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Animal Welfare Cases: Best practice for farmed insect welfare: Lessons from Black soldier flies

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Summary

Short Summary

The market for insect farming is developing rapidly – but so is evidence that insects may be sentient animals with welfare needs. This raises urgent ethical and scientific questions of how we can assess and improve their welfare. Using black soldier flies (*Hermetia illucens*) as a case study, this case explores practical ways to answer these questions for farmed insects.

Abstract

There is a growing concern for the welfare of farmed insects, due to recognition of their probable sentience and their increasing use. Ensuring good welfare requires implementing best practice in welfare assessment and in developing evidence-based welfare guidelines for housing and husbandry. This case study on black soldier flies (*Hermetia illucens*) examines some potential methods for both, highlighting current knowledge gaps and the most urgent research priorities for insect welfare.

Learning outcomes

1. Understand the ethical and scientific basis for insect welfare considerations
2. Develop and evaluate methods for assessing insect welfare
3. Apply welfare principles to developing evidence-based welfare guidelines for farmed insects, based on knowledge of their species-specific housing and husbandry needs

Why is this case of value?

Insect farming is a rapidly developing new industry. This was originally seen as a welfare improvement over farming vertebrate species, due to the perceived lack of sentience in insects (i.e. the capacity for felt experience with positive and negative valence; Browning & Birch 2022). However, new research on insects' mental capacities (Gibbons et al. 2022) has raised concerns about the potential welfare needs of insects.

As insect farming expands to meet demands for food, feed, and research, the potential for large-scale welfare issues increases. Given emerging evidence of insect sentience and the lack of established welfare assessments, this case highlights the urgent need for scientifically validated

welfare indicators and ethical husbandry practices. By applying welfare assessment tools and species-specific research, this case provides a foundation for improving insect welfare and proactively shaping industry standards.

This case study describes the principles for best practice in farmed insect welfare assessment and development of welfare guidelines, using black soldier flies as an example. It is relevant to scientists, insect farmers and other industry stakeholders who want to ensure high welfare housing and husbandry. The principles described here can be used when developing best practice welfare assessment and welfare guidelines for different insect species.

Background and context

Use of insects is also increasing rapidly with the rise of insect farming for human food and animal feed, particularly crickets, mealworms, and black soldier flies.[1] The number of farmed insects is potentially orders of magnitude higher than any other taxa, with around 1 trillion insects slaughtered annually[1], compared with around 70 billion chickens, 1.5 billion pigs and 300 million cattle[2] (Figure 1).

