The Unsettling Eros of Contact Zones
Queering evolution in the CandidaHomo ecology

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BSc (Hons), MSc (Biological Arts)

This thesis is presented for the degree of Doctor of Philosophy of The University of Western Australia
School of Human Sciences
2018
THESIS DECLARATION

I, Natarsha Bates, certify that:

This thesis has been substantially accomplished during enrolment in the degree. This thesis does not contain material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of The University of Western Australia and where applicable, any partner institution responsible for the joint–award of this degree.

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This thesis contains only sole–authored work, some of which has been published and/or prepared for publication under sole authorship.

Signature

Date: 21/8/18
**ABSTRACT**

*Candida albicans* is a yeast, one species of the hundreds that thrive in the ecologies of the human body. Human bodies are complex and fluid ecologies: warm and moist, viscous and dry, exposed and enfolded and comprising hundreds of microbial species. *C. albicans* has adapted to almost every ecological niche, inhabiting the mouth and the gastrointestinal tract, settling under foreskins, between toes and (in)famously dwelling in the vagina. We have co-evolved; *Homo sapiens* provides myriad ecological niches for *C. albicans*. We (*Candida and Homo*) are in relentless re-orientation, responding to changes in pH, temperature, moisture and nutrients and tentatively traversing the affordances of each other’s bodies. We are animated by chemical transmissions and constant reproduction; transfigured by sensation.

This interdisciplinary research project combines scientific experimentation, art-making, evolutionary ecology and queer theory to posit the human body as a queer ecology. The sexuality, performativity and community of *C. albicans* within this ecology are explored through the apparatuses of science, art and evolutionary and queer theories. Three aspects of queer being–in–the–world, i.e., sexuality, gender, and kinship, are woven through three aspects of evolutionary theory, i.e., sexual, natural and kin selection, to form heterotopic alliances and learn how to eat better together.


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This research was supported by an Australian Postgraduate Award and a UWA Safety Net Top Up Award.

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For my beloved fremily Beth, Deb, Dev, Elena, Felix, Jane, Lisa, Megs, PremNath, Ruedi, Sue & Tiff. I did it!

Master Bates, PhD.
# Authorship Declaration: Sole Author Publications

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Signature

Date: 21/8/18
PROLOGUE

I am a scavenger: a feminist, an artist, a scientist. What, how, why matter to me. Like an ant, I palp and stroke/sniff at the edges to discover what is good to take back to the nest. Like a cat, I bask in the fascinating and disdain the disinterested. Like a dog, I roll in the rotten and run off with thrown sticks. I am formed from the exhalation of cyanobacteria and millennia of evolution. My body seethes and pulses with hundreds of other species, fashioned and transfigured by tiny lives and deaths, host to a thriving ecology. We are in relentless re-orientation, sensitive to pH, temperature, moisture and nutrients, tentatively traversing the affordances of each other’s bodies. Our bodies are animated by chemical transmissions and constant reproduction; transfigured by sensation.

As a scavenger-host, I am response-able for my ecology, to care for and about it. I forage knowledge, materials, ideas, tools and hunt transient alliances. I transmogrify ingredients into evocative victuals, sampling and nibbling, testing and sipping, kneading and folding, assembling and serving. I offer a transspecies degustation, companionable portions for consideration and transformation. I transmute the human body into a more–than–human ecology—a site of sustenance for nonhuman life, food and shelter, reproduction and kinship.

1 Previously published in “Queer Affordances: The Human as Trans*Ecology” (Bates 2017).
Figure 1 *Candida albicans* photographs taken with a pinhole camera. Photo by author.
INTRODUCTION: MATTEREALISING CANDIDA ALBICANS

OVERVIEW

This thesis explores what it means to be human when we recognise our bodies as multispecies ecologies. I focus on the intimate and fraught contact zones of biology, aesthetics, culture and care between *Homo sapiens* and *Candida albicans*, the yeast commonly known as thrush (Figure 2). *C. albicans* is one of the hundreds of viral/bacterial/fungal/insect species dwelling in the complex ecologies of the human body. Between 50 and 80 per cent of humans are hosts to *C. albicans* (Odds 1988), introduced to our bodies during birth or sex and via medical devices and prosthetics (Alam et al. 2014; Noble, Gianetti, and Witchley 2016). *C. albicans* is highly plastic, phenotypically and genotypically responsive to its environment (Scaduto and Bennett 2015). It transitions between benign commensalism and irritating, occasionally life-threatening infections (Figure 3) in response to changes in pH, temperature, nutrients and energy sources, hormones, other microorganisms and host immune cells. Humans in turn shift between ignorance and irritation, discomfort and even rage at the inflammation and discharges caused by infections. Highly adaptive, *C. albicans* occupies almost every available ecological niche in the human biome and has a particularly evocative cultural valency for humans, especially women.

![Figure 2 Scanning electron micrograph of Candida albicans. Photo by author.](image)

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2 This term refers to Monika Buscher’s “mattereality,” which plays with Karen Barad’s intra-active phenomena, posthuman performativity and the mattering of matter (Barad 2015). Mattereality emphasises that the matter of which reality is comprised, matters.

3 Parts of this overview are adapted from “HumanThrush Entanglements: *Homo sapiens* as a Multispecies Ecology” (Bates 2013).

4 This usage of contact zones refers to the power relations and (mis)understandings that emerge from haptic, embodied encounters between “Others” (Pratt 1991; Haraway 2008).

5 Commensalism is “the close relationship between two organisms, in which one organism (the commensal organism) benefits without affecting its host. The term is derived from the Latin ‘commensalis,’ which means ‘sharing a table’” (Ene and Bennett 2014, 248)
With *C. albicans*, I explore the complex ecology of the human body to understand what it means to be multispecies communities—co-evolved, interdependent companion species⁶—rather than autonomous individuals. However, the microbe is not just “good to think with” (Haraway 2003, 5): the different stories we tell—biological and artistic, evolutionary and ecological, medical and queer—have very material effects for the bodies involved. Lives and deaths hinge on these stories, which are best untangled using an interdisciplinary methodology that encompasses theory and practice, discourse and being, knowledge and experience, art and science and reaches across and into microbiology, evolutionary ecology, queerness and aesthetics—disciplines through which we learn how bodies can be in the world.

