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1 **Robotic bees for crop pollination: why drones cannot replace biodiversity**

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13

14 **Abstract**

15 The notion that robotic crop pollination will solve the decline in pollinators has gained wide
16 popularity recently (Figure 1), and in March 2018 Walmart filed a patent for autonomous robot bees.
17 However, we present six arguments showing that this is a technically and economically inviable
18 ‘solution’ at present and poses substantial ecological and moral risks: (1) despite recent advances,
19 robotic pollination is far from being able to replace bees to pollinate crops efficiently; (2) using
20 robots is very unlikely to be economically viable; (3) there would be unacceptably high
21 environmental costs; (4) wider ecosystems would be damaged; (5) it would erode the values of
22 biodiversity; and, (6) relying on robotic pollination could actually lead to major food insecurity.

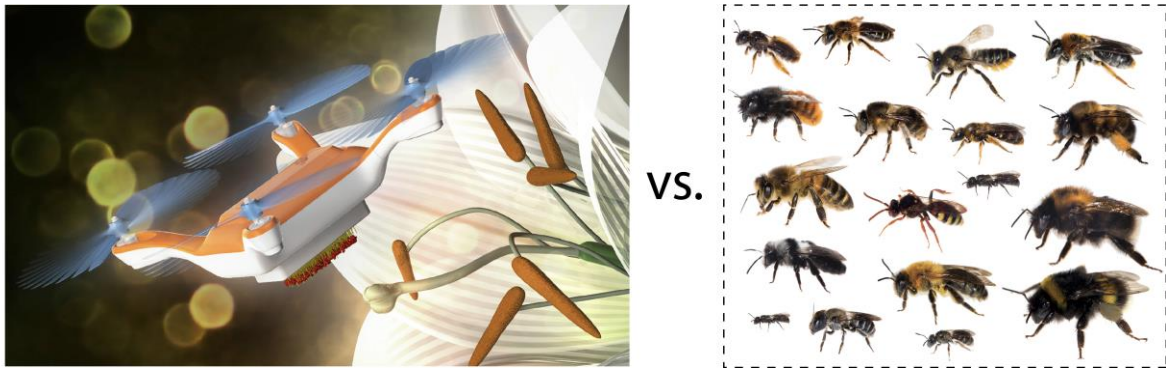
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24 **Main text**

25 Throughout the Anthropocene, biodiversity has underpinned a wide range of ecosystems goods and
26 services providing multiple benefits to people and improving human wellbeing (Díaz et al. 2015).
27 Often these services are unrecognized or perceived to be 'free' (Daly and Farley 2010), and the
28 increasing threats to their ongoing provision poses major challenges for society on how to protect
29 and manage biodiversity (Global Biodiversity Outlook 4, 2014).

30 Nature has elegantly solved many challenges, and scientists and engineers can learn a great deal by
31 studying biodiversity and nature. For instance, the growing field of biomimicry, and its many success
32 stories, is a direct testimony of how innovative engineering solutions derived from the study of
33 adaptations in the natural world can benefit our societies from transport to architecture, swimsuits
34 or even military camouflage (Benyus 2002). Prototype robots are being developed as autonomous
35 weeding machines for agricultural crops (Reuters 2018). A recent study by Harvard researchers
36 Chechetka and colleagues (2017), and the breaking news of Walmart filing a patent for autonomous
37 robot bees (Business Insider 2018), both propose bringing together the fields of biomimetic science
38 and miniature robotics to address the looming crop pollination crisis as the need for insect
39 pollination increases while the population of managed and wild pollinator decline (Aizen & Harder
40 2007, Potts et al. 2016). Public concern for pollinators, and the pollination service they provide, has
41 grown rapidly and a quick 'technological fix' to the problem seems quite appealing, especially when
42 the developers of prototype robotic bees claim that they will be able to safeguard crop pollination in
43 the near future. In contrast, the Intergovernmental Platform on Biodiversity and Ecosystem Services
44 global assessment of pollinators, pollination and food production (IPBES 2016) and the Convention
45 on Biological Diversity (CBD 2018) found no evidence to include robotic bees as a credible response
46 option to loss of pollinators or pollination. In this discussion, we recognise that nature can inspire
47 cutting edge technology, but put forward robust arguments showing that robotic pollination is
48 currently incapable of delivering crop pollination to sustain production on a world scale, and even if
49 the technology was developed sufficiently, then there are strong economic, ecological and social

50 reasons not to pursue this route (Figure 1). Given the increasing scientific, political and public
51 interest in the plight of pollinators, it is important we separate the evidence-based response options
52 from those which are highly speculative and make unrealistic claims as to their putative
53 effectiveness. The aim of this piece is to present a considered view on the opportunities and risks for
54 securing crop pollination services with and without robotic bees. We highlight that emerging
55 technologies have many beneficial roles to play in society, but in this case there is no justification for
56 needlessly trying to replace a key component of biodiversity which can readily be protected and
57 enhanced.



