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1 **Do amateurs and citizen science fill the gaps left by scientists?**

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12 Abstract:

13 The diversity of insects is tremendous and so is the effort needed to assess it in order to
14 better understand insect ecology as well as their role for the functioning of ecosystems.
15 While the interest of academics and naturalists for these species has always existed, it is
16 only recently that such interest started to reach society more generally. From insect
17 taxonomy and distribution to the collection of large range and long scale monitoring data, the
18 involvement of non-academics in research outputs is growing. Is this a sign of scientists not
19 being able to meet expectations or of science getting more and more entrenched in society?
20 We argue for the latter, highlighting the opportunities that such involvement of amateurs in
21 insect science represent for insect conservation.

22

23

24 **Introduction:**

25 The diversity of insects is huge, with more than one million described species (Roskov et al.,
26 2019). Hence, the effort needed to assess (Stork, 1998) and relate this diversity to insects'
27 roles in the functioning of ecosystems (Price, 1997) is tremendous. While the interest of
28 academics and naturalists for these species has always existed, it is only recently that such
29 interest started to reach society more generally (IPBES, 2016). This came with the rising
30 concern of insect decline largely popularized by the fate of pollinators (Buchmann & Nabhan
31 1996; Hall & Martins, 2020). Since then, research effort to characterize this decline and
32 associated causes and consequences is growing (Didham et al., 2020). In what follows, we
33 investigate to what extent amateurs may help professional scientists fill the gaps of
34 knowledge on insects, and how this joint effort may be an opportunity to better entrench
35 science in society.

36

37

38 **Role of non-professionals in the knowledge of insect diversity, distribution and** 39 **taxonomy**

40 Since the end of the XXth century, the development of online taxonomical and bibliographical
41 databases, digital photography, and social media where people can share photos and help
42 each other identifying them has given a new momentum to the input of amateurs to the
43 knowledge of biodiversity, and in particular insects (Marshall 2008). Skilled amateurs provide
44 pictures for identification atlases, sometimes in the framework of targeted searches for rare
45 taxa triggered by professional taxonomists, or are enrolled in citizen science projects to map
46 occurrences of threatened insect species (Campanaro et al., 2017; Zapponi et al., 2017). In
47 this context, the XIXth century amateur who was a bug collector is now often a digital
48 photography collector. Other initiatives are open to anyone interested, skilled or not, and aim
49 at recording insect occurrence data, often without a protocol or sampling plan. They gather a
50 huge quantity of data on insect distribution, either targeting specific insect groups (moths or
51 ladybirds for instance [https://butterfly-conservation.org/our-work/recording-and-](https://butterfly-conservation.org/our-work/recording-and-monitoring/national-moth-recording-scheme)
52 [monitoring/national-moth-recording-scheme](https://butterfly-conservation.org/our-work/recording-and-monitoring/national-moth-recording-scheme)
53 <https://www.coleoptera.org.uk/coccinellidae/home>), or any organism, including insects (e.g.
54 <https://www.inaturalist.org/>; <https://www.ispotnature.org/>).

55 However, the contribution of amateurs to the knowledge on insects, and in particular
56 taxonomical knowledge, is not restricted to projects driven by professional biologists. Non-

57 professionals, i.e. people who do not hold a position in which they are remunerated for
58 performing taxonomy, are known to take a significant part in the building of taxonomical
59 knowledge: for instance, between 1998 and 2007, they described 62% of new species from
60 Europe, 70% of which being insects, and authored 54% of European species
61 synonymizations (Fontaine et al., 2012). Amateur contributions extends far beyond
62 charismatic groups such as butterflies or seashells: between 1998 and 2007, they described
63 53% of new European Diptera, 57% of Coleoptera, and 84% of Orthoptera. Similar figures
64 showing the importance of amateur contributions to insect taxonomy are found in other parts
65 of the world, for instance French Guyana, where non-professionals provided 65% of new
66 insect records between 2008 and 2013, and collected 74% of new species holotypes (Brûlé
67 & Touroult, 2014). The importance of their contribution is such that the synergy between
68 amateurs and professionals in insect systematics has been qualified as « a backbone of the
69 primary research on biodiversity » (Audisio 2017), and that the decline in their numbers will
70 have an impact upon information generated on insects, and hence on their conservation
71 (Hopkins & Freckelton, 2006). For this reason, a better integration of amateurs in academic
72 teams, with formalized collaborations, training for the use and interpretation of technological
73 tools such as DNA sequencing and help in securing grants has been advocated to solve the
74 Taxonomic Impediment (Fontaine et al., 2012; Coleman, 2015)

75 Amateurs also make significant contribution to the scientific knowledge of insects by donating
76 books and article collections to museum libraries. This was recently analyzed for the
77 contribution of a local Canadian entomologist, whose entomological book and article
78 collection is now hosted by the Macdonald Campus Library from McGill University, and
79 includes many titles not found in any other Canadian university library (Waters & MacKenzie
80 2018). Similarly, amateurs have produced insect collections, sometimes of high scientific
81 value, which may be lost forever unless there is a coordinated effort to register those private
82 collections and find the funding to acquire them and secure their preservation (Fischer et al.,
83 2021).

