Impacts of climate change on the Bee Industry

Geospatial assessment and associated ecosystem services in Western Australia using multi-agent modelling of socio-ecological systems

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Foreword

There are many environmental situations that impact the availability of flora that enables beekeepers to keep their honey bees healthy, producing honey or pollination ready. However, to understand the impact of changes to environmental conditions it is first necessary to identify the types of floral resources required, their geographic distribution and their nutritional value. To this end, species distribution modelling was employed to understand the current distribution of 30 melliferous flora species identified as important to Western Australian beekeepers creating a geographic database of current resource availability.

However, through discussions with local beekeepers, it became evident that there were concerns over how access to these resources would change over time and what this would mean for the economic viability of the industry, particularly how beekeepers migrate their hives around the state to access nectar and pollen events. In Western Australia, climate change is already being experienced and affecting the beekeeping industry, but what is less understood is how this environmental change will require beekeepers to adjust their hive migration approach. To answer this and other related questions, an Agent-Based Model (B-Agent) was developed to aid in our understanding of how changes in the geographic distribution of key floral species will impact approaches to accessing floral resources. The model not only helps beekeepers with their business planning but also land managers make changes required to sustain a vibrant honey bee industry.

As an example of the utility of this model, the impact of climate change on beekeepers' access to resources was used to examine how projected shifts in key floral species will ultimately increase the travel distances and time required by beekeepers. The power of the tool is in helping both beekeepers and Government organisations understand the impact of natural and managed events on the resource requirements of future generations of beekeepers.

Dr Liz Barbour
CEO

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About the Authors

Vidushi Patel has over ten years' experience in applications of geospatial tools and techniques to examine environmental management issues within natural and built environments. She completed a MSc in Geology and MSc in Geomatics in India. She has worked as a Research Associate at the Centre of Environmental Planning and Technology University (CEPTU), India offering spatial solutions to a range of spatial problems in the public and private sectors. After moving to Australia, her research interests expanded to explore interactions between nature and human systems using her expertise in geospatial applications.

Bryan Boruff is an Associate Professor in the UWA School of Agriculture and Environment at The University of Western Australia (UWA). Bryan's expertise is in the application of Geographic Information Systems (GIS) and Remote Sensing technologies to the study of environmental hazards. Over the past decade, Bryan's research interests have expanded to encompass a range of environmental management issues including renewable energy and agricultural production, population health, sustainable livelihoods and the development of spatially enabled eResearch tools. He has extensive experience working in developing nations in multidisciplinary settings with academic, private and government stakeholders.

Eloise Biggs is an adjunct lecturer at UWA and contributes to research and supervision in environmental geography. Ellie's research interests mainly encompass the spatial and temporal analysis of environmental data, predominantly within the fields of water resources and climate change. The focus of her doctoral research was on hydrological modelling of rural catchments and the spatiotemporal analysis of hydroclimatological time-series data. The latter has also influenced research investigating precipitation change (extreme events) in Nepal. Her current research uses spatial mapping to look at changes in water vulnerability, water (in)security, poverty and environmental change. Ellie has worked on projects which look at environmental risk/vulnerability, the links between climate and tea production, and also the synergies between the water-energy-food nexus and sustainable livelihoods.

Natasha Pauli is a geographer and senior lecturer in the UWA School of Agriculture and Environment with a particular interest in understanding human-environment interactions in the management of biological resources. Some of her broad research interests include local knowledge and use of biological and environmental resources for livelihoods and ecosystem management, ecosystem services in mosaic landscapes (including smallholder agriculture, broadacre agriculture, and spatially diverse urban landscapes), and the interactions between natural and social systems in environmental management and planning. Prior to joining UWA, she worked in a variety of roles including environmental scientist with a consultant firm in Perth, as an environmental officer with the WA state government Department of Water, and with the Zoological Society of London in international conservation policy. She has field experience in a range of ecosystem, cultures and environments including locations in Honduras, Cambodia, Colombia, Timor-Leste, Fiji and Australia.

Acknowledgments

- Noongar elders past, present and emerging, who are the traditional custodians of the southwest of Western Australia where this research was conducted.

- Australian commercial beekeeping industry, particularly research participants from WA's southwest region

- Bee Industry Council of Western Australia (BICWA)

- Cooperative Research Centre for Honey Bee Products and CEO Liz Barbour

- Staff from the Department of Biodiversity Conservation and Attractions (DBCA), Department of Primary Industries and Regional Development (DPIRD), University of Western Australia (UWA).

How to read this report

This report is a summary of insights from a larger PhD project. This report is to provide abstracts and links to the academic outputs including:

- PhD thesis
- Publications in academic journals (see paper 1 – 5)
- Published data (link embedded in Paper 3)
- Link for the beehive migration agent-based model (see Industry output section)

The Academic and Industry Outputs section highlights deliverables from the project including abstracts/links of academic outputs published or submitted for publication as well as infographics, which are high-level summaries of the results.

