Title: Industrial rearing of edible insects could be a major source of new biological invasions

Authors: Alok Bang[1*], Franck Courchamp[2]

Affiliations: [1]Department of Biological Sciences, Indian Institute of Science Education and Research, Pune, 411008, India. E-mail: alokbang@gmail.com

[2]Université Paris-Saclay, CNRS, AgroParisTech, Ecologie Systématique Evolution, 91405, Orsay, France. E-mail: franck.courchamp@u-psud.fr

Author contributions: F.C. conceived the idea; A.B. wrote the first draft of the manuscript; both authors contributed to the final edit.

Type of article: Viewpoints

Short title: The risks of mass-rearing edible insects

Keywords: biodiversity conservation, biological invasions, biosecurity, conservation policy, economy, edible insects, invasive species, non-native, species trade.

Number of words in abstract: 140

Number of words in main text: 1900

Number of references: 15

Number of figures: 2

[*]**Correspondence to:** Alok Bang, Indian Institute of Science Education and Research (IISER), Dr Homi Bhabha Road, Pashan, Pune, India. Telephone: +91-9850888102. E-Mail: alokbang@gmail.com

Abstract

The recent upsurge in the edible insect market has seen industrialisation and intensification without adequate regulatory policy guidelines in place. The species being reared and sold are often non-native, in rearing centres not equipped to contain the species, and in areas without regional or national pre-entry regulations, post-entry monitoring guidelines and early response programs to address escapee species. Such unregulated transport, trade and rearing of species, compounded by the policy and implementation loopholes at the regional, national and international levels will most likely lead to new biological invasions, as has been witnessed with other unregulated trade practices. To avoid this, it is necessary to monitor and regulate the species to be reared, to improve the quarantine guidelines of the rearing centres, and to be more stringent about the policies and practices that allow movements of non-native species across international borders.

Our food habits have contributed significantly to global changes in the environment such as deforestation and climate change. How ecologically sustainable is the chain of food production to food consumption is hence, a critical socio-ecological enquiry. Entomophagy—dietary consumption of insects—is increasingly seen as a solution, and consequently, an emerging alternative in the global food industry (van Huis 2013). We contend here that since it follows the same route of industrialisation and intensification than vertebrate-based traditional food production, and has modest policy and regulatory guidelines in the context of infrastructure, species movements and trade, it may add to another component of global change: biological invasions.

Currently, over two billion people in 130 countries belonging to over 3000 ethnic groups consume 1000-2200 insect species directly as a part of their traditional diets (Jongema 2017). The historical negative bias towards insect consumption is now diminishing in Europe and European-driven populations, mostly due to the perceived nutritional, ecological, ethical and economic benefits (van Huis 2013). Insects offer several advantages over traditional non-vegetarian diet in terms of higher protein-to fat ratios, less demand during development on water and other resources, lower carbon footprint, higher conversion efficiency values, low capital investment, three-dimensional rearing possibilities, shorter generation time, higher fecundity, higher resilience to diseases, and finally, a novelty in food preparations (van Huis 2013). These positive aspects of an insect-based diet have contributed to the establishment of an industry with an overall global market estimate of USD 400 million and is projected to rise to USD 700 million-1.2 billion by 2024, with major market share increases in Europe and North America (Dunkel & Payne 2016).

POSSIBLE NEGATIVE IMPLICATIONS OF INDUSTRIAL INSECT FARMING

Insects are known to be successful invaders worldwide in most ecosystems, causing ecological and economic catastrophes costing at least 70 billion dollars annually (Bradshaw *et al.* 2016). In addition to cause crop or forest destruction, and potential health hazards, invasive insects can cause damage to the native biodiversity by hybridisation, by aiding the spread of pathogens, by way of trophic impacts such as predation and parasitism, and/or by competition for resources (Hulme 2007). Historical accumulation curves of the introduction of non-native species to newer areas of habitats, which is correlated with human-mediated species dispersal, have not yet reached saturation (Seebens *et al.* 2017). The changes in thermal gradients, which historically prevented ectothermic species such as insects from invading colder habitats, has resulted in range expansions of many insect species (Bellard *et al.* 2013), and will open new regions for invasions to many species that are escaping from industrial insect farms. All these factors highlight the importance of studying the biology and ecology of insects concerned by such mass-rearing, improving biosecurity frameworks and quarantine facilities as well as establishing adequate strategic plans, legislation, policies and budgets to contain post-border release of these potentially invasive species.