84 **Amateurs, scientists and long-term insect surveys**

85 Except managed honeybees, for which numerous national agricultural administrations
86 collected data for decades, and agricultural or silvicultural pests for which some monitoring
87 programs started early on (e.g. Watt & Hicks 2000, Bell et al. 2015), time series of insects
88 are scarce. However, such data are highly needed in the current context of a potential insect
89 Armageddon (Leather, 2017, Wagner et al. 2021). Despite recent studies relying on relatively
90 short time series from academic origins (Sanchez-Bayo & Wyckhuys 2019, van Klink et al.
91 2020, Crossley et al. 2020, Høye et al. 2021, Schowalter et al. 2021), most of our knowledge

92 on insect temporal trends comes from the analysis of insect records from collections (e.g.
93 Beismejier et al 2006, Ollerton et al. 2014, Powney et al. 2019, Soroye et al. 2020, Duchenne
94 et al. 2020). Such data and in particular historical collections or records, allowing turning the
95 clock back enough to minimize the shifting baseline issue (Pauly 1995), have been collected
96 and curated largely thanks to numerous non-professional but passionate entomologists
97 (Brunelle 1997). Although natural history museums were also involved in collecting and are
98 in charge of preserving such precious specimens, the contribution of amateurs and
99 associated entomological societies must be acknowledged. For example, the UK Bees,
100 Wasps and Ants Recording Society (BWARS), with ca. 500 members, is thought to have one
101 of the most detailed available databases on these taxa for a single country, with records
102 going back a century (Beismejier et al. 2006, Ollerton et al. 2014, Powney et al. 2019).
103 Although associated from the start to academics, it largely relies on non-professionals for
104 data collection and curation. The same is true for the UK hoverfly recording scheme whose
105 data were also recently analysed (Beismejier et al. 2006, Powney et al. 2019).

106 However, though invaluable, such insect occurrence data, also called opportunistic data, are
107 most commonly collected with unknown protocol and observation pressure, which make
108 statistical analyses a difficult task (van Dooren, 2016; Didham et al., 2020). For this reason,
109 large range and long-term monitoring schemes following standardized protocols have been
110 launched, in order to produce abundance data while minimizing sampling biases. These
111 schemes, managed by academic institutions and/or entomological societies, rely heavily on
112 the participation of volunteers to reach data collection with large spatiotemporal coverage.
113 The earliest schemes relied on skilled naturalists, such as the UK Butterfly Monitoring
114 Schemes, launched in 1976, which now compiles species temporal series of species
115 abundance for over more than 4000 locations in the United Kingdom with roughly as many
116 participants (<https://www.ukbms.org/>). Another striking example is the Krefeld Entomological
117 Society in Germany, with ca. 50 members, which provided the data for the iconic Hallmann et
118 al. study (2017), showing a 75 percent decline in flying insect biomass since 1989 (Bruch et
119 al. 2013). Here again, many of the members are hobbyists as the same time as being world
120 experts on their favorite insects. At the onset of the XXIst century, new schemes have been
121 opened to the general public (Silvertown, 2009), with dedicated protocols suited for
122 participants with no prior knowledge of insects. For instance, the French Garden Butterfly
123 Count, launched in 2006, has reached more than 10,000 participants (Fontaine et al., 2016).
124 Since then, numerous participatory monitoring schemes are flourishing, targeting other
125 groups attractive to the general public, such as dragonflies, moths or pollinators (e.g.
126 <https://www.vlinderstichting.nl/wat-wij-doen/meetnetten/meetnet-libellen>;

127 ecology.org.uk/gms2019; <https://www.spipoll.org/>), or documenting flower-insect interactions
128 (Deguines et al., 2012).

129 In addition to providing the material for numerous scientific articles and books on various
130 aspects of insect ecology, protocolled monitoring data are also used to produce indicators as
131 official statistics to inform governmental agencies on biodiversity trends and help them set
132 and assess the outcome of conservation policies (Brereton et al 2011). Such citizen science,
133 associating academics, entomological societies and volunteers to monitor biodiversity and
134 provide accurate indicators to stakeholders, if not free, is recognized as being cost effective
135 and less vulnerable to funding variances (Couvét et al. 2008, Levrel et al. 2010, Mackechnie
136 et al. 2011).

137 **Amateurs involved in insect citizen science help entrench science in society**

138 Enlarging the communities of amateur insect researchers has significant and important
139 consequences on insects' conservation (Oberhauser & Prysby, 2008), but also on the
140 relationships between science and the society.