Introduction

CRC Objective

Understand bee hive migration decisions to predict the impact of climate-change and policy on the future of the honey bee product industry

Impact

This research has identified social-ecological interconnectivities within the beekeeping industry. The impacts of three priority pressures including: i) availability, access and utilization of forage sites, ii) burning of forage resources and, iii) climate change on the sustainability of the WA bee industry. A change in spatial distribution of suitable habitat for important bee forage species relative to future climate has been produced using thirty species targeted by beekeepers in Western Australia. In addition to its use in guiding beehive migration patterns, change in species range potentially informs future initiatives of conservation/revegetation/plantation with key bee forage species. The research has developed an agent-based beehive migration model as a decision support tool with the capabilities to access the impacts of various sustainability pressures on the WA beekeeping industry.

Research Design

The following figure highlights key research objectives, research methods used and the outputs for each objective.

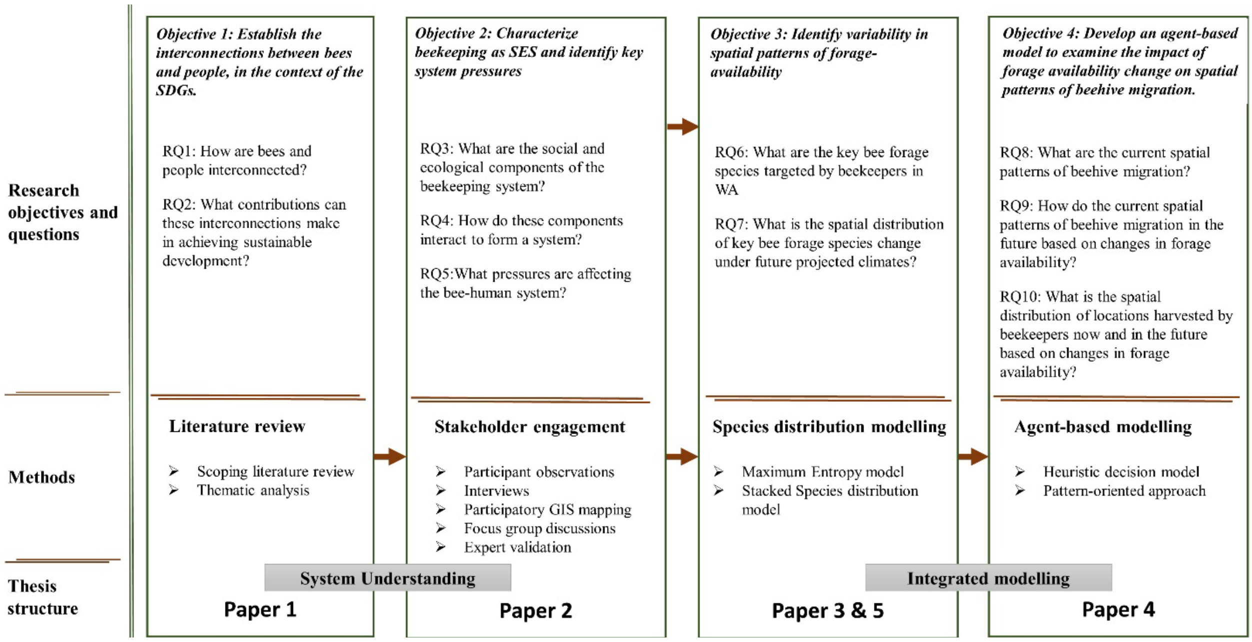

Figure 1: Research Design: developing the evidence base and relationships to reflect the dynamism of the industry

Output

This project contributes to the following Outputs as stated in the Funding Agreement:

1.1 Present bee hive site movement and productivity information, complemented by the identification and mapping of bee flora (citizen science)

Sustainability of beekeeping depend on continuous access to quality forage resources. A range of pressures effect forage resources for bees as well as the sustainability of the beekeeping industry. In migratory beekeeping, a range of social and ecological factors (e.g. forage availability and access, travel distance and livelihood dependence on beekeeping etc.) contribute to beekeepers' hive migration decisions and spatial patterns associated with the annual migration sequence.

To model beehive site movement patterns, this research has taken a mixed method approach as outlined in the following section. Various social and ecological components and their interconnectivities has been identified using a range of stakeholder engagement methods. Information related to target bee forage species, their location and flowering times were used in preparing forage availability scenarios for the beehive migration model. Two published papers contribute to this output. The abstract and links to these papers are provided in the Academic outputs section below.