Most stories about candida are from the human perspective: the physical effects on and in a human body and the human emotional experiences during an infection. Candida is not the protagonist of these stories. This thesis, however, activates a more–than–human ecology through discursive and aesthetic explorations of candida and human cohabitation. I position the human body as a queer ecology, a fecund environment of myriad organisms, including candida. This ecology is largely indifferent to human cognition—reproducing, communicating, sensing, touching, eating, excreting, secreting, exploring, creating, transforming and dying. It is not completely indifferent to human biology, however. Who and what we ingest matters. Food, drink, antibiotics, prosthetics, hormones become the matter of others and determine “who lives and who dies” (Haraway 2016, 2), when, where and how. This is a microbiopolitical ecology,⁷

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⁶ “Companion species” describes the interdependent development, cohabitation and co-evolution of species (Haraway 2003).

⁷ Heather Paxson (2008, 17) describes microbiopolitics as “the creation of categories of nonhuman biological agents; the anthropocentric evaluation of such agents; and the elaboration of appropriate human behaviors given our entanglement with microbes engaged in infection, inoculation, and digestion.”
formed and transformed by the consumption, surveillance and exploitation of microbial bodies (Paxson 2008).

In this thesis, I untangle four main threads of this microbiopolitical ecology: the biology of *C. albicans*, evolutionary ecology, queer theory and art. I review current scientific knowledge of *C. albicans* biology to understand the scientific story of how *C. albicans* experiences its world—how it reproduces, behaves, communicates, responds and manipulates its environment. Different evolutionary mechanisms, i.e., sexual, natural and kin selection, are examined to trace understandings of how bodies evolve to be as they are. Importantly, I map the heteronormative biases of these understandings to discuss how they affect the CandidaHomo ecology. I argue that the CandidaHomo ecology is queer, where queer is the complex, sensual, response-ability of worlding. I explore sex and reproduction, the trans*performativity of bodies and environment and the eros of community, untangling how these have been influenced by evolutionary theories and how they can be used to rethink these theories. The material-semiotics of these threads are then drawn together in several artworks that were generated during this research. These artworks are intra-active and performative resolutions of the microbiopolitics of CandidaHomo ecologies.

In the rest of this introductory chapter, I describe how this project came about, what I intended and my approach. I briefly contextualise the main threads (*C. albicans* biology, evolutionary theory, queer theory and art-making) and discuss the significance of this research and the contributions it makes to how we understand the microbiopolitics of bodies. Finally, I provide a guide to navigating this document.

**Rationale & Aims**

In 2012, I was completely transfigured by the information that our bodies are only ten percent human (Savage 1977, 31). Originally trained in biotechnology, I was already fascinated by and making artwork that explored the aesthetics involved in caring for nonhuman organisms used in scientific research—those organisms that stand in for the human, that we use to learn about ourselves. I was particularly interested in the pests, the unappreciated, the uncharismatic—fruitflies, moulds, weeds and candida—and the behaviours involved in keeping them alive and in killing them. This process involved de-humanising

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8 *CandidaHomo* is a neologism that describes the naturecultural entanglement of candida and human.
9 Response-ability is the responsibility to “enable responsiveness,” particularly in scientific studies (Schrader 2010, 298).
10 Material-semiotic indicates the entanglement of materiality with semiotics, which is derived from literary theory (Haraway 1991).
11 Parts of this rationale are adapted from “Holobiontism is my life: Response to Scott Gilbert lecture ‘We are all lichens’ 14 October 2015” (Bates 2016a).
12 This proportion has recently been revised to fifty percent (Abbott 2016), although the figure depends on the metrics used.
myself—or more accurately, coming to understand the human as more–than–human natureculture, as a complex multispecies body formed by biology and culture.

In 2011, I produced *in vitero*, a nine-month performance/installation work (Bates 2012). Part of this work involved living with and caring for candida and seven other species of scientific model organisms installed in a public art gallery (Figure 4). Audience responses to the candida were unexpectedly gendered: although almost every woman knew exactly what this organism was, very few men did. Although many women responded with disgust, a few were fascinated and spent quite a lot of time in front of the display (Figure 5). Men who knew were excited and desperate to talk about their experiences. I was utterly stunned. I had thought that growing and displaying candida in uterus-shaped vessels would be hilarious.13 Far from being an amusing one-liner, however, the experience taught me how gendered our relationships with nonhumans can be, even with microbes, and how effective art can be in transforming these relationships.

Figure 4 *in vitero*, 2011, performance/installation still. SymbioticA and PICA, Perth. Photo reproduced by permission from Megan Schlipalius.

13 And it was.
That was the moment I fell in love.

However, I continued to think of the human as an anatomical, physiological, genetic, immunological, developmental and evolutionary individual. The revelation of the microbiome shattered me—I wasn’t becoming: I already was. Already a teeming, seething crowd. Always already multiple. Always already symbiotic. The vertigo of this understanding was utterly thrilling. Rather than sublime horror, I experienced a profound relief, a joy in the sensual complexity of my myriad body. It made perfect sense to me that we are sites of sustenance for nonhuman life, coagulations of opportunistic evolution and ecological kinships.

I became fascinated by the naturecultures of *C. albicans*: Who talks about it (or doesn’t)? How is it talked about? Where is it talked about (or not)? How does it live? Where does it live? How is it affected by how, where and when we talk (or don’t) about it? How have we co-evolved? How are we co-evolving? How does it intersect with gender, race, age, sexuality, technology? What are the implications, biologically, culturally and ethically, for us and for *C. albicans*, of thinking about us as companion species? I became obsessed and discovered a complex and queer ecology of discursive absences and overdetermination, biomedical discipline and cultural disgust, intimacy, eros, mutual surveillance, fecundity, heteronormative bias, biological essentialism, plasticity, response-ability and mattering.
I now make art that gestures towards this erotic abyss, towards the candida—art that asks what it is like to slide through the moist, warm folds of a human body; to caress and manipulate, but never see the other; to gorge on food and multiply without restraint; to ooze and slip over surfaces and breach cell walls in frenzied fecundity; to elongate and distend your body, twining around obstacles; to change sex in order to have sex; to be ruptured by antifungals and macrophages; to build cities and invite cohabitation.

This thesis discusses some of the microbiopolitics of CandidaHomo ecologies, entangling candida with contemporary biopolitical regimes and acknowledging microbial agency. Microbiopolitics (Paxson 2008) draws on Michel Foucault’s biopolitics and the reliance of human naturecultures on microbial categorisation and control. Paxson argues that “neglect of the microbe distort[s] our...view of the social world” (19) and Mieke Wolf (2015, 281) concludes that microbiopolitics “are based on the premise that body processes and life become the subject of orders of Power and Knowledge, and because of that, they are political interventions, which provide a starting point” (281). Exploration of the intimate relations between humans and candida provide an important and under-considered political intervention.

So, to start.