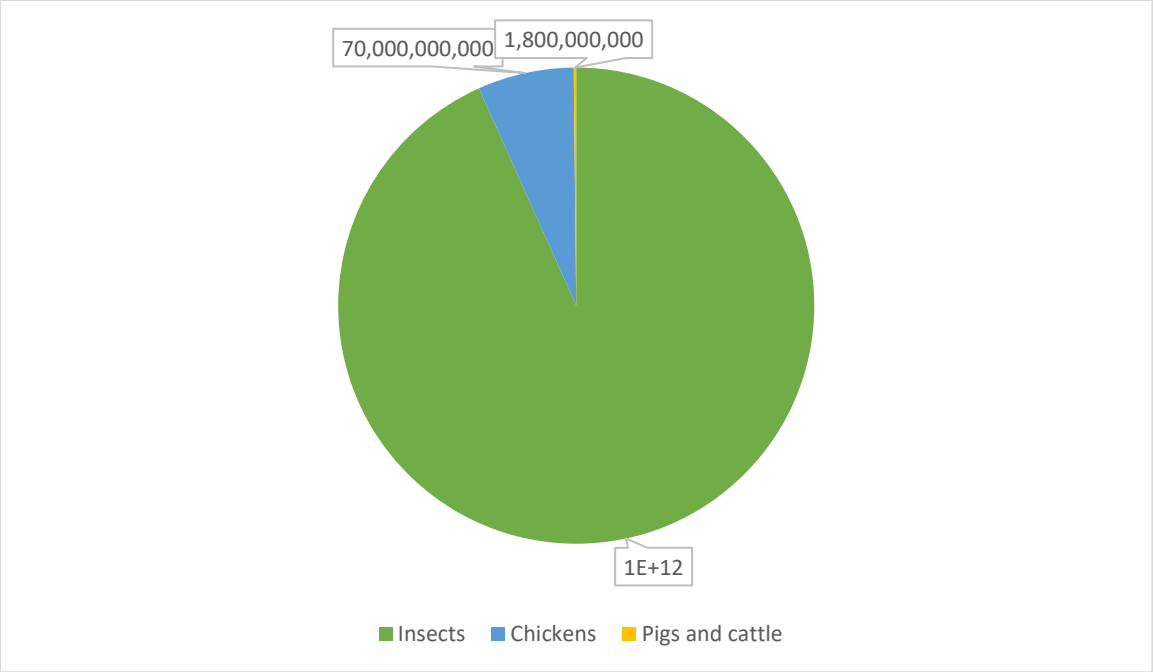

Figure 1: Numbers of farmed insects slaughtered annually, versus other terrestrial species

While insect farming is often taken to be a humane alternative to farming vertebrates (e.g. replacing fish meal for feed in aquaculture), if insects are sentient this may not be the case and there is an increasing concern for insect welfare (Broom, 2013; Van Huis, 2021; Voulgari-Kokota et al., 2023; Barrett & Adcock, 2023; Fischer et al., 2024). A recent review of the evidence for insect sentience (Gibbons et al., 2022) found that several orders of insects met many of the criteria for sentience developed by Birch et al. (2021; see also Crump et al., 2022). Additionally, the New York Declaration

[1] https://rethinkpriorities.org/publications/insects-raised-for-food-and-feed
[2] https://rethinkpriorities.org/research-area/estimates-of-global-captive-vertebrate-numbers/

on Consciousness (Andrews et al., 2024) explicitly recognises the “realistic possibility” of insect sentience.

Sentience is commonly taken to ground moral consideration (Veit & Browning, 2023) and is now being recognised in animal welfare legislation in some countries (Blattner, 2019). In the case of uncertainty, where there is at least some good-quality evidence of sentience, it is often advised to adopt a precautionary principle and enact proportional protections for the animals in question (Birch, 2017). With insect farming still in its infancy, where industry guidelines and codes of practice are still being developed, now may be a key time for ensuring insect welfare is protected. In this Case Study, we will use the example of farmed black soldier fly larvae to outline some key principles for welfare assessment and building welfare guidelines.

Black soldier flies (*Hermetia illucens*) are one of the insect species predicted to play a significant role in the spread and rise of insect farming (Figure 2). Currently around 200-300 billion animals are estimated to be farmed annually - most slaughtered at the larval stage for animal feed - a number that is expected to continue to rise rapidly (Barrett et al., 2023). For this reason, they have recently received some pioneering attention in terms of their welfare (Barrett et al., 2023; Cattaneo et al., 2024a,b; Kortsmit et al., 2023) and serve as an excellent case study for the application of the best-practice principles for ensuring good welfare. Black soldier flies belong to the order Diptera, for which Gibbons et al. (2022) found strong evidence of the capacity for pain in adults and substantial evidence in first instar juveniles. Given this evidence, it is sensible to apply a precautionary approach to minimise the risk of suffering where relatively simple and/or low-cost measures can be taken to prevent this. While there is still very little work specifically on developing animal-based welfare indicators for BSF adults or larvae, there has been some seeking to determine which welfare conditions are best for them, which can then also be applied as environmental indicators. In this case we will look at how welfare principles could be applied to a hypothetical black soldier fly farm, developing principles that can be applied both within this context and across other insect farming situations.