1.4 Beehive migration models, incorporating current and future barriers to hive site accessibility were developed and tested as a decision support tool for beekeepers. Key pressures on the beekeeping industry have been identified as i) availability, access and utilization of forage sites; ii) climate change and, iii) burning of forage resources. Beekeepers' decision-making to select optimum forage sites is critical in the sustainability of migratory beekeeping system, yet beehive migration models lack explicit inclusion of beekeeper's decision-making. To assess the impacts of future barriers on the migratory beekeeping system, the research has adopted a hybrid modelling approach combining GIS based participatory mapping, a machine learning algorithm and agent-based modelling. The model developed in this research has represented beehive migration as a key interaction within the beekeeping system. The model results discuss impacts of future climate on changes in spatial distribution of forage related decision criteria for beekeepers using three key patterns observed in the beekeeping system in WA: i) spatial distribution of harvested cells, ii) average number of times beekeepers migrate per year and, iii) comparison of mean travel distance between commercial and semi-commercial beekeepers. These findings are reported in three peer-reviewed journal publications.

Research Approvals

Approval for this research was provided by the UWA Ethics committee - RA/4/1/924

Academic outputs

PhD Thesis

The impacts of climate change on structurally interconnected social-ecological systems: using integrated spatial modelling to assess beehive migration patterns in Western Australia.

Abstract
Beekeeping represents a unique social-ecological system (SES) where bees, humans, and forage landscapes interact to provide a range of ecosystem services. The decline in global bee stocks due to complex natural and anthropogenic drivers is impacting bee system contributions that ultimately support sustainable development. Managing these natural and anthropogenic pressures requires a systems approach to understand how pressures manifest within the system. The bee industry as a socio-ecological system has been relatively unexplored to date, with even fewer examples of integrated models that allow for the examination of pressures on the sustainability of this unique industry.

To address this gap, this thesis presents a social-ecological characterisation of the beekeeping system using Elinor Ostrom's social-ecological systems framework, and develops an integrated modelling approach, the B-Agent, to assess the impacts of climate pressures on the Western Australian (WA) beekeeping SES. Serving as a roadmap for the development of bee-human system solutions, this research addresses four objectives: i) develop an understanding of the interconnections between bees and people, in the context of the Sustainable Development Goals (SDGs), ii) through the lens of social-ecological systems thinking, characterise the elements, patterns, processes, and feedbacks of a commercial honey production system as well as the pressures acting on the system, iii) identify spatial patterns of forage-availability under future climate scenarios in WA, and iv) develop an agent-based model representing the beehive migration process to examine how changes in forage-availability will effect spatial patterns of beehive migration. A system perspective was used to address the first two

objectives, specifically, a social-ecological systems framework was used to facilitate an understanding of the structural interconnectivity between social and ecological elements of commercial honey production in WA, and to identify the biophysical and anthropogenic pressures acting on the system. To address objectives three and four, an integrated spatial modelling framework, the B-Agent is presented, integrating multiple stakeholder engagement approaches, species distribution modelling, and an agent-based model to simulate a key social-ecological interaction – beehive migration.

More specifically, a novel assessment of the critical contributions bees make to our planet's future sustainable development is presented, with examples drawn from a variety of case studies to highlight the potential contribution of bees to 15 of the 17 United Nations Sustainable Development Goals (SDGs) and at least 30 SDG targets. In addition to addressing the first research objective, this study emphasised the need for using a system approach to understand interconnectivities within the coupled bee-human system, and identified eight thematic priority areas for further investigation into bee-human relationships.

To further investigate the bee-human system, the first application of Elinor Ostrom's social-ecological system (SES) framework to the beekeeping industry, addressing the second objective, is presented. To describe the beekeeping industry, 163 SES variables outlining system elements, key patterns of interaction, and critical pressures emerging from SES interconnectivities were identified using literature and iterative stakeholder engagement. Here, results indicate the need for new modelling approaches to inform resource management decisions ensuring effective pollination and long-term apiary production.

To address this need, the B-Agent model was developed to examine the impact of climate change on the beekeeping SES. The B-Agent model represents an agent-based model developed through a series of stakeholder interviews to identify key forage species targeted by WA apiarists for honey production. A species distribution model (SDM), Maxent, was then used to model the distribution of key flora now and under a future climate scenario. SDMs for individual species were then attributed with associated flowering times to map the distribution of monthly forage availability across the southwest of WA. Finally, monthly forage availability maps were integrated with an agent-based model (ABM) representing the spatial decision-making process of migratory commercial beekeepers to examine the impacts of changes in forage availability on spatial migration patterns.

Species distribution modelling results highlight the effects of climate change on individual forage species, where over half of key flora identified by beekeepers will lose portions of their current geographic range with a trend in lateral and poleward expansion. The impact of changes to bee forage distributions was reflected in changes to future beehive migration patterns resulting from the ABM, indicating an increase in beekeeper travel distance and an eastward shift in future apiary forage locations.