Although much has been written about C. albicans from biomedical and evolutionary perspectives, this is almost exclusively focused on how to kill it: immunology and disease, prevention and elimination. This is understandable, given the pain it causes, cost of treatment and the increasing risk of mortality from nosocomial infections (Nobile and Johnson 2015). However, recurrent infections are common, particularly vulvovaginal infections, and women learn to live with it. Although there is much anecdotal evidence as to how to manage recurrent infections that focus on modifying human behaviour, research tends to focus on acute infections rather than this chronic living with. I am fascinated by this gap, which Jane Southwell (1996) describes as “suffer and be still.” This project has been partly motivated by this lack—how do women learn to live with this? If you can’t just kill something, how do you re-orient your relationship? How might this extend to a broader ecological ethic?

Given that C. albicans is a commensal of the human ecology, which lives in most humans and trains our immune systems, very few studies investigate C. albicans as a commensal, let alone its potential benefits. Pires-Goncalves et al. (2007) and Jouault et al. (2009) are rare exceptions, although commensalism research

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has increased in recent years. Epidemiological research identifies global distribution and risk but rarely engages in social or cultural analysis. For example, Alli et al. (2017) and Moreira et al. (2001) draw attention to the epidemiological influences of geography, ethnicity, socioeconomics, sexual practices and environmental factors such as hygiene and nutrition but discuss this information only in terms of incidence and treatment. I have found very few anthropological or sociological studies, with the exceptions of Alissa Overend’s (2010) examination of the discursive and biomedical instability of candida-associated “leaky gut syndrome” and Angebault et al. (2013), who note that the majority of C. albicans research has been conducted in industrialised nations, where the rates of commensal C. albicans are significantly higher than in isolated communities (40–80 percent v 3–7 percent). Angebault et al. (2013) argue that researchers in industrialised nations have universalised these higher rates, which may, in fact, be due to understudied cultural effects.

Further, given its cultural and biological valence for women, it is most alarming that feminist, queer and body theorists and historians of science have ignored candida despite their interest in other body fluids and excretions such as menstrual blood, breast milk, semen, HIV and fat. Southwell’s (1996) article “Suffer and be still: Candida and the gender politics of medical research,” which discusses the neglect of vulvovaginal candidiasis by the medical community, is the exception. Annemarie Mol (2002, 32) argues that disease “depends on everything and everyone that is active while it is being practiced.” And so, the silence of feminist, queer and body scholars on the race, gender, sexual, age and ability biases of human discourses about C. albicans disturbs, chafes, inflames me. I have begun to fill some of these gaps through publications (Bates 2013; Bates and Schlipalius 2013; Bates 2015c; 2016a; b; 2017; forthcoming 2018b; a), artworks and in this thesis. Rather than discuss the human experience, which is overrepresented, in this thesis I attempt “candida writing,” as Haraway (2003) would say. How does this much maligned (dare I say “hated”?) inhabitant experience our bodies? What causes it to irritate, inflame, aggravate? How does it reproduce, eat, die? Donna Haraway (2015, 161) argues that “bacteria and fungi abound to give us metaphors; but, metaphors aside (good luck with that!), we have a mammalian job to do, with our biotic and abiotic symbiotic collaborators, co-laborers.” The mammalian job that I do here gives voice to the voiceless, untangling and transforming the co-labour of the CandidaHomo ecology.

The overarching aim of this project is to explore what we know about how C. albicans experiences its world, add new perspectives to human stories of contagion and antagonism and better understand the

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15 Refer, for example, to Pande, Chen, and Noble (2013); Pérez, Kumamoto, and Johnson (2013); Martins et al. (2014); Underhill and Iliev (2014); and Neville, d’Enfert, and Bougnoux (2015).
16 At least in English.
17 Paraphrasing “dog writing” (Haraway 2003).
extraordinary complexity of the ecology of the candida ecology. I do so as a commitment to “the flourishing of significant otherness” (Haraway 2003, 3).

I have several other aims, including to:

- Describe an interdisciplinary research methodology that weaves together conceptual and material ways of knowing and experiencing bodies and respects artistic practice as both material-semiotic research method and outcome;
- Examine the tangible aesthetic experiences of *C. albicans* and explore touch and sensation as ways of knowing the world;
- Re-orient the human body as a queer ecology by exploring more–than–human sex and reproduction, the trans* performativity of bodies and interspecies kinships;
- Explore the microbiopolitics of *CandidaHomo* ecologies by:
  1. Reviewing the current scientific knowledge about *C. albicans* reproduction, plasticity and sociality;
  2. Describing some of the evolutionary dynamics experienced by *C. albicans* in the human body—sexual, natural and kin—and discussing the heteronormative biases in dominant evolutionary theories;
  3. Exploring *C. albicans* from a queer perspective, including sex, reproduction and gender, trans* theories of mutable bodies and families of choice;
  4. Discussing the legacy of evolutionary theories in queer theory and exploring how each can reconfigure the other to broaden understandings of bodies;
  5. Untangling the assumptions underlying evolutionary ecology and queer theories through practice-led experimentation and art-making with *C. albicans*; and
- Stay with the trouble (Haraway 2016).

**Research Approach**

As I mentioned in the prologue, I am a scavenger. I make sense of the world through multiple lenses—my body, senses and thoughts. I am entangled in phenomena and interested in the connections between things, bodies, practices, ideas. Trained in both scientific and artistic experimental practice, matter matters to me. Trained in feminist, queer and environmental activism, aesthetics and philosophy, theory also matters to me. The materiality of theory and theories of materiality matter. This is the stuff of being-in-the-

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18 Parts of this discussion are adapted from “Cutting together–apart the mould” (Bates 2015a) and “We have never been *Homo sapiens: CandidaHomo naturecultures*” (Bates 2015c).
19 Halberstam (1998) describes scavenging as a research method.
world, of naturecultures, of microbiopolitics. My approach to research is instinctively interdisciplinary, including practical laboratory and art-making experiments and material-semiotic scavenging from microbiology, art and craft, contemporary aesthetics, philosophy, pop culture, feminist and queer theory, anthropology, post-colonialism, race and crip theory, ecology, environmental biology and humanities, speculative fiction, evolutionary biology and theory, biotechnology, sculpture, media theory and imaging practices. To weave these disparate personae together, I use a queer research method that questions the origins and effects of concepts and categories rather than reify them in an allegedly generalizable variable-oriented paradigm, because these categories do not always align with lived experiences...Queer...research methods [also] reject the fetishizing of the observable. If empiricism grants authority to categories that are operationalized into observable units, then to queer empiricism means to embrace multiplicity, misalignments, and silences. (Brim and Ghaziani 2016, 16–17)

I have adopted Donna Haraway’s analytical methods, figurations and the cat’s cradle, and Karen Barad’s understanding of the apparatus. Haraway and Barad developed these methods to map transitory convergences of bodies, concepts, technologies, economies and the un-objective political and material consequences of knowledge production. These tools are ideal for teasing out the tacit, implicit and unspoken. They encourage rigorous exploration without foreclosure and demand self-reflection and diffraction.