<Insert Figure 2 here>

Figure 2: Black Soldier Fly larvae (source: https://commons.wikimedia.org/wiki/File:Hermetiaillucens.jpg)

Assessing welfare

Imagine a manager or caretaker within a black soldier fly (BSF) farm, who is interested in improving their welfare. The first step is to assess the welfare of the BSFs, for monitoring how well they are doing and evaluating their welfare under different conditions. Behavioural, physiological, and environmental indicators can be used to assess an animal’s welfare but these must first be validated: i.e., tested to ensure they are actually measuring what they are intended to measure (Browning, 2023). Selection of indicators will depend on the goal of assessment – for instance, whether to form a judgement about an animal’s current welfare state, to identify areas for improvement, or to investigate the impact of a specific condition.

A key problem for assessing welfare within the BSF farm is a current lack of good welfare indicators. Almost no indicators have been validated for use with insects, and none for black soldier flies specifically. However, there have been a few notable attempts to develop and apply welfare indicators or assessments for insects. Cognitive judgement bias tests, that assess the level of

optimism or pessimism in judgements about ambiguous stimuli as a proxy for welfare, have been applied in bees (Bateson et al., 2011) and fruit flies (Deakin et al., 2018). A welfare assessment framework, the Animal Welfare Assessment Grid, has been recently adapted for cockroaches (Free & Wolfensohn, 2023). In line with work on hippocampal volume and neurogenesis as potential markers of cumulative welfare in mammals (Poirier et al., 2019), the rate of neurogenesis in the mushroom bodies (thought to be potentially analogous to the hippocampus) of crickets was shown to increase in enriched environments (Scotto Lomassese et al., 2000). These indicators could be tested for their accuracy and validity within the BSF farm context.

With so few indicators available, it is of highest priority to develop and validate welfare measures for use with black solider flies and other insects. Unfortunately, existing indicators are largely based on research on vertebrates, primarily mammals - a 2014 review on animal welfare science makes no mention of insects (Walker et al., 2014). Often these indicators are extrapolated to new species, but this strategy is far less likely to work with insects. Insects, like all invertebrates, have strong physiological and behavioural differences from vertebrates (e.g. stress physiology, brain anatomy, behavioural responses) that need to be accounted for in the validation process. A recent review has highlighted some of the most promising welfare indicators for farmed insects, including BSF (Johnson & Barrett 2025).

Current welfare assessments for black soldier flies are most often based on mortality rates (Barrett et al., 2023). While mortality rates might capture the worst states (i.e. those that lead to death), they will be insensitive to other milder forms of suffering, as well as unable to represent states of positive welfare. However, it has been suggested that as insects are less resilient to poor housing conditions and will die faster, mortality rates may serve as a better indicator in insects than for other taxa (Boppré & Vane-Wright, 2019). On the other hand, dead insects can fail to be detected, due to cannibalism for example, meaning mortality rates may be undercounted (Barrett & Fischer, 2023). Other 'welfare' measures are really measures of productivity (e.g. growth, reproduction) (Cattaneo et al., 2024a,b), which will only loosely correlate with welfare as experienced by the animal - and therefore have been criticized in the larger far animal welfare literature (Hemsworth et al., 2015; Browning, 2020; Zachut et al., 2020; Linstädt et al., 2024).

One potential method for assessing BSF welfare - a common method in captive vertebrate animals - is the use of welfare assessment frameworks that bring together a range of different indicators representing different aspects of the animals' environment and experience (e.g. Five Freedoms, Five Domains, as discussed below). These frameworks typically use a mix of animal-based indicators that directly represent the experience of the animal, and environmental indicators that instead represent conditions that are likely to impact welfare. But it is important to keep in mind when applying these existing welfare assessment frameworks - originally built with the needs of vertebrate livestock in mind - to insects, they must be appropriately modified for the specific needs and priorities of insects. For instance, it may be of much less concern that insects have sufficient space to fully stretch out their bodies, since they are small and have an inflexible exoskeleton, but the abiotic environmental factors such as oxygen levels and humidity can play a much larger role (Voulgari-Kokota et al., 2023).