The B-Agent approach provides an evidence base to explain the structural interconnectivities between forage landscapes and beehive migration decisions. By modelling the impact of climate change on forage availability, this research highlights the importance of tools and approaches for informing management decisions that ensure the sustainability of WA beekeeping. Through a representation of the structural interconnectivity between forage environments and beehive migration decisions, B-Agent provides a framework for examining the likely impacts of both biophysical and anthropogenic pressures on the spatial pattern of beehive migration relative to variations in the state of forage availability into the future.

Publications in academic journals

Paper 1: Why bees are critical for achieving sustainable development (Thesis Chapter 3, in its entirety)

Abstract
Reductions in global bee populations are threatening the pollination benefits to both the planet and people. Whilst the contribution of bee pollination in promoting sustainable development goals through food security and biodiversity is widely acknowledged, a range of other benefits provided by bees has yet to be fully recognised. We explore the contributions of bees towards achieving the United Nation's Sustainable Development Goals (SDGs). Our insights suggest that bees potentially contribute towards 15 of the 17 SDGs and a minimum of 30 SDG targets. We identify common themes in which bees play an essential role, and suggest that improved understanding of bee contributions to sustainable development is crucial for ensuring viable bee systems.

Access link:
Patel, V., Pauli, N., Biggs, E., Barbour, L., Boruff, B. Why bees are critical for achieving sustainable development. Ambio 50, 49–59 (2021). https://doi.org/10.1007/s13280-020-01333-9.

Paper 2: Using a social-ecological system approach to enhance understanding of structural interconnectivities within the beekeeping industry for sustainable decision-making (Thesis Chapter 4, in its entirety)

Abstract
The social-ecological system framework (SESF) is a comprehensive, multitiered conceptual framework often used to understand human-environment interactions and outcomes. This research employs the SESF to understand key interactions within the bee-human system (beekeeping) through an applied case study of migratory beekeeping in Western Australia (WA). Apiarists in WA migrate their hives pursuing concurrent flowering events across the state. These intrastate migratory operations are governed by biophysical factors, e.g., health and diversity of forage species, as well as legislated and negotiated access to forage resource locations. Strict biosecurity regulations, natural and controlled burning events, and changes in land use planning affect natural resource-dependent livelihoods by influencing flowering patterns and access to valuable resources. Through the lens of Ostrom's SESF, we (i) identify the social and ecological components of the WA beekeeping industry; (ii) establish how these components interact to form a system; and (iii) determine the pressures affecting this bee-human system. We combine a review of scholarly and grey literature with information from key industry stakeholders collected through participant observation, individual semi-structured interviews, and group dialog to determine and verify first-, second-, and third-tier variables as SESF components. Finally, we validate the identified variables through expert appraisal with key beekeepers in the industry. Our results identify the governance system, actors, resource system, and resource units comprising the beekeeping industry in WA. Using this approach, we

identify three principal system pressures including access to apiary sites, burning of forage, and climate change impacts on the system, which influence the SES and its sustainability. Our approach provides for an improved understanding of SES complexities and outputs that should be used to support improved sustainable management of common pooled resources to ensure effective pollination and sustained apiary production.

Access link

Patel, V., E. M. Biggs, N. Pauli, and B. Boruff. 2020. Using a social-ecological system approach to enhance understanding of structural interconnectivities within the beekeeping industry for sustainable decision-making. Ecology and Society 25(2):24. https://doi.org/10.5751/ES-11639-250224.

Paper 3: Data representing climate-induced changes in the spatial distribution of key bee forage species for southwest Western Australia (Part of thesis Chapter 5)

Abstract

The dataset includes (i) species occurrence points, and (ii) Species Distribution Model (SDM) outputs under current conditions and a moderate emission (RCP 6.0) climate scenario, for 30 key bee forage species in southwest Western Australia (WA). Occurrence data were obtained from open data sources and through stakeholder engagement processes. SDM outputs were predicted using the Maxent algorithm with the change in species range analysed using QGIS software. The model outputs provide insight into the potential implications of cli- mate change on important bee forage species in southwest WA, including dominant melliferous tree and shrub species. Changes in these species are likely to have repercussions to the ecological and social systems where a facilitatory relationship exists. This dataset is important for informing conservation efforts within the southwest Australian biodiversity hotspot.

Access link

Patel, V., B. Boruff, E. Biggs, and N. Pauli. 2023. Data representing climate-induced changes in the spatial distribution of key bee forage species for southwest Western Australia. Data in Brief 46:108783. https://doi.org/10.1016/j.dib.2022.108783.