Naturecultures and companion species

In The Companion Species Manifesto (TCSM), Donna Haraway (2003) insists that nature and culture have always been inseparable: that “nature” is both biology and cultural construction and “culture” is both discursive and biological. By collapsing the two words into one—“natureculture”—she expands Bruno Latour’s hyphenated “nature-cultures.” Latour’s hyphen articulates a dialectical relationship between the two notions and the plural infers multiple influences and interactions. Haraway’s “natureculture” similarly points to the multiplicities of natures and cultures. However, naturecultures are co-constitutive, not dialectic; inseparable, mutualistic entanglements of all entailed by each. Marianne DeKoven (2006) contests that nature is privileged over culture when Haraway (2003, 11) writes “I have come to see cyborgs as junior siblings in the much bigger, queer family of companion species.” However, the oblique power of natureculture lies in Haraway’s assertion of the entanglement of “biopower and biosociality, as well as of technoscience” (5). Haraway complicates the nature-culture dyad by insisting that naturecultures are biological, technological and cultural (biotechnocultural) all the way down:

Cyborgs and companion species each bring together the human and non-human, the organic and technological, carbon and silicon, freedom and structure, history and myth, the rich and the poor, the state and the subject, diversity and depletion, modernity and postmodernity, and nature and culture in unexpected ways. (4)
This biotechnoculture is foundational to my approach to the *CandidaHomo* ecology.

Haraway’s (2003) “companion species” simultaneously produce and are produced by biotechnocultures. Companion species acknowledges and explores the myriad ways human naturecultures are entangled with other species and the political and ethical implications of living and becoming-with. This notion is complex and compelling and has been discussed in myriad ways since its introduction in *TCSM*. TCSM offers a pragmatic, poetic, and occasionally obtuse guide to how “an ethics and politics committed to the flourishing of significant otherness [might] be learned from taking [interspecies] relationships seriously” (3).

Thinking of candida and human as companion species means emphatically rejecting candida as metaphor and insisting that they “are not surrogates for theory; they are not here just to think with. They are here to live with” (5). Like Haraway’s dogs, candida is “in the garden from the get go” (5). *The Unsettling Eros of Contact Zones* embraces the guide demonstrated in *TCSM* and its 2008 explication, *When Species Meet*, to tease out the complex naturecultural entanglements of *Candida* and *Homo*.

**The promise of figuration**

*CandidaHomo* reconfigures the *Homo* body as an ecology of companion species. In its more traditional usage, “figuration” describes how figurative or allegorical representations are formed. In “Ecce Homo, Ain’t (Ar’n’t) I a Woman, and Inappropriate/d Others: The Human in a Posthumanist Landscape,” Haraway (1992) alludes to the definition of such figuration as “determination to a certain form,” implying that these figurations are tools for biopolitical control; representations that reinforce the parameters of culturally acceptable bodies. Haraway (1992, 86) urges feminists to “resist literal figuration, and...erupt in powerful new tropes, new figures of speech, new turns of historical possibility.” Michelle Bastian (2006) argues that Haraway’s

> figurations provide a framework within which everyday decisions might be made differently. They suggest another way of orienting oneself within one’s environment by offering possibilities of understanding and acting...Figurations are able to perform this work by revealing the underlying assumptions of specific discourses and showing the ways in which these discourses fail or contradict themselves. (1029–1030)

However, Harawayan figurations do even more important work than Bastian suggests. They reveal underlying assumptions, failures and contradictions. They also expose the material effects of such discourses, i.e., how “certain forms” emerge from the convergence of discourses—scientific, social,

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20 For example, Jordan (2011, 266) asks, “are technologies species?,” and the concomitant, “are species technologies?,” and interestingly uses surfboards to poke at the complexities of companion species.

21 In *TCSM*, Haraway describes dogs in this way. At first glance, *TCSM* seems to be just about dogs and indeed, for the most part, *TCSM* traces the co-evolution of dogs and humans.


23 OED Online 2017; emphasis added.
historical, physiological, genetic, economic, ethical, religious, spiritual, political, etc—that would not be possible singly. Hence, examining these discourses articulates and transfigures their various emergent effects (past, present and future).

My research approach does exactly this, reforming figurations by gathering, arranging and rearranging discourses, processes, investments, bodies, histories, language, environments, experiences. Following Haraway, the figurations offered here are not allegorical, or figurative representations. Instead, they map and embody the diverse political and semiotic dynamics embedded within CandidaHomo ecologies. New conceptual and material “tropes, figures of speech, and historical [and future] possibilities” are formed through this thesis and the artworks that emerged during this research, encouraging re-figurations of the relationships between Candida and Homo. These re-figurations are facilitated by another of Haraway’s tools, the Cat’s cradle.

Cat’s cradles—seriously playful/playfully serious

Haraway is an inspirational and generous scavenger. Her writings are laden bowers, bones buried by dogs, and tangled webs that give permission to be scientist, artist, theorist and cultural commentator. In “A Game of Cat’s Cradle: Science Studies, Feminist Theory, Cultural Studies,” she adopts the ancient string game of the cat’s cradle as a seriously playful and playfully serious scavenging method, adapting it to map the processes, discourses, matter and bodies that form figurations. Haraway’s cat’s cradle attends to both the ostensibly significant and the profoundly frivolous and traces the material effects of political, scientific and cultural semiotics. This project weaves a CandidaHomo cradle (Figure 6), scavenging from microbiology, evolutionary ecology, queer theory, aesthetics and art, to reconfigure the naturecultural entanglements between Candida and Homo.

Figure 6 Cat’s cradle woven by the thesis. Adapted from Furness Jayne (1906, fig. 741)

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The Unsettling Eros of Contact Zones

A cat’s cradle is, like all Haraway’s figurations, both metaphor and matter. The game is a dynamic, tangible map of the multiple lineages of *CandidaHomo* ecologies. The cat’s cradle game comprises a series of figures that contain the same ingredients but materialise them differently. Each figure is strung and restrung to “reconfigure what counts as knowledge in the interests of reconstituting the generative forces of embodiment” (Haraway 1994, 62). Each cradle forms from another and is an immanent state of becoming. Or more correctly, a figure is always present but is more or less resolved. The figures played in this project clarify how “diverse bodies and meanings coshape one another” (Haraway 2008, 4) in the *CandidaHomo* ecology. For, as Matthew Gandy (2012, 738) argues, “phenomena must be understood not only in their own specific context but also in relation to the intentionality and power relations of knowledge construction itself.”