Welfare assessment of BSF (and other insects) should ideally proceed through use of reliable validated indicators for the species, and development of such indicators should be a high research priority. This includes building welfare assessment frameworks from models such as the Five Freedoms or Five Domains, suitably adapted for the needs and priorities of insects. Where such measures are not yet available, the BSF farmer may proceed with cautious use of other proxies such as mortality or growth rates, so long as their limitations are acknowledged. In the meantime, they

may serve as useful ways of validating other indicators, due to their close link to fitness (which can be assumed to often underlie welfare experience).

Producing welfare guidelines

As well as welfare assessment, high-welfare BSF farming requires welfare guidelines and codes of best practice (e.g. Fischer et al., 2024) advising on which housing and husbandry conditions (e.g. food, shelter, social interactions, and behavioural enrichment) are necessary for good welfare. When considering other farmed insect species, given the diversity of insect taxa, welfare needs will vary markedly across species and even across life-stages within species. This requires methods for determining what conditions are significant for the welfare of the insects one is working with. Our BSF farmer would need to carefully study the current guidance on the best welfare conditions for BSF at both larval and adult life stages.

One useful starting point is an understanding of the ecology and natural history of the species - a point that has been emphasised by Vougari-Kokota et al. (2023). This can act as a guide to what is likely to be important to the animals, from the environmental conditions (temperature, lighting, humidity), perceptual environment (noise, vibrations, electrical fields), diet, and behavioural needs (social interactions, foraging, shelter) to the species' life-history. This then serves as a base description of conditions likely to be good for welfare.

The natural history approach has been used for black soldier flies. For instance, Barrett et al. (2023) combine mortality rates as a rough proxy for extreme states of poor welfare with consideration of a range of environmental conditions that, given the biology of the species, are likely to lead to (sublethal) poor welfare outcomes. Here they apply the principle of understanding the species' ecology and natural history, emphasising that "understanding the biology of BSF is critical to contextualising potential welfare concerns that may arise in industry settings" (p. 120). They consider typical behaviour and physiological needs at all life stages to identify possible welfare risks including disease, predation, nutrition, and environmental conditions such as temperature, humidity, and type of substrate. A similar approach was taken by Kortsmit et al. (2023) who examined the range of key BSF behaviours across different life stages and discussed how these can be influenced by different environmental factors. As we do, both papers conclude with an urgent call for further research to provide more definitive answers about BSF welfare.

Considering natural history must be done cautiously, to avoid committing the 'naturalistic fallacy' and assuming what is natural must necessarily be good for the animal. Instead, further tests are needed to establish that the suggested conditions really do lead to better welfare. These could include use of preference and motivation tests; developed to measure how much animals care about alternative conditions and look at how hard they will work to obtain different resources (representing how much they value that resource) (Dawkins, 1990; Kirkden & Pajor, 2006). Welfare indicators can also be applied to compare the welfare of animals under different conditions and see which are best for them.

Another useful guiding tool for compiling lists of possible BSF welfare needs is the use of welfare assessment frameworks. One of the earliest such frameworks is the simple 'Five Freedoms' model (Brambell, 1965). This model focuses on the provision of five key freedoms for good animal welfare: freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury, and disease; freedom to express normal behaviour; and freedom from fear and distress. This framework has limitations, such as the focus on avoiding negative states without much recognition of positive

welfare (Mellor, 2016). A newer and more comprehensive framework is the Five Domains model (Mellor et al., 2020) that assesses welfare through looking at the range of affective experiences an animal undergoes, focussed through the Domains of nutrition, physical environment, health, and behavioural opportunities (Figure 2). Again, thinking through the possible impacts within each of these domains can help build a list of what might matter for BSF welfare. This method will typically incorporate the natural history approach described above, to link the lists to the biology of the species.