RESILIENT SPECIES, TOUGHER ERADICATION

Out of the 2200 species of edible insects reported in the traditional diet around the world (Jongema 2017), several are currently reared industrially at a mass production level (Fig. 1) (van Huis 2013), and numerous other species could be expected to follow given the growth rate of the entomophagy industry. What makes the species chosen for entomophagy exceptionally dangerous is that the traits that make them appropriate for mass rearing are the very traits that could also make them successful and problematic invasive species: high fecundity, generalist feeding and nesting habits, resilience to climate changes and fluctuations, low resource requirements, and high disease resistance (van Huis 2013;

Ricciardi *et al.* 2017). Additionally, species are approved for importation keeping in mind the effect of their pathogens on humans or vertebrate hosts, but not on native invertebrates, despite potential susceptibility of the native invertebrate species to these new pathogens. Many of these incoming insects have high pathogenic loads but also have developed high immune responses due to co-evolution between the hosts and their pathogens, unlike the native species in new habitats.

This concern is not unfounded as it is reminiscent of many such past activities where movements of species for several commerce-driven activities has resulted in a deliberate or accidental release of non-native species and their pathogens, as seen in the pet trade, ornamental trade, biological pest control programs, medicinal use, species for scientific laboratory experiments and educational exhibits, fur industry, silk production, and pollination (Kumschick *et al.* 2016). There are recorded instances of exotic species imported as a food source turning into invasive species, as seen in the case of the giant African snail (*Achatina fulica*). Other flagship examples of commerce-and industry-driven invasions include the introduction of the American mink (*Neovison vison*) to Europe for fur farming where the released individuals or the escapees became invasive (Kumschick *et al.* 2016). Already, several of the mass-reared insect species have become cosmopolitan in distribution and are treated as serious pests and invasive species (Fig. 1) (Fiaboe *et al.* 2012). More species, or new varieties or strains of the former, could join them as the market expands.

POTENTIAL AREAS OF INVASIONS

While many of the existing farms and companies are located in East and Southeast Asia including China, new larger companies with considerable market share are upcoming in Europe and North America, where 15 of the top 20 companies in the edible insect market in the world are now located (Dossey *et al.* 2016). Regardless of the region, the biosecurity on these farms is rarely of regulatory standards to prevent or respond to unintentional escapes. Given the ease of rearing insects, many of these facilities have an annual turnover of rearing millions of individuals (Fig. 2) (Weissman *et al.* 2012). Even if a tiny percentage of these individuals manage to escape, it still contributes towards a sizable founder population, one that has been selected for being fast-growing at both the organism and population levels.

POLICY AND IMPLEMENTATION LOOPHOLES

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

These guiding principles are also strewn with certain ambiguities which allow movements of non-native species under technical loopholes. For example, under the invasive species guiding principles exercised in the European Union (EU), deliberate introductions of organisms are to be prevented, but regulation over accidental introductions are not exercised. Another example is of The Convention on International Trade on Endangered Species of Flora and Fauna (CITES), which prevents the importation of invasive species. However, there is no regulation on captive breeding and pet industry within whose purview the species reared for entomophagy might be reared and sold (Hulme 2007). In some instances, the policies of different international agencies are in direct conflict with each other, such as those of the World Trade Organization (WTO) promoting an unrestricted movement of products and those of the Convention on Biological Diversity (CBD) and CITES promoting regulation of these movements.

Low prioritisation by nation-states to implement international policy guidelines is another likely cause of biological invasions. For example, low prioritisation in the EU of article 8(h) of CBD dealing with non-native species has resulted in fewer resources directed to regulate movements of species.

While food safety-related risk assessment is increasingly exercised when for human consumption, regional and local invasion risk assessment and management protocols are not readily available for specific species, habitats or pathways of introduction, especially when for animal feed, even in developed countries. This often results in directives for a minimal set of notorious species which are blacklisted. A species not on the 'blacklist', only because of its unassessed nature, could still be mass-reared and accidentally released (Simberloff 2006; Weissman *et al.* 2012).

Finally, the biosecurity status of these rearing facilities is worrying. Inferior, diseased or unrequired stocks should be destroyed but are often released in the environment (Weissman *et al.* 2012). Numerous escapees have been reported in the south- and south-east Asia (AFP 2013). Even in high-income countries where the rearing facilities could be more rigorous towards containment, low awareness and commitment on the part of the stakeholders often result in illegal selling, frequent and high numbers of escapees, and absence of monitoring and early response programs, resulting in establishment and spread (Weissman *et al.* 2012).

AVOIDING NEW INVASIONS: THE WAY FORWARD

Population viability information on every potential species for farming should be available. Host-specific herbivore species may be less damaging than generalist omnivorous species. Species inept at living outside the mass-rearing facilities due to incompatibility with the new environments should be preferred, which can be assessed through climate niche modeling (e.g., species distribution modeling). Additionally, the mass rearing facilities should be developed on the lines of pathogen housing facilities, where pathogens are broadly classified into four different biosafety levels based on their pathogenicity and potential impacts.

