Detailed Research Description

Background Insects are integral to our lives – they help to feed us and clear up our waste. Through loss of natural habitat, their way of life, like ours, is threatened. But insects remain 'other': annoying and often frightening. We need new approaches that can help to create emotional connections with them for our mutual environmental well-being. This project aims to do this by focusing on our most charismatic group of pollinators, bees, and by crossing traditional disciplinary boundaries, building a virtual 'hive' to bring together the perspectives of arts, humanities and bioenvironmental science working on honey-bees, bumble bees, and other wild bees.

This project will recover ideas from a multi-disciplinary and multi-dimensional seventeenth-century printed book, Charles Butler's *The Feminine Monarchie of the Bees* which aimed to advance understanding of honey-bee 'emotions' and social behaviour over three editions, first by notating the sounds of rival queen bees in monophonic renditions (1609), then by blending bee and human 'voices' in a performable polyphonic madrigal (1623), and finally by developing a new phonetic font to visually represent speech (1634). It will do so in order to: (1) explore how acoustic humanities can contribute to a new area in bio-environmental science, which is exploring the emotion-like states of bees; (2) explore how sounded artworks of wild bees can give expression to an ecosystemic experience of the natural world, past and present; (3) gain a better understanding of how biologists, humanists and artists can work together where they share a common interest, e.g. in animal behaviour, communication and emotions; (4) create a Bee Book for our time.

This project will test three hypotheses:

(1) That emotion-like states can be studied in bees using techniques adapted from human psychological experiments;

(2) That acoustic humanities can offer new ways of advancing interdisciplinary research;

(3) That living art forms can enable a shared understanding of the natural environment.

It has five **objectives**:

(1) to understand how Butler used his training in grammar, rhetoric and music (acoustic humanities) to advance his understanding of honey-bees;

(2) to prepare an annotated edition of *The Feminine Monarchie* (1623), collated against the 1609 and 1634 editions to understand the immersive experience of the hive he created;

(3) to update and broaden our understanding of bees in a digital Bee Book with new research in bio-environmental science exploring the emotion-like states of bees;

(4) through arts practice (music) to explore how acoustic humanities can create new connections between humanists, artists, scientists;

(5) to explore the potential of the idea of the digital 'book' for new modes of dissemination.

Significance 'Bee-ing Human' will have implications for how we think about: (1) the 'emotions' of bees and our connection to them; (2) anthropomorphism and its role in scientific understanding (Bekoff 2008); (3) practical exchanges across disciplines; (4) the role of audition and performance as well as observation in knowledge-acquisition; (5) the opportunities of the digital for collaboration as well as dissemination. Our research hive includes a biologist who works on bees and cognition; researchers and practitioners in the arts and humanities who share expertise on sound (and voice) as a signifying system for communicating emotions, and digital humanists working alongside the Research Software Development team at Newcastle University with whom we will explore the possibilities and limitations of the digital domain to give expression to the kind of holistic view of the natural world that Butler tried to create in print. We will study the interrelationship between bees and humans – e.g. the 'emotion-like' states of bees, and the integration of the sounds of bees and humans in written and musical compositions – to create new understanding of and emotional connections for humans with bees for our mutual well-being.

Methods Butler's ability to think across fields, from rhetoric to animal behaviour, and his use of grammar, rhetoric and music – acoustic humanities – to explore the sociability of the hive is the inspiration for our own research 'hive'. This project has three interconnected work packages (see WP 1-3 below) encompassing the use of rhetoric and music theory to explore bee and human communication and emotions; the scientific measurement of 'emotion-like' states in bees; the creative exploration of the emotions of human-bee interactions today. Each WP has its own activities and methods – scholarly editing; rhetorical/musical analysis; performance; creative composition; the study of cognitive biases etc. – but by working together we will recover Butler's acoustic humanities for the study of bees in the 21st century, while also exploring new ways of working across disciplinary structures to advance our understanding of bees, and our connections with them. We will connect our WPs in three ways: (1) through regular conversation at monthly catch-ups, reading groups, lab/field observation, and a seminar series hosted by the University Humanities Research Institute on Animals, Humans, Emotions; (2) through bi-annual reviews with our Advisory Board; (3) via collaboration on a shared output: a 21st-century digital Bee Book.