<Insert Figure 3 here>

Figure 3: The Five Domains Model (Mellor et al. 2020)

Welfare assessment frameworks have been used for black soldier flies, such as Cattaneo et al. (2024b), who draw on the 'Five Freedoms' framework. The authors acknowledge the limitations of this framework but still consider it a useful entry point into considering the key welfare risks for a species. They assessed the optimal diet for BSF larvae, including variety and quantity, applying it to the freedoms relating to nutrition, comfort, and normal behaviour. They also looked at optimal stocking densities, where higher densities restricted movement and feeding behaviour, suggesting that higher densities would violate "both the second and fourth freedoms: freedom from discomfort and freedom to express normal behavior, respectively" (Cattaneo et al., 2024b, p. 17). Voulgari-Kokota et al. (2023) take a similar approach when breaking down the likely welfare needs of farmed BSF and house flies. They examined the categories of nutrition, physical environment, health, avoidance of suffering, enabling natural behaviour, investigating positive states, and promoting agency.

Developing best practice housing and husbandry guidelines for insects requires knowledge and understanding of which conditions really are necessary for good welfare. Collecting this information can start by compiling lists of possible welfare needs, using knowledge of the biology and natural history of the species alongside the categories found in welfare assessment frameworks. These should then be tested using experimental methods such as preference and motivation tests, and other established welfare indicators.

Conclusions

In this Case we have looked at how best practice principles could be applied within black soldier fly farming, for welfare assessment and development of welfare guidelines based on the housing and husbandry conditions plausibly necessary for good BSF welfare. However, we have also highlighted the current gaps in these areas - there are few validated welfare indicators for any insects, and limited knowledge on the best conditions to promote their welfare. Ideally any welfare measure should be valid, complete (i.e. reflects the full range of welfare experiences, including both positively and negatively valenced affects), and feasible (can be easily operationalised in the context of use) (Browning, 2022). Right now there are very few codes of best practice or husbandry guidelines for captive insects. The Insect Welfare Research Society has released a set of welfare guidelines for research (Fischer et al., 2024), however these are necessarily general without any species-specific husbandry recommendations. While we have discussed the principles of insect welfare through the case study of farmed black soldier flies, these principles can be applied beyond the insects as food

and feed industry to other types of captive insect housing, including in laboratories, zoos or aquariums, and even insects kept as pets.

Some key areas for further research include developing and validating welfare indicators and/or welfare assessment tools for insects. It is also important to investigate the most important conditions impacting welfare, particularly for the most commonly housed species (black soldier flies, crickets, mealworms). This includes an urgent need for research and development of humane slaughter techniques for insects, as the current commonly used methods may prolong suffering during dying (Barrett et al., 2024). In the meantime, we can work with our knowledge of the biology of these species to predict the probable welfare risks and construct provisional welfare guidelines that can be updated as more knowledge emerges.

One final point to keep in mind is that insect welfare needs may be easier to meet than for other animals. Insects are small and (relatively) behaviourally simple, unlikely to require complex cognitive challenges. It's plausible that they have simpler needs than vertebrate livestock. This means it might be possible to keep farmed insects under high-welfare conditions, so long as we know what is good for them. Ensuring good insect welfare is important for meeting our ethical duties, maintaining social license to operate and in many cases will improve production outcomes (Barrett & Adcock, 2023). Thus, with the development of validated welfare indicators and species-specific welfare guidelines, we may be able to meet the needs of the animals alongside those of other stakeholders.

Discussion points

1. Given the potential for insects to experience suffering, what ethical obligations do we have toward them?
2. What are the main difficulties in developing welfare indicators for insects? Can methods used for vertebrates be adapted, or do we need entirely new approaches?
3. Given the findings on insect welfare, what specific policy changes or industry practices should be considered? Are there practical ways to improve insect welfare that also meet the economic needs of the industries that use them?

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