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1 **Industrial rearing of edible insects could be a major source of new biological invasions**

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9

10 Running head: The downside of entomophagy

11

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16

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18

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22

23 Our food habits have contributed significantly to changes in the environment. Global change
24 is in part fueled by excess consumption of meat, primarily of beef, which participates in
25 deforestation (through pastures mostly in South America) and in climate change through
26 methane emissions by livestock and massive water and food intake per kilogram of meat
27 production (1). How ecologically sustainable is the chain of food production to food
28 consumption is a critical socio-ecological enquiry. Entomophagy—dietary consumption of
29 insects—is increasingly seen as a solution, as it lowers many of the global change-related
30 consequences of the current meat-based diet of an increasing part of the human population
31 (2). As a result, entomophagy is a rapidly emerging alternative in the global food industry for
32 human, pet and cattle food. We contend here that since it follows the same route of
33 industrialization and intensification than vertebrate-based traditional food production, it may
34 add to another component of global change: biological invasions.

35 Currently, over two billion people in 130 countries belonging to over 3000 ethnic
36 groups consume 1000-2200 insect species directly as a part of their traditional diets (3, 4).
37 The historical negative bias towards insect consumption is now diminishing in Europe and
38 European-driven populations, mostly due to the perceived nutritional, ecological, ethical and
39 economic benefits (2). Insects offer several advantages over traditional non-vegetarian diet in
40 terms of higher protein-to fat ratios, less demand during development on water and other
41 resources, lower carbon footprint, higher conversion efficiency values, low capital
42 investment, three-dimensional rearing possibilities, lower generation time, higher fecundity,
43 higher resilience to diseases, and finally, a novelty in food preparations (2, 3). These positive
44 implications of an insect-based diet have contributed to the establishment of an industry with
45 an overall global market estimate of USD 400 million and is projected to rise to USD 700
46 million-1.2 billion by 2024, with major market share increases in Europe and North America
47 (5, 6).

48

49 **Possible Negative Implications of Industrial Insect Farming**

50 Insects are known to be successful invaders worldwide in most ecosystems, causing
51 ecological and economic catastrophes costing at least 70 billion dollars annually (7). In
52 addition to cause crop or forest destruction, and potential health hazards, invasive insects can
53 cause damage to the native biodiversity by hybridization, by aiding the spread of pathogens,
54 by way of trophic impacts such as predation and parasitism, and/or by competition for
55 resources (8). Historical accumulation curves of the introduction of non-native species to
56 newer areas of habitats, which is correlated with human-mediated species dispersal, have not
57 yet reached saturation (9). The collapse of the thermal barrier, which historically prevented
58 ectothermic species such as insects from invading colder habitats, has resulted in range
59 expansions of many insect species (10) and will open new regions for invasions to many
60 species that are escaping from industrial insect farms. All these factors highlight the
61 importance of studying the biology and ecology of insects concerned by such mass-rearing,
62 improving biosecurity frameworks and quarantine facilities as well as establishing adequate
63 strategic plans, legislation, policies and budgets to contain post-border release of these
64 potentially invasive species.

65

66 **Resilient Species, Tougher Eradication**

67 Out of the 2200 species of edible insects reported in the traditional diet around the world (4),
68 several are currently reared industrially at a mass production level (Fig. 1) (2), and numerous
69 other species could be expected to follow given the growth rate of the entomophagy industry.
70 What makes the species chosen for entomophagy exceptionally dangerous is that the traits
71 that make them appropriate for mass rearing are the very traits that could also make them
72 successful and problematic invasive species: high fecundity, generalist feeding and nesting

73 habits, resilience to climate changes and fluctuations, low resource requirements, and high
74 disease resistance (2, 11).

75 This concern is not unfounded as it is reminiscent of many such past activities where
76 movements of species for several commerce-driven activities has resulted in a deliberate or
77 accidental release of non-native species, as seen in pet trade, ornamental trade, biological pest
78 control programmes, medicinal use, species for laboratory scientific experiments and
79 educational exhibits, fur industry, silk production, and pollination (12). There are recorded
80 instances of exotic species imported as a food source turning into invasive species, as seen in
81 the case of the giant African snail (*Achatina fulica*) (13). Other flagship examples of
82 commerce-and industry-driven invasions include the introduction of the American mink
83 (*Neovison vison*) to Europe for fur farming where the released individuals or the escapees
84 became invasive (14). Already, several of the mass-reared insect species have become
85 cosmopolitan in distribution and are treated as serious pests and invasive species (Fig. 1)
86 (15). More species, or new varieties or strains of the former, could join them as the market
87 expands.

88

89 **Potential areas of invasions**

90 While many of the existing farms and companies are located in East and Southeast Asia
91 including China, new larger companies with considerable market share are upcoming in
92 Europe and North America, where 15 of the top 20 companies in the edible insect market in
93 the world are now located (16). Regardless of the region, the biosecurity on these farms is
94 rarely of regulatory standards to prevent or respond to unintentional escapes. Given the ease
95 of rearing insects, many of these facilities have an annual turnover of rearing millions of
96 individuals (Fig. 2) (17). Even if a tiny percentage of these individuals manage to escape, it

97 still contributes towards a sizable founder population, one that has been selected for being
98 fast-growing at both the organism and population levels.

99

100 **Policy and Implementation Loopholes**

101 Most existing international policy and guiding principles related to the movement, rearing
102 and escapes of non-native species take into account economic impacts in managed
103 ecosystems such as agriculture, livestock and fisheries. The economic and biodiversity losses
104 in natural ecosystems are likely higher and also difficult to quantify, and yet, they do not
105 come under the direct purview of many of these policies.