Haraway (2008, 4) argues that the partners in these cradles “do not precede the meeting...[rather they are] figures that help grapple inside the flesh of mortal world-making entanglements,” which has made them a useful tool to “grapple inside the flesh” of the *CandidaHomo* ecology. In fact, this project is cradles all the way down—the project, this thesis, this introduction (Figure 7). Each chapter, experiment and artwork are rewoven cradles—figurations that play in the naturecultures of *CandidaHomo* ecologies. However, although they are material-semiotic maps, cradles conceptualise but are not themselves the technologies used to comprehend and experience *C. albicans*. Such technologies frame and form bodies, generating biopolitical figurations or, for the purposes of this project, microbiopolitical figurations.

![Cat’s cradle of the introduction. Adapted from Furness Jayne (1906, fig. 744)](image)

**Apparatuses and matterality**

Like Haraway, Karen Barad (2007) argues that there is no pre-existing, independent reality waiting to be discovered. Rather, *matterality* emerges from intra-actions and the apparatuses that generate those intra-actions (Barad 2007; 2015; Bates 2015a). Apparatuses materialise the discursive cradles and attend to the differential agencies of the partners in them. An apparatus *is* the physical and/or sensual *material* and the theoretical or conceptual frameworks in which an intra-action emerges. It is therefore ontoepistemological, an inseparable entanglement of being and knowing and inextricably “material-
discursive”²⁵ (Barad 2003, 816). Apparatuses perform “agential cuts,” which are “‘local’ resolutions within a phenomenon” (Barad 2012a, 32). Agential cuts are not observers/subjects looking out at external Others/objects. Rather, self looks at self—appropriate for exploring the CandidaHomo ecology. This is an “exteriority-within,” a simultaneous cutting “together-apart” (32). Matter at all scales has agency but apparatuses recognise “practices of differentiating engaged in by nonhumans, whereby nonhumans differentiate themselves from their environments, from other nonhumans, and from humans, as well as from other others” (Barad 2012a, 31). They are an obligation to pay attention to what gets included and what gets excluded, to what counts and why, and to the consequences of those inclusions/exclusions. In this, apparatuses are like cat’s cradles. They are not just tools for reconfiguring what counts as knowledge, however. They are intrinsic to its formation and consequences. This thesis and each chapter are apparatuses and agential cuts, as are the experiments and artistic outcomes. I take up Barad’s urge to become accountable for cuts made and attend to those made by candida. In doing so, this project “materializes [the] effects” produced by these cuts (31), creating and exploring apparatuses that cut the CandidaHomo ecology together-apart.

Practice-led research

I am interested in the cuts enacted by apparatuses; how they evoke and generate particular material-semiotics and afford or foreclose matterial agency. I am interested in the materiality and performativity of CandidaHomo ecologies: the matter of bodies; the laboratory equipment necessary for care, nurture, killing and preservation; the imaging devices essential for navigating the spatiotemporal scales between C. albicans and H. sapiens; the architectural spaces of laboratory, gallery, hospital and domicile; the art-making materials for care, display, protection and preservation; the paper, books, pens, computers that facilitate knowledge production, consumption and transmission; the texture of surfaces; the caress of smells; the oppressiveness of heat and cold; the flow of liquid and the soft resistance of agar; the durability of plastic; and the immateriality of light. Consequently, practical experimentation and creation, both scientific and artistic, have been integral to this project. I have used scientific protocols and artistic practices to play in the CandidaHomo ecology, to untangle how humans generate knowledge of candida and, more importantly, how candida generates knowledge of humans. I shift between material-discursivity and material-semiotics, acknowledging the fine distinctions between discourse and semiotics that are so important for making science and art.

²⁵ “Material-discursive practices are specific iterative enactments—agential intra-actions—through which matter is differentially engaged and articulated (in the emergence of boundaries and meanings)...The point is not merely that there are important material factors in addition to discursive ones; rather, the issue is the conjoined material-discursive nature of constraints, conditions, and practices. The fact that material and discursive constraints and exclusions are intertwined points to the limited validity of analyses that attempt to determine individual effects of material or discursive factors” (Barad 2003, 823).
I frame this practice-led research through Barad’s understanding of agential apparatuses as performative representations, Michel Foucault’s (1990) *scientia sexualis and ars erotica*, by which he differentiates the mechanics of knowledge production from the pleasure of experience, and Yoko Ono’s (2000) *instruction painting*, which separates practice from realisation, opening a work of art to aleatory and collaborative production. Barad, Foucault and Ono all value the performativity of bodies and production through collaboration or relationality and critique or reject reductionist claims to truth and determination to certain form. This framing allows me to explore the particular ways experiences/knowledge between species are generated through apparatuses, be they scientific, artistic, queer, evolutionary, ecological, conceptual, sensual or microbiopolitical. This research method opens diverse spaces for *Candida* agency and *Candida Homo* response-ability, recognising the value of scientific and artistic practices and interrogating the underlying assumptions and embedded biases of both.

Barad (2007) rejects *representationalism* and insists upon performativity. She is very clear that entities are not independent of their representation. The system that assumes an autonomous “representer,” who uncovers knowledge from an external “represented,” ignores the “practices through which representations are produced.” This system is common in scientific knowledge production, where data is considered to be synecdochical. This is obviously not restricted to science: this is how semiotics works. However, a Baradian world is not *waiting* to be represented, it is *always already* represented, or more correctly, it is always already *representations*—performative representations, where representations are not abstractions of the real, but apparatuses; contiguous, iterative materializations of phenomena. Understanding representations as apparatuses recognises their roles in framing knowledge but more importantly here, acknowledges their performative materialities and distinct connotations of what *candida* is—in—the—world.

Scientific protocols, despite their aspirations to standardisation, replicability and reliability, rely on consistent laboratory conditions, identical equipment, clear protocols, tacit knowledge and haptic familiarity.²⁶ The method understands numerical data as a synecdoche of phenomena. Care of and for an other is implicit in the process and lost in translation between phenomenon and data. Failures are frequent and crucial for the process and are also lost in the translation to results, conclusions or publication. Foucault (1990) describes this system of representationalism as *scientia sexualis*, where lived experience is reduced to an informatic body that can be studied, taken apart and comprehended, revealing the “truth” of the thing (Rocha 2011). However, laboratory conditions are inconsistent, equipment is never identical and breaks down, protocols are rarely clear, tacit knowledge is difficult to share and takes time to learn. In this sense, scientific experiments are Baradian apparatuses, performative iterations that manifest and map “material engagements with the world” (Barad 2007, 49) and, of course, are themselves material

²⁶ By which I mean that the actions of the practitioner become more similar with repetition and less prone to variation or error.
engagements in which *ars erotica* lurks.²⁷ Practices of *ars erotica* (Foucault 1990) value sex as a human experience, appreciating and preserving actions which can bring about pleasure. They also haunt *scientia sexualis*.