Dataset Link

Patel, Vidushi; Boruff, Bryan; Biggs, Eloise; Pauli, Natasha (2022), “Climate induced change in spatial distribution of bee forage species in Southwest Western Australia”, Mendeley Data, V3, https://doi.org/10.17632/9vnztvcrcp.3.

Paper 4: Assessing the influence of variation in forage availability on spatial patterns of beehive migration using a hybrid modelling approach - B-Agent (Thesis Chapter 6, in its entirety)

Abstract

The contribution of beekeeping towards achieving sustainable development is increasingly being recognised. Beekeeping is a landscape-scale process requiring an integrated management approach to address multiple sustainability challenges. Accessing quality forage resources is a key social-ecological interaction within a beekeeping system. The state of the forage landscape affects the

decision-making by beekeepers to optimise forage locations for beehives placement and, in turn, influences the sustainability of beekeeping systems. To date, the complex interconnectivities of beehive migration management have not been included in models of beekeeping systems. As such, this research provides a spatially explicit hybrid agent-based model – B-Agent, which utilises multiple stakeholder engagement approaches to derive beekeepers decision rules, and hybridises a machine-learning algorithm to build forage availability scenarios with an agent-based model to simulate beehive migration processes. Here, we use the Western Australian beekeeping sector as an application for method development, testing the model using a pattern-oriented approach for its ability to reproduce patterns in (i) distances travelled by beekeepers, (ii) the frequency of beehive migration, and (iii) the spatial distribution of forage site locations harvested by beekeepers within a year. The pattern analysis is performed for current baseline conditions. An assessment is made as to likely future change using climate change scenarios to vary forage availability. Relative to the baseline, the results show an increase in travel distance and frequency of hive migration for beekeepers for future forage availability, and provides an indication that the spatial distribution of forage harvest locations used by beekeepers will shift towards eastern regions of Western Australia. This research provides an important novel tool for assessing migratory pressures on the beekeeping system. Through our presented spatial modelling framework an evidence-base can be harnessed for better informed management decisions to improve the long-term sustainability of beekeeping systems, not only in Western Australia but transferable worldwide.

Access link

This paper is currently in revision process with the journal of Applied Geography.

Paper 5: Temporally stacked bee forage species distribution modelling for flower abundance mapping (Part of thesis Chapter 5)

Abstract

Predicting spatial distribution of flowering forage availability is critical for guiding migratory beekeeping decisions. Species distribution modelling (SDM) is widely used to predict the geographic distribution or species ranges. Stacked distributions of multiple species (S-SDM) have been used in predicting species richness or assemblages. Here, we present a method for stacking SDMs based on a temporal element, the flowering phenology of melliferous flora species. First, we used presence-only data for thirty key forage species used for honey production in Western Australia, combined with environmental variables for predicting the geographic distribution of species, using MaxEnt software. The output distribution grids were then stacked based on monthly flowering times of each species to develop grids representing the richness of flowering species by grid cell. While designed for modelling flowering forage availability for a migratory beekeeping system, the approach can be used for predicting temporal forage availability for a range of different fauna that rely on melliferous flora.

Access link

This paper is submitted as a MethodsX paper alongside paper 4 in Applied Geography.

Conference Talks

- Institute of Australian Geographers Conference July 2019: "Socio-ecological dimensions of the West Australian (WA) bee industry: Spatial patterns and processes associated with migratory beekeeping"
- Free and Open Source Software for Geospatial (FOSS4G) conference Perth 2021: "An agent-based model of migratory beekeeping in Western Australia"
- Australasian Honeybee Conference 2021: "Social-ecological representation of beekeeping system: Unfolding interconnectivities for sustainable decision-making"
- International Environmental Modelling and Software Society conference 4 – 8 July 2022: "Assessing the impact of forage availability variation on spatial patterns of beehive migration using a hybrid modelling approach - B-Agent"

Research Poster

Third Australian Bee Congress June 2018: "A geospatial assessment of commercial beekeepers' hive migration patterns in Western Australia"

Toolkit

B-Agent - A hybrid Agent-Based Model (ABM) for beehive migration:
Basic version of the Beehive migration ABM is available at NetLogo modelling commons: http://modelingcommons.org/browse/one_model/6959#model_tabs_browse_info.
This version does not include any data but provides a proof of concept for hive migration modelling decisions. Agents (beekeepers and loads of beehives) and forage environments are randomly created.