The main output of our research will be a 21st-century digital Bee Book inspired by Butler's own multi-dimensional, multi-edition, and immersive book *The Feminine Monarchie*. Butler experimented with the most advanced technology for disseminating knowledge of his day, the printing press, exploring how sound could be represented on the page: he commissioned new typeface to represent the

phonetic alphabet he developed to represent the speaking voice; and he notated the sounds (and emotions) of queen bees inside the hive, turning a simple score of bee piping in 1609 into a madrigal in table book format in 1623. A table book is ‘quintessentially sociable’ (Wistreich 2009). Butler’s use of it enabled him to blend (not blur) bee and human voices so we experience the communication of a ‘feminine monarchy’, defined by Butler as a household rather than a military camp (cf. Topsell, 1608). As the frontispiece to the 1623 and 1634 editions indicates, the book is an immersive ‘hive’: we look, we enter; we listen, we join in.

Our Bee Book aims to reinvent this experience in the digital domain, and we will work with Newcastle University’s Research Software Engineers to create a custom-built platform to host it. Our Bee Book will be visualised as a hive. Like Butler we will invite users into a lively, animated hive. Unlike Butler, we can animate his buzzing bees, creating both movement and sound. Once inside our Book the viewer will see a series of connected cells, which offer different entry points for readers/auditors. The contents of our Book will be similarly interactive. They will include, in addition to an annotated edition of the 1623 edition of *The Feminine Monarchie*, collated with the 1609 and 1634 editions, examples of and commentary on Butler's works on grammar, rhetoric and music; the first complete translation of his underpinning work on rhetoric, *Rameae Rhetoricae Libri Duo* (1597), based on the most popular school rhetoric book of the 16th century that explores the relationship between voice and emotion; animations of Butler’s notations of bee sounds, and his madrigal in table book form, ‘Melissomelos’ (the Greek word for beekeeper); new versions of ‘Melissomelos’, including in tablet form to enable users to explore the relationship between text and voice (human and instrumental) in today’s acoustic and social spaces; and data from Nityananda’s experiments in the laboratory – a more stable setting than the field – reproduced in formats inspired by Butler’s book: for example, a view of the lab experiments through the eyes of a bee.

We have chosen a digital format for our edition of *The Feminine Monarchie* because we want to animate the immersive learning experience that Butler tried to achieve in print; and we have chosen to publish it in a digital Bee Book because it is part of an interdisciplinary *exchange*, and we want to showcase this in a way that is not possible in conventional academic publication; we also want to reach different audiences: both scholars across disciplines, and the public. Our Bee Book is our ‘hive’ and our ‘lab’, and we want to explore – in conversation with software engineers – how we can use digital technology to express the ideas likely to emerge from this project: e.g. how source images like a score or a script might be translated into sounding objects, as well as explore and create interactive apps to share the exploratory research experience. Because this research project is experimental, and we are aware that new research opportunities will emerge as we progress, we will publish information about what does not work as well as what does.

The importance of the Bee Book as a means to explore and update as well as share *The Feminine Monarchie*, the laboratory work and the creative practice, all explain why we are involving the University’s Research Software Engineers from the start.

The pool of RSEs is led by Mark Turner, and it is his time that is costed into this project; however, he works as part of a team with complimentary skills and expertise essential for a project like this with different aspects to it. We know that this team-based approach will work for us: with them we have been testing and piloting ways to *animate texts*, with the help of internal Newcastle University funding (2016-2020). Our work to date has been small-scale, proof-of-concept, but we have been able to explore what we can do together: in pilots we have explored ways to animate woodcuts; to represent musical variants, and the relationship between multiple versions of a developing composition. A key connector for us is Sousa Garcia, the RA on this project. With a background in software engineering and literary studies, and as the RA previously on the Animating Text Project, which created links with the RSE pool at Newcastle University, Sousa Garcia has the expertise to prepare the texts so they are machine readable according to the standards approved by the international Text Encoding Initiative consortium.