141 First, insect citizen-science projects make insects more real and relevant for the society. It
142 has already been shown that some amateurs increase their entomological knowledge and
143 modify their gardening practices to be environmentally-friendly (Cosquer et al. 2012,
144 Deguines et al. 2018, 2020). Although current press coverage of insect decline remains weak
145 (Althaus et al. 2021), involving amateurs and publicizing the results of these large spatial and
146 temporal scientific surveys of insects can make insects more visible in public space, as
147 exemplified by the hundreds of news stories, thousands of tweets and dozens of policy
148 documents related to the Hallmann et al. study (2017) on insect decline in Germany
149 (<https://www.altmetric.com/details/27610705>).

150 Secondly, insect citizen-science projects provide opportunities for volunteers to be in close
151 contact with insects in their habitats, to experience nature (Clayton et al. 2017): when
152 observing insects in their garden to collect scientific data, volunteers are physically involved
153 in data collection, standing up on tiptoes or squatting down, feeling too cold or too hot. They
154 use all their senses, vision of course, but also hearing, touching, smelling, even tasting. They
155 are also emotionally involved in their experiences: curious or anxious, disgusted, enjoying
156 themselves, happy and proud, they can feel all these emotional states during their citizen-
157 science experiences. Finally, they often pay attention to all interactions between the natural
158 living beings they focus on and spontaneously adopt context-dependent situated
159 perspectives (see Bang 2015), in which they also relate to the objects of their inquiry.
160 Collecting insects' citizen-science data enlarges volunteers' perceptions of nature.

161 Third and consequently, amateurs involved in insect citizen science monitoring programs
162 learn different ways to do science (Trumbull et al., 2000): they converge with scientists in
163 taxonomic identification and ecological scientific knowledge on biodiversity functioning, but
164 they complete this knowledge with embodied knowledge, by being physically involved in their
165 discovery of insects. Such embodied knowledge has been progressively disqualified in
166 western science, which legitimates distancing and decontextualizing ways to describe nature,
167 considered to be the only way to reach objectivity (Medin and Bang 2014). Yet, embodied
168 and practical knowledge is of prominent importance to re-link theory and practice (Macintyre
169 Latta & Buck 2008), and amateurs challenge scientists in their scientific norms and world
170 visions.

171 Finally, in joining citizen-science programs, amateurs enter a community of participants with
172 which they exchange during meetings or via dedicated social networks. The presence of
173 scientists in these communities can be an important motivation for volunteers to legitimate
174 their participation (Cosquer et al. 2012). But these enlarged communities with scientists and
175 non-scientists who share interests in insect knowledge and conservation represent also new
176 arenas that force scientists to quit a socially comfortable sphere, to present and share their
177 knowledge with other social spheres, and to be challenged by people who do not have the
178 same worldviews.

179

180 **Perspective**

181 Rather than filling a gap left by scientists, we argue that amateurs contribute with scientists to
182 increase knowledge on insects, with citizen science projects currently favoring the
183 complementarity between their contributions and helping to entrench science and insect
184 conservation issues in society (IPBES, 2019). If the embodied knowledge of amateurs,
185 relating scientific knowledge to emotions and feelings, is recognized as key for them to care
186 about insects, one has to recognize that such embodied, emotional and close relationships
187 with natural living elements is also key to the motivation and creativity of academics: « After
188 spending 32 of my 41 years in the field, I'm still agog at life's splendour. The beauty I see as I
189 search for dragonflies on expeditions in Gabon or watch birds around Stellenbosch on my
190 way to work can be so absurd it makes me laugh, so diverse it makes me gasp for air, so
191 intense that I binge-watch as if there is a cliff-hanger in every impression. » (Dijkstra, 2016).
192 Citizen-science, in making scientists and non-scientists close together, may help modern
193 science to enlarge their world visions, toward more relational epistemologies (Bang 2015).

194 Such a vision might be challenged by the recent and fast developments of identification
195 systems based artificial intelligence (AI) that make automatic species identification from

196 pictures or sounds increasingly accurate, rapid and reliable (Høye et al. 2021). These AI
197 systems are already used in programs collecting opportunistic occurrence data (e.g. the
198 obsidentify app aiming at identifying all species from pictures including insects
199 <https://observations.be/>). Such technology also leads to the development of sensors for
200 biodiversity monitoring, including insects (Ärje et al. 2020), offering potentially better
201 sampling than amateurs can provide. Amateurs can contribute to such AI-based identification
202 development by constituting huge training databases of annotated pictures, but it is not clear
203 whether automatic identification help amateurs to learn how to identify species. Likewise
204 sensors question the need for amateur involvement in biodiversity observations, and thereby
205 the opportunity to experience nature. While being a fascinating opportunity, AI is
206 transforming the current collaboration between amateurs and scientists, and some thinking is
207 needed to use such technology in a way the truly benefits both scientists and amateurs in
208 their quest to know and conserve insects.

209

210

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