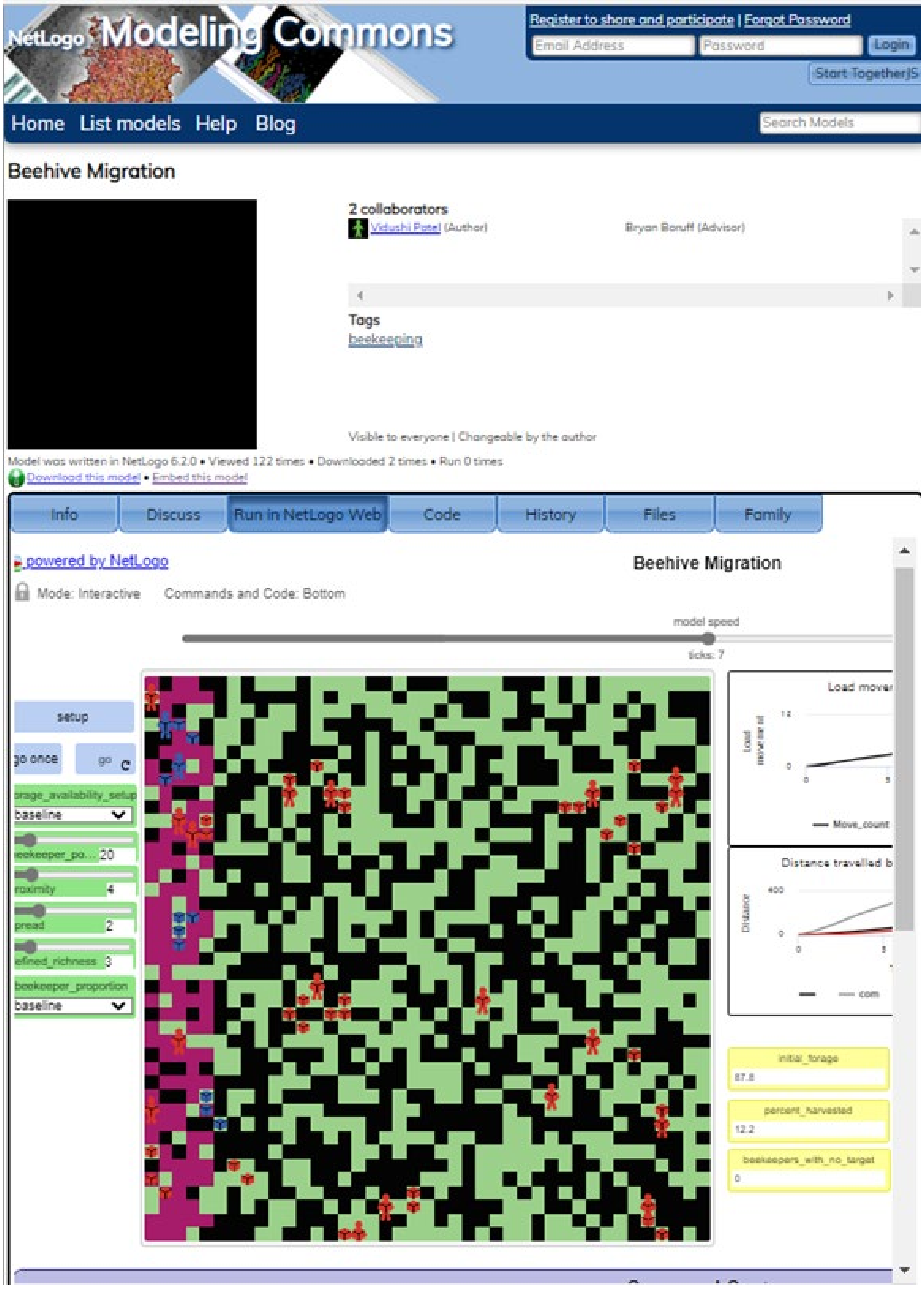

Figure 2: Beehive migration agent-based model where agents (beekeepers & loads) and forage environments do not correspond to data collected from Western Australian beekeepers. This version represents beehive migration decisions embedded in B-Agent.