WP1: Voices and Bees (Richards, Sousa Garcia, Williamson)

The English clergyman Charles Butler (1560-1647) is probably best known for his bee manual, *Feminine Monarchie of the Bees*, which offers advice to beekeepers on how to look after their stocks to harvest honey (Austern 1998, Woolfson 2010). Butler offers advice by notating the sound of queen bees to help beekeepers understand their emotions. He developed this approach over three decades and over three editions (as described above). To be sure, Butler makes mistakes: he misidentifies the 'vocalists' in the life of the hive, and misattributes emotions to them (he mistakes a virgin queen for the queen 'mother' and misreads signs of aggression as pleading and mourning). However, his approach enabled him to make advances too (e.g. by correctly identifying the sex of the 'queen' bee), while his notation of queen-bee piping is remarkably accurate (Jackson and Kotva, 2017). Butler's observation and audition of bees led him to reconceive their community as a household rather than a military camp, and this change in metaphor enabled him to think differently about the 'emotions' that sustain bee and human communities. Most importantly, his conception of a book as an interactive 'hive' in which readers can experience and share his insights is the inspiration for our own immersive Bee Book. This WP has two strands:

(i) A new edition of *The Feminine Monarchie* for the Bee Book. The 1623 edition is our copy-text; it will be collated against 1609 and 1634, and all variants will be recorded so we understand how his project developed. The main changes are to the 1609 edition: Butler adds content to the 1623 edition, developing the description of emotions attributed to bees especially, and develops a madrigal in table book format. The main change to the 1634 edition is the phonetic spelling of the whole text. We have also noted two significant musical revisions to 1634: a minor (and partially successful) revision to the Contratenor at bars 25-26; the change to the typography of the second bee-droning section, with much clearer grouping of minims into groups of three; this improves the legibility of the printed text, and suggests modification in the light of experience and/or feedback. All texts will be encoded so they are

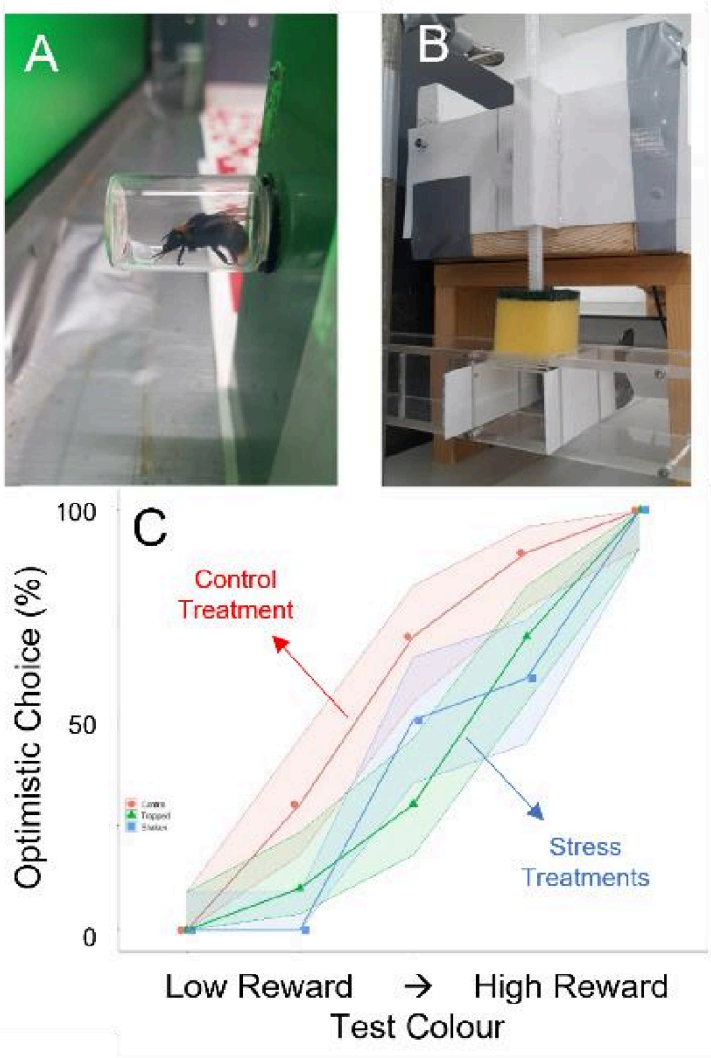
machine-readable, and fully annotated to explain Butler's source material, and also understand (and update/correct) his scientific observations. The three musical scores (1609, 1623, 1634) will also be published in a separate 'cell' and animated: we will work with Hogg, and Jackson and Wistreich from our Advisory Board, to interpret the scores for performance. Finally, the new text will be fully annotated, and we will pay particular attention to the sound features; the contemporary context; intertextual allusions; the significance of feminising the hive.

