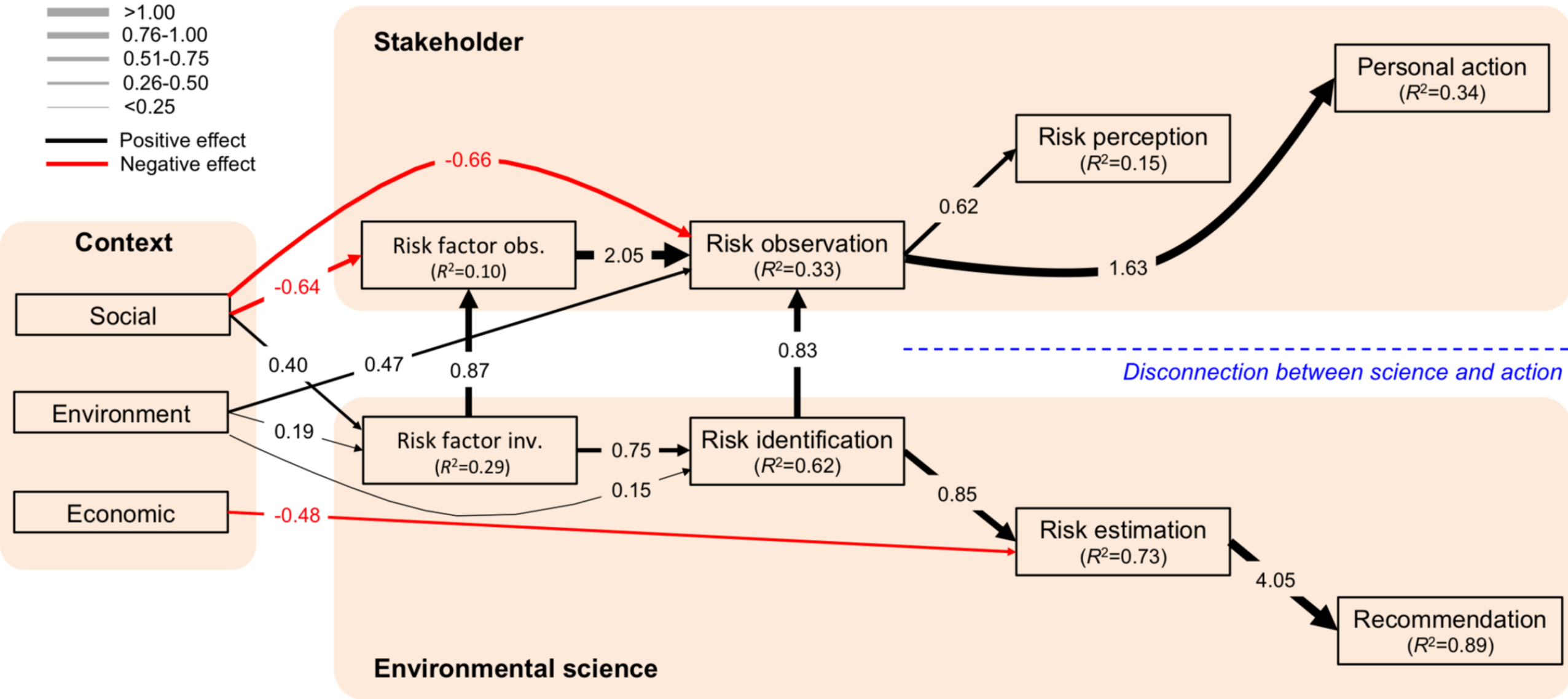
Economic

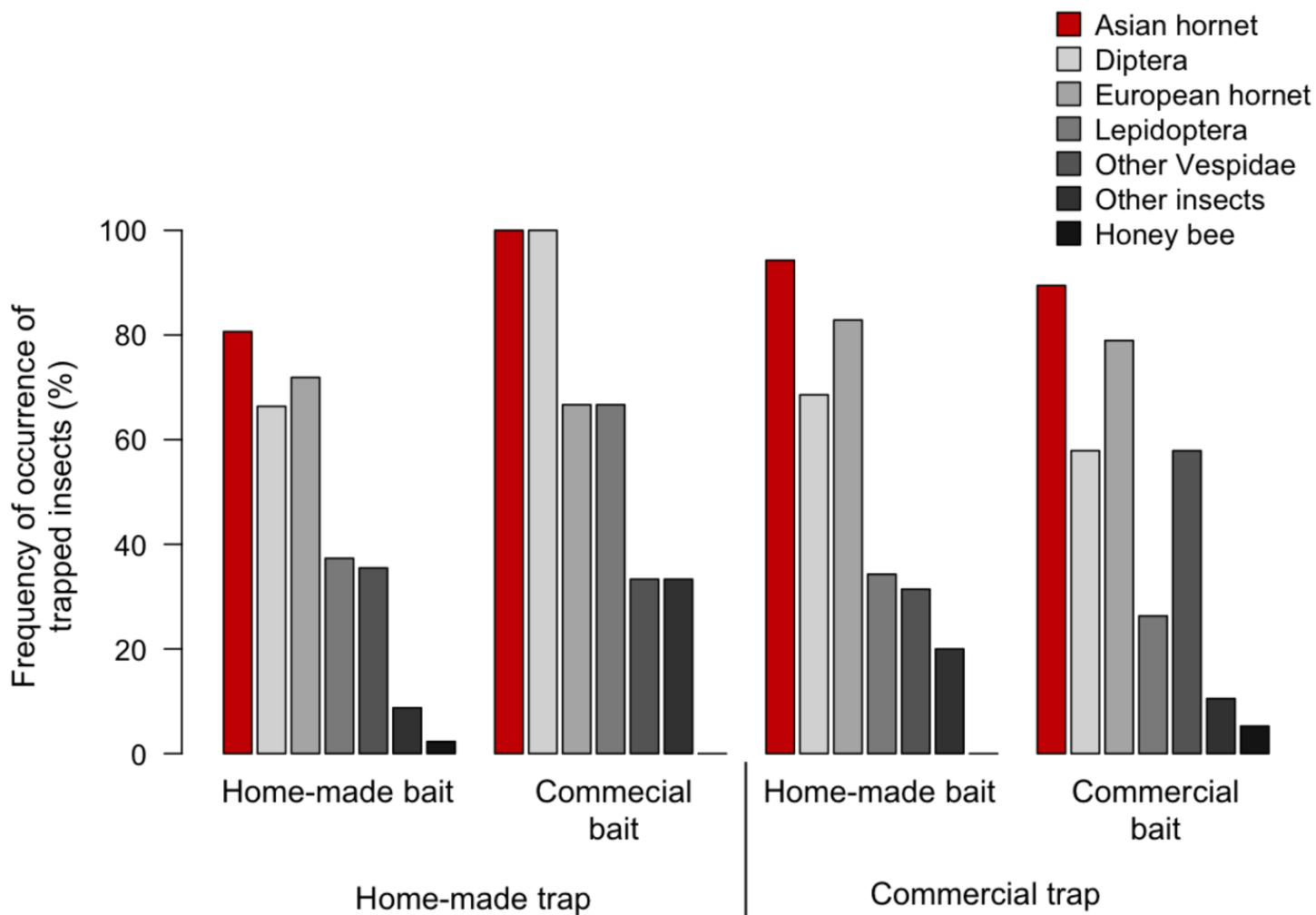
Risk estimation
($R^2=0.73$)

Recommendation
($R^2=0.89$)

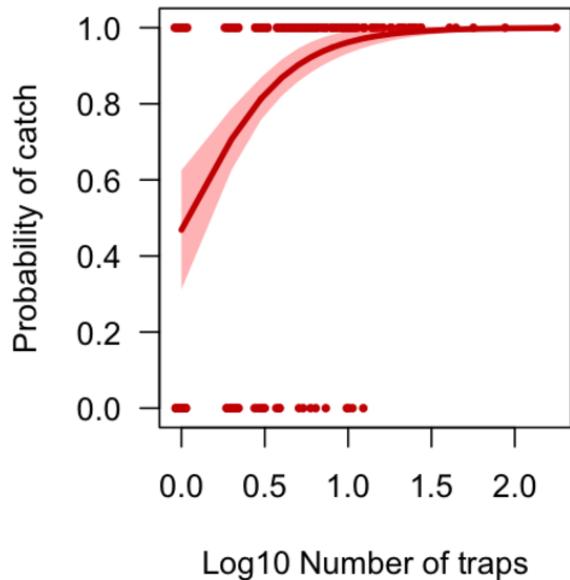
Environmental science

Disconnection between science and action





(a) Asian hornet



(b) Other insects