International policies and guiding principles need to include certification, quarantine, post-entry monitoring and early response programs. The development of protocols of impact risk-assessment is essential because it assists in classifying species based on different risk categories, from low to high risk of invasion, as has been practiced in island nations such as Australia and New Zealand (Hulme *et al.* 2018). These island nations also have a more rigorous approach towards importing any living species, by developing a 'whitelist', wherein every non-native species is considered potentially dangerous till proved to be safe by a risk profiling. In contrast, the more widely implemented approach of a 'blacklist', wherein every species is acceptable for import unless specifically banned, relies on scientists needing to prove that a species is problematic, with all the associated caveats when it would go against economic pressure. Adopting a 'whitelisting' approach is more stringent and hence more effective in controlling potential invasions (Simberloff 2006); it is also more logical as the assessment would need to be done only for species considered for the industry.

Resource availability to develop these protocols and infrastructure requires trained human resource and financial capital which should ideally come from the industry. This is not only because they are the fiscal beneficiaries, but also because industry-driven voluntary codes of conduct and their investment in the research on the biology and ecology of the species to be reared have a direct influence on the deliberate introductions of non-native species. For example, the cost of risk assessment of weeds is borne by industries in New Zealand, following which the country has approved fewer than 100 plant species for introduction in the last century. Contrastingly, neighboring Australia has a government-funded risk assessment program, resulting in the admission of more than 1500 plant species for cultivation in the last century (Hulme *et al.* 2018). Consequently, any insect mass-rearing industry should be legally and financially accountable for the biological invasions they would create or allow.

CONCLUSION

We caution that industrial rearing of insects for entomophagy is based on the production of massive quantities of non-native insect species of considerable invasion potential to newer areas of habitats, in regions which lack sufficient regulatory frameworks, and in facilities from where the intentional or accidental release of these insects is highly likely. This is especially important looking at the growth prospects of this industry in the future, lack thereof we might be standing at the precipice of a new solution turned-on-its-head to become a threat to global biodiversity.

ACKNOWLEDGMENTS

A.B. acknowledges support by the postdoctoral fellowship from Indian Institute of Science Education and Research, Pune; F.C. is supported by the Invasion Biology AXA Chair and the AlienScenario Biodiversa project. F.C. conceived the idea of this piece while at the 2018 ANDINA IV Workshop and would like to thank the organisers for their invitation to this stimulating meeting. The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

No new data were used for this article.

REFERENCES AND NOTES

AFP. (2013). *One million cockroaches escape from Chinese farm*. *Telegr.* Available at: https://www.telegraph.co.uk/news/worldnews/asia/china/10264868/One-million-cockroaches-escape-from-Chinese-farm.html. Last accessed 12 December 2019.

Bellard, C., Thuiller, W., Leroy, B., Genovesi, P., Bakkenes, M. & Courchamp, F. (2013). Will climate change promote future invasions? *Glob. Chang. Biol.*, 19, 3740–3748.

Bradshaw, C.J.A., Leroy, B., Bellard, C., Roiz, D., Albert, C., Fournier, A., *et al.* (2016). Massive yet grossly underestimated global costs of invasive insects. *Nat. Commun.*, 12986.

Dossey, A.T., Tatum, J.T. & McGill, W.L. (2016). Modern insect-based food industry: current status, insect processing technology, and recommendations moving forward. In: *Insects as sustainable food ingredients: production, processing and food applications* (eds. Dossey, A.T., Morales-Ramos, J.A. & Rojas, M.G.). Academic Press, pp. 113–152.

Dunkel, F. V & Payne, C. (2016). Introduction to edible insects. In: *Insects as sustainable food ingredients: production, processing and food applications* (eds. Dossey, A.T., Morales-Ramos, J.A. & Rojas, M.G.). Academic Press, pp. 1–27.

Fiaboe, K., Peterson, A., Kairo, M. & Roda, A. (2012). Predicting the potential worldwide distribution of the red palm weevil Rhynchophorus ferrugineus (Olivier) (Coleoptera: Curculionidae) using ecological niche modeling. *Florida Entomol.*, 95, 659–673.

van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annu. Rev. Entomol.*, 58, 563–583.

Hulme, P.E. (2007). Biological invasions in Europe: drivers, pressures, states, impacts and responses. In: *Biodiversity under threat* (eds. Hester, R. & Harrison, R.). pp. 56–80.