106 These guiding principles are also strewn with certain ambiguities which allow
107 movements of non-native species under technical loopholes. For example, under the invasive
108 species guiding principles exercised in the European Union, deliberate introductions of
109 organisms are to be prevented, but regulation over accidental introductions are not exercised.
110 Another example is of The Convention on International Trade on Endangered Species of
111 Flora and Fauna (CITES) which prevents the importation of invasive species, but there is no
112 regulation on captive breeding and pet industry within whose purview the species reared for
113 entomophagy might be reared and sold (8). In some instances, the policies of different
114 international agencies are in direct conflict with each other, such as those of the World Trade
115 Organization (WTO) promoting an unrestricted movement of products and those of the
116 Convention on Biological Diversity (CBD) and CITES promoting regulation of these
117 movements (18).

118 Low prioritisation by nation-states to implement international guiding policies and
119 principles is another likely cause of biological invasions, as seen for example, of low
120 prioritisation in European Union of article 8(h) of Convention on Biological Diversity (CBD)

121 dealing with non-native species, which results in fewer resources directed to regulate
122 movements of species (8).

123 While food safety-related risk assessment is increasingly exercised when for human
124 consumption (19), regional and local invasion risk assessment and management protocols are
125 not readily available for specific species, habitats or pathways of introduction, especially
126 when for animal feed, even in developed countries. This often results in directives for a
127 minimal set of notorious species which are blacklisted. A species not on the 'blacklist', only
128 because of its unassessed nature, could still be mass-reared and accidentally released (17, 20).

129 Finally, the biosecurity status of these rearing facilities is worrying. Inferior, diseased
130 or unrequired stocks should be destroyed but are often released in the environment (17).
131 Numerous escapees have been reported in the south- and south-east Asia (21). Even in high-
132 income countries where the rearing facilities could be more rigorous towards containment,
133 low awareness and commitment on the part of the stakeholders often result in illegal selling,
134 frequent and high numbers of escapees, and absence of monitoring and early response
135 programs increase establishment and spread (17).

136

137 **Avoiding New Invasions: The Way Forward**

138 International policies and guiding principles need to include certification, quarantine, post-
139 entry monitoring and early response programs. The development of protocols of impact risk-
140 assessment is essential because it assists in classifying species based on different risk
141 categories, from low to high risk of invasion, as has been practised in island nations such as
142 Australia and New Zealand (22). These island nations also have a more rigorous approach
143 towards importing any living species, by developing a 'whitelist', wherein every non-native
144 species is considered potentially dangerous till proved to be safe by a risk profiling. In
145 contrast, the more widely implemented approach of a 'blacklist', wherein every species is

146 acceptable for import unless specifically banned, relies on scientists needing to prove that a
147 species is problematic, with all the associated caveats when it would go against economic
148 pressure. Adopting a ‘whitelisting’ approach is more stringent and hence more effective in
149 controlling potential invasions (20); it is also more logical as the assessment would need to be
150 done only for species considered for the industry.

151 Eventually, the mass rearing facilities should be developed on the lines of pathogen
152 housing facilities, where pathogens are broadly classified into four different biosafety levels
153 based on their pathogenicity and potential impacts.

154 Resource availability to develop these protocols and infrastructure requires trained
155 human resource and financial capital which should ideally come from the industry. This is
156 not only because they are the fiscal beneficiaries, but also because industry-driven voluntary
157 codes of conduct and their investment in the research on the biology and ecology of the
158 species to be reared have a direct influence on the deliberate introductions of non-native
159 species. For example, the cost of risk assessment of weeds is borne by industries in New
160 Zealand, following which the country has approved fewer than 100 plant species for
161 introduction in the last century. Contrastingly, neighboring Australia has a government-
162 funded risk assessment program, resulting in the admission of more than 1500 plant species
163 for cultivation in the last century (22). Consequently, any insect mass-rearing industry should
164 be legally and financially accountable for the biological invasions they would create or allow.

165

166 **Conclusion**

167 We caution that industrial rearing of insects for entomophagy is based on the production of
168 massive quantities of non-native insect species of considerable invasion potential to newer
169 areas of habitats, in regions which lack sufficient regulatory frameworks, and in facilities
170 from where the intentional or accidental release of these insects is highly likely. This is

171 especially important looking at the growth prospects of this industry in the future, lack
172 thereof we might be standing at the precipice of a new solution turned-on-its-head to become
173 a threat to global biodiversity.

174

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180 stimulating meeting.

181

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233

234

235 **Figure Legends**

236 **Fig. 1.** Some of the most popularly consumed and industrially reared insect species, their
237 recipes and the damage they are already reported to cause. (A-C) palm weevil
238 (*Rhynchophorus ferrugineus*), raw larvae or their soup, and, their infestation causing
239 mortality of the palms; (D-F) litter beetle (*Alphitobius diaperinus*), burger made from its
240 larvae, and its infestation of poultry houses; (G-I) desert locust (*Schistocerca gregaria*),
241 locust taco, and the locust swarms causing substantial crop damages and thereby impacting
242 food security. Image courtesy of Wikimedia Commons and Food and Agriculture
243 Organization (FAO).

244

245 **Fig. 2.** Insect rearing facilities. (A, B) Small rearing centres, and, (C, D) large industrial
246 rearing facilities. Despite the differences in sophistication in rearing techniques, both types
247 of rearing facilities lack tight biosecurity measures. Image courtesy of Food and Agriculture
248 Organization (FAO).

249 **Figures**

250 **Fig. 1.**



251

252

