The Journal of Open Source Software

pybeepop+: A Python wrapper for the BeePop+ honey bee colony model

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DOI: 10.xxxxxx/draft

Software

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Editor:

Submitted: 27 September 2024
Published: unpublished

Summary

Honey bees (*Apis mellifera* L.) provide critical pollination services for both natural and agricultural systems, with $50 billion USD of crops completely dependent on pollination in the United States alone (Reilly et al., 2020). However, honey bees are facing a wide range of stressors resulting in elevated colony failure rates including climate change (Zapata-Hernández et al., 2024), pathogens (Evans & Schwarz, 2011), habitat loss and decreased food availability (Donkersley et al., 2014; Goulson et al., 2015), and exposure to pesticides (Goulson et al., 2015; Woodcock et al., 2017). Agent-based colony simulation models, such as the BeePop+ model developed by US EPA and USDA (Garber et al., 2022), offer the opportunity to explore how these interacting stressors may impact colony dynamics such as colony size, honey production and overwintering success across a variety of scenarios. Agent-based models can also produce emergent behavior that is typical of complex systems such as eusocial bee colonies. These models can also be used to predict colony-level pesticide impacts based on toxicological information gathered from laboratory tests on single bees. The pybeepop+ package for Python provides a convenient and modern interface for running BeePop+ that facilitates greater adoption and application by the scientific, academic, conservation, and industry community.

Statement of need

The BeePop+ colony simulation model was published in 2022 by the US EPA and USDA to support the pesticide risk assessment process (Garber et al., 2022). BeePop+ was an update to the existing USDA model VarroaPop (DeGrandi-Hoffman & Curry, 2005), which added pesticide exposure and effects modeling capabilities. BeePop+ is an agent-based model which simulates dynamics such as queen egg-laying behavior, development and food consumption of brood and adult bees, and foraging activity patterns based on weather. Queens are simulated as individual agents, while other castes are simulated as collective 'day-cohort' agents. Pesticide exposure occurs via collection of contaminated pollen and nectar, with pesticide residue levels set by the user via a daily residue file. Interactions with parasitic *Varroa destructor* mites can also be simulated simultaneously. A sensitivity analysis of BeePop+ input parameters is available in Kuan et al. (2018).

The pybeepop+ Python package wraps the C++-based BeePop+ model in an easy to use application programing interface (API). Previously, the BeePop+ model was only accessible via built-in C++ interface functions (Curry, 2022), or a web-based graphical user interface (United States Department of Agriculture, 2023). The pybeepop+ package is designed to provide a fast and user-friendly method for running BeePop+ in Python, a programing language which is widely used in scientific settings. It also allows for rapid modification of BeePop+ parameter values and input files, which enables automated, high-throughput analyses that require many hundreds or thousands of model runs. Model results are output as pandas (The pandas

development team, 2020) `DataFrame` objects (or `JSON` strings), which facilitates downstream analysis and plotting.

An early version of the `pybeepop+` package was used to fit `BeePop+` to empirical data from a honey bee colony feeding study using Bayesian inference (Minucci et al., 2021). The Python-native interface of `pybeepop+` allowed for integration with the `pyABC` package (Klinger et al., 2018) for sampling and `dask` (Dask Development Team, 2016) for parallelization of over 10 million individual model runs. The `pybeepop+` package is currently being used by the US EPA to fit `BeePop+` to a range of colony feeding study datasets across several pesticides to explore the generalizability of the model.

The `pybeepop+` package includes pre-compiled binary versions of `BeePop+` for Windows (64-bit) and Linux (64-bit). The package will try to detect your platform and architecture and use the correct library binary. For Linux, a wide range of distributions are supported with the 'manylinux' and 'musllinux' standards. Alternately, `BeePop+` can be built from source on any Linux system and `pybeepop+` can connect to an alternate shared library binary specified by the user.

Acknowledgements

We thank Tom Purucker, Deron Smith, and several anonymous reviewers for manuscript and code review and edits. This paper has been reviewed in accordance with Agency policy and approved for publication. The views expressed in this article are those of the authors and do not necessarily represent the views or policies of the US EPA. Any mention of trade names, products, or services does not imply an endorsement by the US EPA.

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