58
59 **Figure 1:** Could robotic drones replace pollinator biodiversity to sustainably deliver pollination
60 services to wild and cultivated flowering plants? The answer is no: as it is currently technically and
61 economically in viable and poses substantial environmental and moral risks. Drone image reprinted
62 from Chechetka et al. (2017) with permission from Elsevier.

63

64 **1. Despite recent advances, robotic pollination is far from being able to replace bees to pollinate**
65 **crops efficiently.** While technology is moving in the direction of unmanned flying robots able to
66 make complex decisions, they are still extraordinarily clumsy and unsophisticated compared to real
67 bees. Flowers represent multimodal sensory billboards involving shape, colour, scent and even
68 iridescence that are detected, approached and manipulated by bees for the collection of pollen,
69 nectar and other floral rewards through neurological and behavioural responses that are still poorly
70 understood (Cresswell 2000). Delivering efficient cross-pollination at the level of species-rich

71 communities of co-occurring plant species, or even in a more homogeneous field of cultivated
72 flowering plants, involves a lot more than taking up the technological challenge of designing a
73 miniature drone flying towards a flower and picking up a fraction of the available pollen grains.
74 There are more than 350,000 species of flowering plants on the planet (Ollerton et al. 2011), and
75 they interact in very unique ways with animals as pollen vectors to bring about sexual reproduction,
76 fruit and seed production, and evolution. Moreover, there are many floral visitors, but only few are
77 actually effective pollinators (King et al. 2013) , and their ecological/behavioural traits diversity, not
78 the sheer abundance of one species of particular bee, has been shown to be a significant driver of
79 pollination efficiency and crop yields (Hoehn et al. 2008; Albrecht et al. 2012; Fründ et al. 2013;
80 Garibaldi et al. 2013; Martins et al. 2015). Technology has taken tiny steps to try to address the
81 pollination process of a few ‘easy’ crops such as sunflowers (*Helianthus annuus*) which have large
82 disk-shaped easily accessible inflorescence, but is still barely out of the starting gates, while
83 evolution, through the high levels of functional biodiversity and complex ecological, crossed the
84 finishing line millions of years ago.

85

86 **2. Using robots is very unlikely to be economically viable.** There are many billions of individual bees
87 and other pollinators across the planet already doing an effective job of crop pollination. Given some
88 of them are declining, the most cost efficient strategy to secure production is to safeguard the
89 pollinators we already have and sustainably manage landscapes to increase their numbers further
90 (IPBES 2016). Trying to replace this existing pollination service with fleets of robots is economically
91 inviable: even if the technology was up to the job, the cost will likely be totally prohibitive. Even at a
92 modest \$10 per bee for example, the total cost would be many 100s of billions of dollars to pollinate
93 the area of insect-pollinated crops that is currently grown over the world. Further, there are the
94 costs of hardware repair and maintenance, command and control infrastructure. For a fraction of
95 the cost of robot pollination, society could implement well-established solutions (Dicks et al. 2016,
96 IPBES 2016) to protect pollinator habitats, reduce threats to pollinators and promote biodiversity-

97 friendly cities and landscapes, thereby protecting nature's heroes instead of trying to replace them
98 at exorbitant costs. This is not to say that in the future private individuals and businesses should not
99 invest in developing such technologies for target niches, as it could potentially have a role to play in
100 food production for a small number of specialist crops for which we currently do not have
101 manageable pollinators (such as for hybrid seed production of nectarless crops such as tomato
102 *Lycopersicon esculentum* or lettuce *Lactuca sativa*; Liu et al. 2007). Robotic pollinators would likely
103 result in spin-off applications outside pollination, however, to use publically funded research or
104 government subsidies is highly questionable when the outcome is likely to be loss of opportunities
105 to protect existing biodiversity.