Scientific protocols are also instruction paintings, since “the work becomes a reality only when others realize the work. Instructions can be realized by different people in many different ways. This allows infinite transformation of the work that the artist [scientist] himself [sic] cannot foresee” (Ono 1966). Art-making, at least the way I do it, tends towards chance and serendipity. It is more open to performative and affective experiences of bodies, the *ars erotica*, than data generation. For this project, I started with instruction science, scavenging from scientific research papers and inserting myself firmly into the *scientia sexualis* apparatus. I collected hundreds of protocols and practised the experiments to comprehend the candida. I also let the candida run wild, gaining intense pleasure and traversing *scientia sexualis* to *ars erotica*. The work became reality only when [candida and I] realized the instructions in many different ways (Figure 8).

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²⁷ *qua Ceci n’est pas une pipe* (Foucault 1983)
The Unsettling Eros of Contact Zones

**Context**

**Evolutionary theory and naturecultures**

From its beginning, evolutionary theory has been firmly grounded in economic and political theory (Lewens 2010). Importantly, Darwin’s theory was strongly informed by the economic theories of Thomas Malthus and Adam Smith (Lewens 2010; Subramaniam 2014). Malthus’ understanding of social competition for scarce resources was reflected in Darwin’s theory that individuals are engaged in a “struggle for existence” (Darwin 1859) which his contemporary Herbert Spencer referred to as “survival of the fittest” (Subramaniam 2014). According to Darwin’s theory, individuals that possess traits that favour their survival in an environment of scarce resources are more likely to pass these traits to the next generation, i.e., they are “selected for.” Darwin also adapted Smith’s understanding of “free competition” and focus on the individual. Variation enables some individuals to better compete with others for the scarce resources and survive to reproduce. How different might evolutionary theory and biology be, if Darwin had used Karl Marx’s social theories rather than Malthus and Smith?

Darwin was also deeply embedded in the politics, economics and science of the British imperialist project, which relied on the theft, exploitation and control of land, resources and bodies (Wilkins 2008). The British Empire was at its height, dominating the economy and politics of the globe through military enforcement and a Smithian policy of free trade (James 1994). The British scientific community was implicated in the acquisition, categorisation and trade of resources and bodies on behalf of the Empire. Slavery was not abolished in England until 1833, only six years before the publication of *The Origin of the Species*. The American and French revolutions and the Napoleonic war had only recently occurred and war was fundamental to British imperialism (Black 2013). In addition, hundreds of thousands of people were dying from yellow fever, bubonic plague, typhus, cholera, smallpox, malaria, influenza epidemics. Evolutionary theory, therefore, emerged in naturecultural conditions of brutal competition and economic and physical exploitation.

Eugenics is also woven through evolutionary theory: Darwin was a plant and animal breeder (Subramaniam 2014); Darwin’s cousin Francis Galton founded human eugenics as a field of study, although it does not seem that Darwin supported his ideas; Social Darwinism adapted Darwinian theory to reinforce biological

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28 Den Boer (1999) describes natural selection as an ecological process that results in “non-survival of the non-fit” rather than “survival of the fittest.” He argues that fitness is not either/or; less fit individuals can still survive and reproduce. Non-survival will happen if a genetic mutation is not viable or if the individual is “unlucky.” Refiguring natural selection as “non-survival of the non-fit” allows continuous reshuffling of genes and gene combinations that may include unfavourable or deleterious traits, spreading the risk of extinction over genotypes and enabling highly sophisticated adaptations to develop and accumulate. He also argues that common assumptions such as competition, reproductive costs, optimization and optimal life-history traits should be critically reconsidered in light of this refiguration. Similarly, Birch (2016) discusses the notion of “survival of the fittest” and critiques the criteria used to determine fitness “maximisation” and the way “maximisation” is measured.
determinism and sex, gender, sexuality and racial biases, although some suffragettes used evolutionary theory to challenge assumptions of women’s subordination (Oikkonen 2015); and eugenicist Julian Huxley coined the term “modern synthesis” in his highly regarded 1942 book Evolution: The Modern Synthesis. The Modern Evolutionary Synthesis, which synthesised natural selection, Mendelian inheritance and population genetics, reinforced “survival of the fittest,” and firmly established sexual reproduction as the driver of inheritance. Mary Jane West-Eberhard (2009) notes that

the synthesis of Darwinism with Mendelian genetics, sometimes called the “Neo-Darwinian” synthesis...led to a concept of evolution driven by random mutation, with complex novelties produced when a series of favorable mutations accumulated under natural selection over time. The emphasis was on transmission genetics, and the phenotype, with its environmentally sensitive development (Darwin’s main subject and the object of natural selection) fell into comparative neglect on the part of evolutionary theorists in favor of a strong emphasis on the role of the gene. (298).

The Modern Synthesis subsequently disentangled itself from human eugenics, although the eugenics of animal husbandry and plant breeding lurk at its core. Walsh (2014b, 295) observes that “modern synthesis evolutionary biology has become the canonical understanding of the process of organic evolution. A central pillar of modern synthesis evolutionary biology is the conception of genes as theoretically privileged entities. They are discrete units of phenotypic control, exclusive units of inheritance, and units of evolution.”

The science of immunology similarly emerged from an antagonistic biomedical model of disease and hygiene during fin de siècle Europe, which was dominated by globalisation, nation-building and war (Sangodeyi 2014). The Spanish influenza pandemic, which resulted in the deaths of over a million people, was rapidly followed by the industrialisation of biological weapons during World War I. Immunology’s proponents argued that our own bodies are sites of competition and war (Greenberg 2005), naturalising “survival of the fittest” and reinforcing it as the driver of evolution. For example, Paul Ehrlich, who worked with Robert Koch on microbial disease and vaccination, developed the foundations of acquired immunology and coined the still commonly used phrases “magic bullet” and “immune surveillance” (Greenberg 2005). The immunological model of “self/non-self” emerged during the intense nationalisation of post-WWII (East-West) Europe and the Russian-US cold war (Greenberg 2005), reiterating earlier militaristic understandings of both evolution and immunology.