(ii) Acoustic Humanities We will develop a connected 'cell' exploring Butler's interest in acoustic humanities. and prepare selections from his books on music theory and grammar that are relevant to this edition, primarily the chapters on singing, or on phonetic spelling. Butler was a schoolmaster in the 1590s, and in 1597 he saw into print a practical rhetorical manual printed to teach delivery (*pronuntiatio*) (or *prolatio*, as Butler calls it, connoting time and rhythm in early music as well as the act of uttering). This rhetoric manual is a practical tool to enable readers to perform the connection between voice and emotion. It is the earliest document we have representing Butler's interest in the voice as a technology of meaning-making. We will commission its translation, and also provide a commentary to explain how it works as a script for improvisation (Richards 2019). Butler's hunch in the 17th century that bees experience emotions anticipates the work of bioenvironmental scientists today exploring the cognitive biases of animals who cannot report on their subjectivity (Bateson et al, 2011), and it connects to the work we will do with Nityananda's lab.

WP2: Bee Emotions (Nityananda and RA)

Humans and insects are evolutionarily distant but face similar problems – finding resources, processing information, making adaptive decisions. Could they have both evolved emotion-like states in response to the challenges they face? Recent work has developed techniques to measure such states in vertebrates, applying them to improve animal welfare (Broom et al, 2019; Paul et al 2005; Mendl et al, 2010). Applying these techniques to insects could help reveal commonalities and differences between these states in humans and insects. Promising new evidence from a handful of studies (Bateson et al, 2011; Perry et al, 2016; Schlüns et al, 2017; Deakin et al, 2018; Perry et al, 2017), has demonstrated the possibility of studying these states in invertebrates but our understanding of them remains meagre. Emotion is defined by biologists as the biological component of altered states, distinct from 'feelings' which involve the subjective component. Emotion can be thought of as an acute change in cognitive and physiological state, in response to a stimulus, which persists even in the absence of the stimulus (Nettle et al, 2012). Mood is defined as a long-term change in state, in response to repeated encounters with a positive or negative stimulus (Mendl et al, 2010; Nettle et al, 2012; Trimmer et al, 2013). Assuming, that humans and insects share similarity in cognitive and behavioural response, Nityananda will work with an RA to adapt two approaches from research on humans and other vertebrates to study emotions and mood: (i) judgement biases as an indicator of state, where an individual's response to

ambiguous stimuli indicates an optimistic or pessimistic state; (ii) reduced consumption of, and responses to rewards as measures of anhedonia (a symptom of depression).