106

107 **3. There would be unacceptably high environmental costs.** There would be a huge energy, carbon,
108 water and material's footprints to extract, transport and process the raw materials, to manufacture,
109 distribute, and operate, maintain and repair all the robot bees and their associated infrastructure,
110 and to ultimately to dispose of or recycle irreparable or broken robots. For instance, what would be
111 the additional environmental impact of mining all the necessary lithium and other rare earth metals,
112 whose current exploitation is already of growing environmental and social concerns? When robots
113 reach the end of their working lives, or become broken or trapped, what is the fate of all their
114 constituent pollutants entering human and wildlife food chains? Characterising the full energetic and
115 environmental costs of robot bee technology through life cycle assessments (LCAs) will likely reveal a
116 carbon footprint and significant negative impacts on the environment that are all incompatible with
117 our aims for a low-carbon, energy-efficient future.

118

119 **4. Wider ecosystems would be damaged.** Populating the world with robotic pollinating machines
120 would be a species invasion of epic proportions. It is well-established for pollinators, wild plants and
121 many elements of biodiversity that alien invasive species cause local/regional extinctions, disrupt

122 species interactions networks, as well as ecosystem functions and services (Geslin 2017). Introducing
123 robotic pollinating machines to remove and spread pollen would disrupt the delicate balance of
124 species already in, and reliant on, agricultural and natural ecosystems by displacing existing
125 pollinators, removing pollen forage, while failing to pollinate all the wild flowering plants reliant on
126 biotic pollination (Ollerton et al. 2011).

127

128 **5. It would erode the values of biodiversity.** Replacing a key component of biodiversity with a
129 technological alternative, while ignoring opportunities to protect it, fails to take account of the
130 multiple values associated with pollinator biodiversity, such as intrinsic (e.g. inherent worth), social
131 (e.g. beekeeping) and cultural (e.g. aesthetic and recreational) values (IPBES 2016). For instance, the
132 high social value placed upon monarch butterflies in North America has helped drive conservation
133 actions for this and other threatened species (Diffendorfer et al. 2014). Other innovations, such as
134 robotic weeding machine with precision spraying systems, can significantly reduce the amount of
135 herbicides used by thereby helping support wider biodiversity (Reuters 2018), which is in stark
136 contrast to pollinating robots aiming to replace biodiversity.

137

138 **6. Relying on robotic bees could actually lead to major food insecurity.** Reliance on a single
139 pollinator is already a high risk strategy for crop pollination (Garibaldi et al. 2013) and the same
140 applies for substituting a diversity of pollinators with robotic devices. While Walmart and others may
141 be proposing new technology to secure supply chains and food production, in reality this approach
142 may increase vulnerability through the failure of complex technology or cyber-attack. Further, low
143 income farmers represent more than 2 billion people reliant on smallholder agriculture in
144 developing nations (Garibaldi et al. 2016), and it is hard to see how these growers will be able to
145 afford robotic pollination services given they struggle to buy even basic agricultural inputs.

146

147 Nature is inspirational and we should seek opportunities to learn from millions of years of evolution.
148 But jumping on the popular pollination band wagon, while deliberately overlooking more than 200
149 years of research on plant-pollinator interactions, by claiming robots can replace bees, or rather
150 "help counter the decline in honeybee populations" (Chechetka et al. 2017) flies in the face of many
151 local, regional, national and international initiatives aiming to safeguard pollinators and their critical
152 values to human well-being (IPBES 2016). The proposed technology is embryonic, the cost
153 prohibitive, and the wider environmental and societal risks unacceptable.

154 Risks to crop pollination need to be addressed, and there are a wide range of options open to society
155 going from well-proven practical interventions (e.g. managing habitats to support wild pollinators
156 and/or augmenting populations of managed pollinators), to new food production systems (e.g.
157 ecological intensification of agriculture to embed pollinators into farming, or breed and/or
158 genetically engineer crops that are parthenocarpic or more self-compatible and self-fertile to
159 produce plants less reliant on biotic pollination) (IPBES, 2016; Knapp et al. 2016). There are well
160 developed practices and policies to reduce the immediate risks to pollinators from pesticides, pest
161 and diseases, and climate change, and also more ambitious approaches to transform societies
162 relationship with nature. Together these provide a portfolio of effective tools and solutions to
163 safeguard crop pollination. One has to wonder whether robotic bees simply represent a
164 technological solution desperately looking for a relevant real-world problem to solve. Miniature
165 flying robots, as with other digital technologies, may have many potentially important uses (Arts et
166 al. 2015). Robotic pollination, however, is simply not the answer to securing widespread crop
167 pollination, and encouraging its development diverts time, money, and other resources that could
168 be directed towards national and international pollinator initiatives and policies (Dicks et al. 2016),
169 striving to secure both biodiversity conservation and food production in a sustainable manner.

170

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