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29 Among many others.
30 Élie Metchnikoff and Paul Ehrlich were co-recipients of the Nobel Prize for Physiology or Medicine in 1908 for their contributions to immunology (Greenberg 2005). Cell-mediated immunity (phagocytosis) was theorised by Mechnikoff in 1882 and antibody formation theory (acquired immunity) was developed by Ehrlich in 1900.
31 Ehrlich also demonstrated that immunity could be inherited, although the mechanism was not genetic.
The Red Queen hypothesis describes the co-evolution of hosts and pathogens as an “evolutionary arms race” (Van Valen 1973; Dawkins and Krebs 1979) and was developed during cold war nuclear proliferation and global cultural and social upheaval, including the civil rights movement, second-wave feminism, sexual liberation, Prague Spring, anti-Vietnam protests and the peace movement, environmentalism, post-colonial immigration, the Northern Ireland conflict, animal liberation, numerous wars of independence throughout colonised countries in Asia, Africa and South America and the HIV epidemic. Evolutionary theories of kin and group selection (Wynne-Edwards 1963; Hamilton 1964a; b; Wilson 1971) also emerged during this period that reinforced the immunological model of “self/non-self” and naturalised cultural antagonisms.

Androcentric and heterosexist models arose following the development of sociobiology, which asserted that human social behaviours are genetic, in the 1970s and evolutionary psychology in the 1990s (Oikkonen 2015).

Several cooperation-driven models of evolution, including symbiosis, followed the social movements of the late twentieth century as alternatives to the competitive individualism and gene-centrism of neo-Darwinism and kin selection theory (Keller 1991; Oyama 2000). Feminist and queer challenges to neo-Darwinism have broadened understandings of the biology of bodies (Colebrook 2010; Parisi 2010; Weinstein 2010; Grosz 2012), although they have not specifically examined the Red Queen and host-pathogen relationships. The ubiquity of the microbiome and its symbiotic relationships has provided significant support for these models and it is now commonly accepted that symbiosis is a driver of evolution (Kiers and West 2015). Twenty-first century evolutionary theories resonate with ecological understandings of environmentalism and immunology as complex and responsive (West-Eberhard 2009), although they are highly contested by neo-Darwinian theorists.

Finally, it is important to note the absence of artificial or “unnatural” selection within most discussions of evolutionary theory (Bell 2005), i.e., the human-induced effects of selective breeding, genetic engineering and biotechnology, all of which intersect in the CandidaHomo queer ecology. Singer (1996), for example, has argued for consideration of human political economies and human-induced environmental change as selection pressures distinct from “natural” selection. Singer’s call resonates with Haraway’s natureculture, urging an interrogation of what evolutionary theory considers to be a natural body.

32 E.O. Wilson’s 1975 book Sociobiology: The new synthesis attempted to explain social behaviours through genetics and evolutionary theory. His assertions of correlations between genes and human social behaviours and structures caused enormous controversy, including accusations of biological determinism, Social Darwinism and universalism (Holtzmann 1977; Spanier 1995).
Co-evolutionary companion species

The “discovery” of the human microbiome in 2001 resulted in a paradigm shift in understanding the complex relationships between hosts and commensal inhabitants (Romani et al. 2015). Monica Bakke (2014) argues that

although [knowledge of these organisms] usually does not really affect our self-recognition directly and is not a threat to our identity, an awareness of it definitely alters the way we think of our bodies, as they no longer can be perceived as sealed vessels, but rather as transspecies environments. This mode of being-in-the-world reconfigures traditional ontological hierarchies and values. (155)

It is now widely accepted that eukaryotic organisms, including humans, rely on microbial associations, i.e. we are communities of mutualistic, commensal and antagonistic symbionts (Guerrero, Berlanga, and Margulis 2013; Garcia and Gerardo 2014; Kopac and Klassen 2016). However, Ley, Peterson, and Gordon (2006, 841) observe that it is “unclear how much traditional ecological theory can be strictly applied to the microbial world.” This is exacerbated by five main factors: (1) theories of the evolutionary dynamics of ecologies developed from observations of the interactions of multicellular macro-organisms (Mideo and Reece 2012); (2) until recently, symbiotic relationships have been considered to be rare and between two or three species, not hundreds; (3) the dominant human-microbe figuration is one of antagonism—infection and disease; (4) mutualistic or commensal symbioses are not historically associated with human bodies; and (5) the features of most of the ecological niches within holobionts are poorly characterised, although micro-niches abound and conditions are highly complex and changeable (Camp et al. 2009). For example, the human intestine (Figure 9) involves mechanical, chemical, immunological and microbial interactions. In fact, niches just millimetres apart can vary so greatly as to be entirely unique. However, Gabaldón, Naranjo-Ortíz, and Marcet-Houben (2016) observe that

three fundamental questions remain poorly addressed: (i) what are the recent selective pressures (at the species and population level) in human fungal pathogens? (ii) are opportunistic pathogens tightly adapted to humans, or do they colonize us from other niches in the environment? and (iii) what preadaptations in the environment favor a jump to an increase virulence in humans? (9)

33 Refer to “HumanThrush entanglements” (Bates 2013) for a discussion of the emergence of the microbiome.
Figure 9 Components of the intestinal mucosal barrier. Human intestinal mucosa barrier mainly consists of a mechanical barrier (a), a chemical barrier (b), an immune barrier (c) and a microbial barrier (d). Reproduced from Yan, Yang, and Tang (2013, fig. 1), with permission from Elsevier.

The Red Queen hypothesis, proposed by Leigh van Valen in 1973, describes the antagonistic co-evolution of predator-prey and host-pathogen relationships (Lively and Morran 2014) and has been repeatedly used to explain the evolution of pathogenicity, virulence and sex in C. albicans (Ene and Bennett 2014). Van Valen (1973) argued that “organisms must constantly adapt, evolve and proliferate not merely to gain a reproductive advantage, but also simply to survive while pitted against ever-evolving opposing organisms in an ever-changing environment.” Consequently, the figuration of C. albicans as an opportunistic pathogen adapted to the human host through the Red Queen mechanism frames CandidaHomo co-evolution as antagonistic, hostile and competitive and engaged in an “evolutionary arms race” (Van Valen 1973; Dawkins and Krebs 1979). However, this arms race cannot explain social behaviours, such as altruism or cooperation, which are common in the CandidaHomo ecology.