i) Judgement Biases: To measure judgement biases in freely flying bees (Perry et al, 2016), Nityananda will use a vision-based paradigm recently developed in his lab with promising initial results (Image; explained below). Bees are presented a colour that indicates if the reward (sucrose solution) is in the tube to the right or the left. One of the colours (e.g. Blue) indicates a high reward (higher concentration) on one side and the other colour (e.g. Green) indicates a low reward on the other. Wrong choices lead to no rewards. After being trained, bees are presented ambiguous colours between the two training colours (e.g. Cyan). Stressed bees interpret these colours as indicating a lower reward and choose the corresponding reward tube – thus making a pessimistic choice. Non-stressed bees are more likely to choose optimistically and fly to the higher rewarding tube. Nityananda and the RA will use this paradigm to test the effects of naturalistic stressors including temperature, isolation, and pesticides. We will also use judgement biases to measure the social impacts of emotional states: All research on insect emotions has so far focussed on individual bees. He will test if these changed states can be transmitted to other bees. Physically agitated bees will be placed in an interaction chamber with another bee and allowed to interact for five minutes. Both bees will then be tested independently for judgement biases. If emotional contagion occurs, the second bee will also show a pessimistic judgement bias, despite not having encountered the physical stressor. [Image explained: A. Bee after entry in a chamber to sample the reward. B. Stress delivered by a foam stamp attached to a linear actuator system that simulates predatory capture of the bee in the tunnel beneath. C. Percentage of optimistic choices (with 68% binomial

confidence intervals), where bees fly to high reward locations, are higher for control bees (red) compared to stressed bees (green and blue). Values on the x-axis indicate low reward on the left and high reward on the right. Values in between are intermediate colours between high and low reward colours and are ambiguous in terms of what reward is indicated.]

ii) Anhedonia and Mood: Animals exposed to chronic stress display anhedonia, i.e., reduced response to reward, which is an important component of depression in humans (Willner et al, 1992; Thomsen, 2015). This approach has not been used in insects. We will adapt this approach to measure if long-term stressors modify bee response to rewards. Bees will be subjected to stressors administered over days. Subsequently, bees will first be trained to approach a 40% sucrose solution and then exposed to two phases of reward: either a 50% solution followed by a 30% solution or the opposite order. The amount of sucrose solution consumed in these conditions will be compared to unstressed control bees. High-speed video recording of the consumption behaviour will be used to determine any differences in the movement of mouthparts and proboscis between treated and control bees. Previous research has shown that bees learn expectation of future rewards based on rewards they encounter (Gil et al, 2007; Gil, 2010). The comparison between bees that experience an initial increase in reward (40% to 50%) and those that experience an initial decrease (40% to 30%) will allow us to ask if chronic stress changes how bees learn these expectations. Differences in response between treated and control bees will indicate disruptions of the mechanisms of reward expectation. Nityananda and the RA will use this paradigm to measure the time-course of stress responses and effects of stress impact and frequency. Finally, our team will explore ways in which the results of this research can be communicated to enable an embodied understanding of it, and how an immersive view of the laboratory through the eyes of a bee can help us look at the science anew.

WP3: Sound Experiments (Hogg)

Just as Butler deployed his knowledge of bees ‘in the field’ in a madrigal, so Hogg will take contemporary scientific and beekeeper’s knowledge of bees as the starting point for a series of compositional projects. This will include: (i) generating sound materials from Nityananda’s experiments, conversations with local bee-keepers, the Natural History Society of Northumbria and the Great North Museum, in dialogue with members of the ongoing Newcastle-Northumbria Universities' RADICAL project, which is focused on the aesthetic dimensions of data sonification. Sonification covers a range of techniques for the transformation of digitally-configured data into sound: in the case of Nityananda’s findings, this could be a sonic representation of changing levels of stress-indicators in bees. In addition to this work with Nityananda, Hogg will also (ii) collect sound materials in the form of field recordings of beehives and wild bee populations, and conduct interviews with contemporary bee-keepers, to produce a series of fixed-media, digital compositions. Finally, he will also (iii) draw on and adapt the form of the table book as a social technology, deriving his ideas and inspiration from Butler's 1623 edition. This will involve him working directly with

singers to devise newly-composed table books, and using digital technologies to recreate the unique spatial properties of this performance practice for the listener. Digital signal processing – specifically impulse response convolution filtering – will allow Hogg to situate the new compositions into virtual acoustic spaces, allowing him to simulate what music might sound like inside of a beehive, an acoustic space to which we cannot, usually, gain access. In terms of the anthropomorphic dimensions of the project, this will afford virtual experiences for the listener, as well as setting up productive dialogues, through creative practice, between the different spaces occupied by the different research strands – the library, the archive, the performing space of the table book, the inside of a beehive.