Hulme, P.E., Brundu, G., Carboni, M., Dehnen-Schmutz, K., Dullinger, S., Early, R., *et al.* (2018). Integrating invasive species policies across ornamental horticulture supply chains to prevent plant invasions. *J. Appl. Ecol.*, 55, 92–98.

Jongema, Y. (2017). *List of edible insects of the world*. *Wageningen Univ.* Available at: https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm. Last accessed .

Kumschick, S., Devenish, A., Kenis, M., Rabitsch, W., Richardson, D.M. & Wilson, J.R.U. (2016). Intentionally introduced terrestrial invertebrates: patterns, risks, and options for management. *Biol. Invasions*, 18, 1077–1088.

Ricciardi, A., Blackburn, T.M., Carlton, J.T., Dick, J.T.A., Hulme, P.E., Iacarella, J.C., *et al.* (2017). Invasion science: a horizon scan of emerging challenges and opportunities. *Trends Ecol. Evol.*, 32, 464–474.

Seebens, H., Blackburn, T.M., Dyer, E.E., Genovesi, P., Hulme, P.E., Jeschke, J.M., *et al.* (2017). No saturation in the accumulation of alien species worldwide. *Nat. Commun.*, 8, 14435.

Simberloff, D. (2006). Risk assessments, blacklists, and white lists for introduced species: are predictions good enough to be useful? *Agric. Resour. Econ. Rev.*, 35, 1–10.

Weissman, D.B., Gray, D.A., Pham, H.T. & Tijssen, P. (2012). Billions and billions sold: pet-feeder crickets (Orthoptera: Gryllidae), commercial cricket farms, an epizootic densovirus, and government regulations make for a potential disaster. *Zootaxa*, 3504, 67–88.

FIGURE LEGENDS

Fig. 1. Two of the most popularly consumed and industrially reared insect species, their recipes and the damage they are already reported to cause. (A-C) palm weevil (*Rhynchophorus ferrugineus*), raw larvae or their soup, and, their infestation causing mortality of the palms; (D-F) litter beetle (*Alphitobius diaperinus*), a burger made from its larvae, and its infestation of poultry houses. Image courtesy of Wikimedia Commons and Food and Agriculture Organization (FAO).

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

FIGURES

Fig. 1.

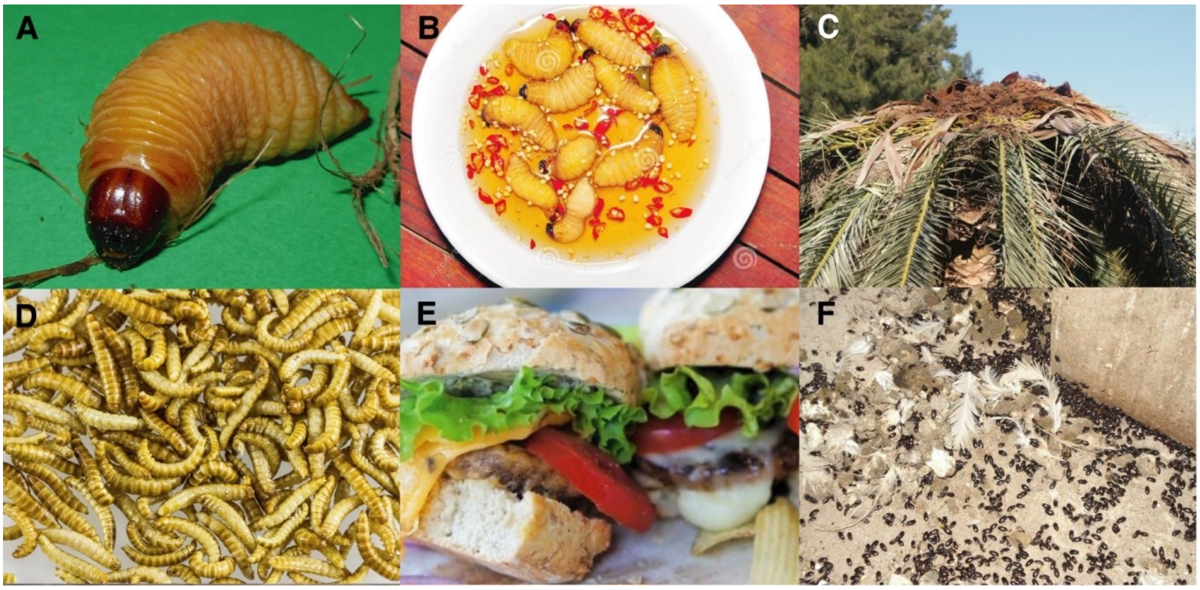

Fig. 2.