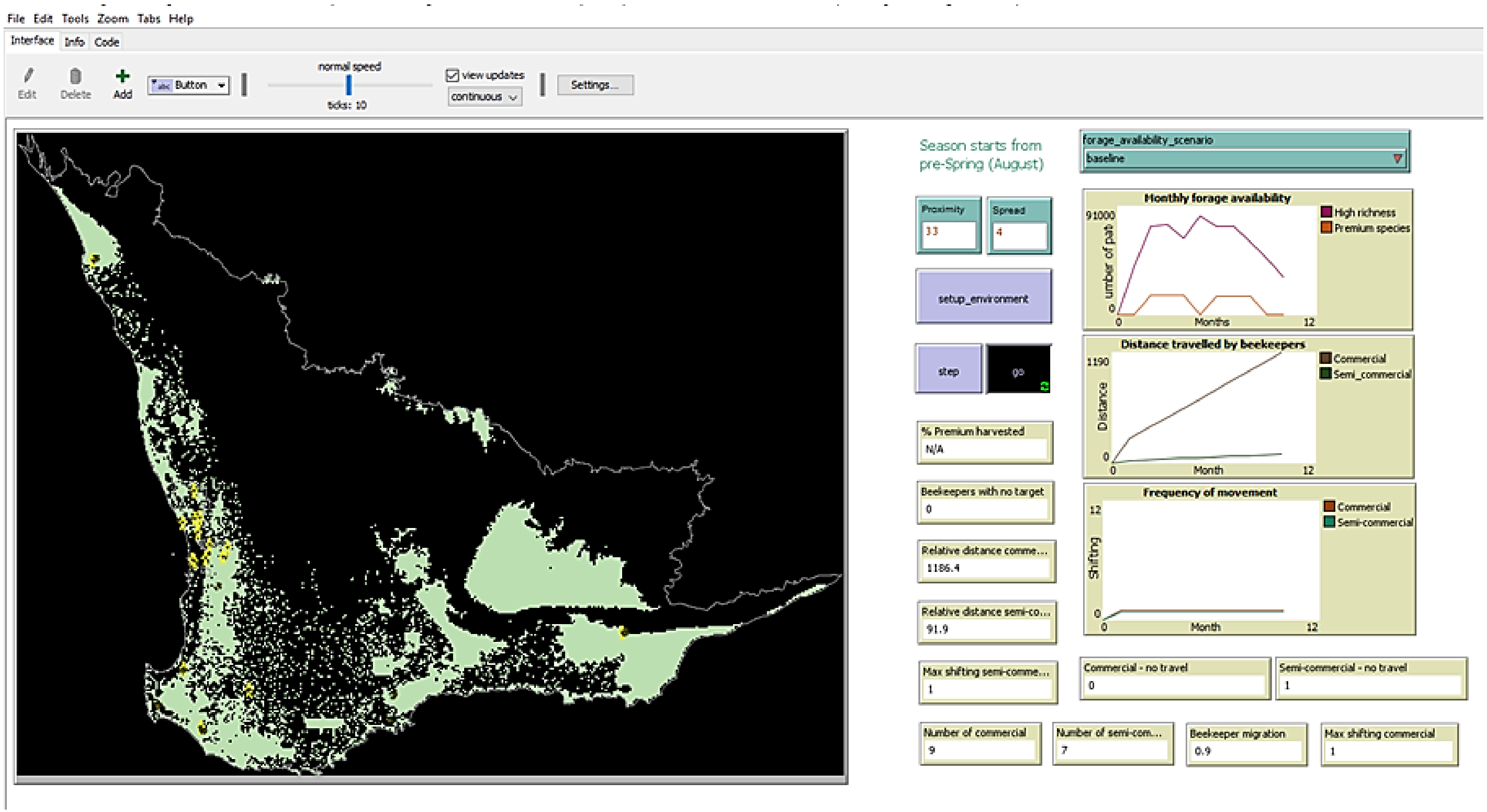

Figure 3: B-agent model interface. The model uses NetLogo software which is free to download and use. This version will be made available online once the publication reporting the model is accepted.

Industry outputs

CRCHBP Case Study Flyer and infographics

B-AGENT: modelling pressures on migratory beekeeping

The CRC for Honey Bee Products has developed the spatial modelling framework B-AGENT to help migratory beekeepers understand the effects of pressures, including climate change and bushfires, on honey bee forage resources.

Migratory beekeeping refers to beekeepers who travel across the country with their beehives following the availability of nectar and pollen flora. Migratory beekeeping depends on access to quality forage sites to maintain bee colony health and produce profitable honey. While Australia is rich in floral diversity, land management practices and irregular flowering events affect the availability of bee forage.

Beekeeping involves interconnected human and environmental systems affected by many pressures, such as climate change and bushfires. Beekeepers, beehives, forage landscapes and land managers are components of the interconnected beekeeping system. Managing the impact of pressures on any one component requires an understanding of how these pressures affect the other components.

Researchers at the CRC for Honey Bee Products identified and modelled beekeeping interconnections to help migratory beekeepers decide their itineraries. CRC researchers developed an integrated model called B-AGENT to bring together human and environmental processes that influence how a beekeeper accesses forage resources.

Understanding the components and connections within the beekeeping system helps beekeepers manage the pressures on their industry.

Researchers identified the key components central to the Western Australian beekeeping system, including:

- environmental change: pressures that affect bee resources
- bee resources: quality habitat required for food
- managed beehives: location of hives at sites with quality forage
- beekeeping interactions: the movement of hives to optimise honey production
- bee governance: state government regulation of site permits, plans and policies
- industry outcomes: bee products and services generate income
- beekeeping practices: to create apiary site demand and stimulate investment
- environmental management: sustainable practices are essential

B-AGENT combines a machine-learning species distribution model and an agent-based model to simulate the landscape of bee forage availability and associated beehive migration patterns to assess the effects of pressures on migratory beekeeping.

Using B-AGENT, CRC researchers conducted a south-west Western Australia case study to model beekeeper decision-making in response to climate change impacts. It showed that climate change is altering the distribution of 30 bee forage species. Because of these changes, hive migration will need to increase and move eastward if commercial beekeepers are to maintain current production levels. The extra travel distance will increase business costs and the working hours of beekeepers.

The modelling components used in B-AGENT to simulate climate change impacts on key forage species and the likely consequences for beekeepers

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Figure 4: B-Agent: modelling pressures on migratory beekeeping

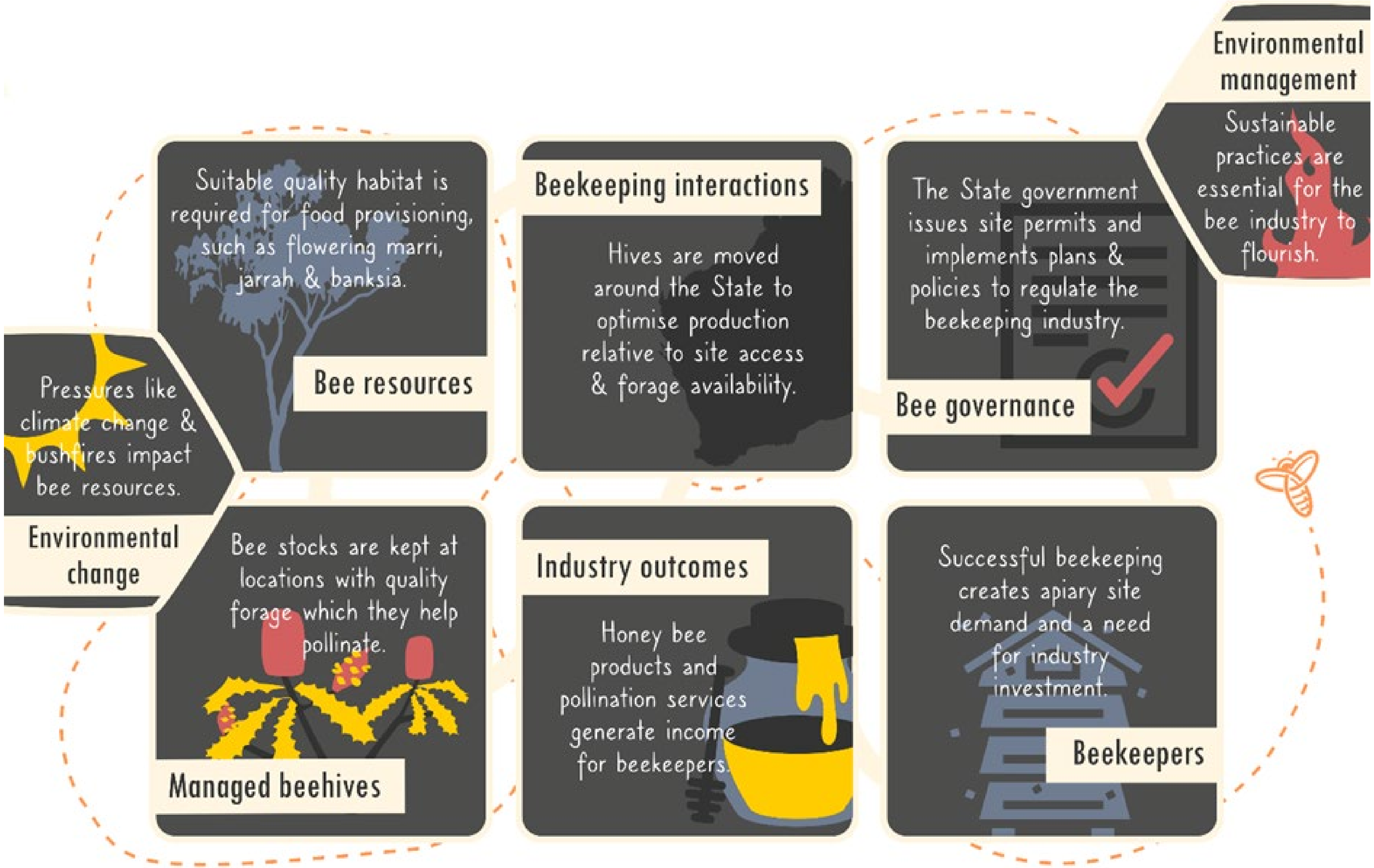

Figure 5: Overview of the key components and interconnections within the WA beekeeping system