The symbiotic ecology bounded by the skins of eukaryotes has come to be known as the “holobiont” (Lederberg 2001). Hundreds of microbial species dwell within the ecological niches of holobionts, however, the evolutionary ecologies of holobionts are poorly understood. Emerging theories of holobiontism

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34 Named after the Red Queen in Lewis Carroll’s Through the Looking-Glass, who tells Alice that “it takes all the running you can do, to keep in the same place” (Heitman, Sun, and James 2013; Sagan 2013a).
35 Palaeontologist Leigh Van Valen (1973) suggested that co-evolution of competing species might explain constant extinction rates in the fossil record.
36 Symbiosis has come to be accepted as a selective pressure (Booth 2014). For much of the twentieth century, symbiotic relationships, such as those of lichen or coral, were considered interesting anomalies. However, they are now thought to be the most common lifestyle, due in large part to the efforts of evolutionary biologist Lynn Margulis.
37 Evolutionary ecology inflects ecology, the study of the interactions of organisms with each other and their environments (Allaby 2015b), i.e., who is there, where they are, what they are doing and how they are doing it, with how the organisms got there and how they adapt. It also highlights the importance of interspecies and environmental
attempt to “reconfigure traditional ontological hierarchies” (Guerrero, Berlanga, and Margulis 2013, 134) by proposing that the *hologenome*, i.e., “the assembly of genetic information contributed by the animal or plant and its associated microbiota” is a single evolutionary unit:

many prokaryotic species establish close and in many cases persistent relationships with members of a wide range of eukaryotic taxa. Second, hosts typically have strong specificity for microbial symbionts and their functions. Third, symbiotic relationships have enhanced the limited metabolic networks of most eukaryotes by contributing several prokaryotic metabolic capabilities, such as methanogenesis, chemolithoautotrophy, nitrogen assimilation, and essential-nutrient anabolism. Also, many prokaryotes defend their symbiotic partners against natural enemies and promote their adaptation to specific ecological conditions. Others may have parasitic or pathogenic effects on their hosts, causing attenuated host fitness and aberrations in reproduction [58]. Finally, host immune genes evolve rapidly in response to microbial symbionts and as a gene family are frequently involved in hybrid incompatibilities. (Guerrero, Berlanga, and Margulis 2013, 135)

However, holobiontism is highly controversial, with many arguing that the theory is too simplistic and individualistic and does not account for the complexity of selection pressures and ecological dynamics within the holobiont (Douglas and Werren 2016; Queller and Strassmann 2016), including the thousands of interkingdom cooperations and competitions between hundreds of uni- and multicellular eukaryotic and prokaryotic species within the *CandidaHomo* ecology. Examination of the ecological dynamics and evolutionary pressures in these “transspecies environments”³⁸ is therefore crucial to understanding the *CandidaHomo* ecology.

In the *CandidaHomo* ecology, a “phenotype” (trait) could be expressed by a cell, an organism, a group of organisms and the host. Ley, Peterson, and Gordon (2006) propose that selection acts at all these levels, drawing on Multi-level Selection Theory (MLST). MLST, which focuses on the phenotype as the level on which selection acts, rather than the genotype, was developed by David Sloan Wilson and Elliott Sober in the 1990s and adapted from the theory of group selection proposed by V.C. Wynne-Edwards (1963). MLST has gained much support, including from E.O. Wilson, who developed kin selection theories from the study of eusocial insects (Sober and Wilson 2011). MLST proposes that if a cell or organism engages in social behaviours that provide a fitness advantage, selection shifts to act on the group. Cooperation and culture could, therefore, be group-level mechanisms for adaptation. The principal argument against multi-level selection theory is that the unit of inheritance is difficult to determine, i.e., it is unclear how trait variation is passed to the next generation (West et al. 2006).

³⁸ Bakke (2014, 155)
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Queer microecologies

This thesis posits the human body as a queer ecology, a complex and diverse entanglement of relationships between *H. sapiens*, *C. albicans*, other microbes, culture and technology. Queer ecologies disrupt the mutually constitutive apparatuses of “nature” and “sexuality” and reconfigure the entanglements of biology, sex, sexuality, intimacy, affiliation, geography, geology, ecology, culture and technology (Sandilands 2016). Queer ecologies entangle the interrogations of queer theory of the intersectional biopolitics of gender, race and sexuality with more–than–human sexualities. Eng, Halberstam, and Muñoz (2005, 4) argue that queer epistemologies “rethink the relationship between intersectionality and normalization from multiple points of view.” Consequently, queer ecologies act to redress the human exceptionalism in queer theory, rethinking the more–than–human biopolitical entanglements of sexuality, gender, race, class, colonisation. The human body is a prolificate beat of myriad more–than–human sexualities, where human cells and microbes, including *C. albicans*, replicate, procreate and propagate. Consequently, the figuration of queer ecology enables me to explore how *CandidaHomo* relationships are constituted and who gets to be at the table, when and where.

As Kath Browne (2006, 888) argues, *queer* is “not a simplistically appropriated identity category, but a fluid set of possibilities and contestations.” Heather Davis (2005, 23) describes queer as “a politics of difference...that uses experiences of oppression and desire as a means of collective political affiliation...It is not a politics of who you are, but of what you do.” Queer, therefore, is the pleasures and struggles of the everyday, the iterative, unconscious generation and regeneration of identity, the transformation and modification of flesh, the grief and trauma of alienation and toxicity, the deep temporality of plastic and fossil fuels, the biopolitics and eros of desire and the commitments and alliances of flourishing. It is vital to remember that nonhumans are not queer (Wilson 2002; Hird 2006b). This is a human understanding, but the apparatus of queer can tease out the heteronormative and androcentric biases and assumptions within ecological and evolutionary theories and scientific and artistic practices of knowledge production. Further, given its commitment to “continuing critique of its exclusionary operations” (Eng, Halberstam, and Muñoz 2005, 1), the apparatuses of ecology, evolutionary theory and microbiology can tease out some the exclusionary operations of queer theory.

Catriona Mortimer-Sandilands (2005, 1) calls for “a ‘queer ecological’ sensibility” that considers ecological devastation in the context of the damaged HIV/AIDS body. David Griffiths (2015) turns Mortimer-
Sandilands’ queer ecological sensibility inwards and attends to the heteronormative microbiopolitics that coalesce on HIV/AIDS bodies. He argues that this discourse relies on understanding the human body as “bounded and unitary” and microbes as “foreign and dangerous intruders” (41). However, although Griffiths attends to the anthropocentric bias towards sexual reproduction in light of the fecundity of cellular reproduction, he fails to re-orient his discussion to the biomedical reductionism, surveillance and control of viral replication and sexuality in the HIV/AIDS body and its implications for viral worlding. Instead, he turns away from the HIV/AIDS body and back to lichen. The queer ecological sensibility I am interested in cultivating re-orients toward the microbiopolitics of the agential cuts made in CandidaHomo ecologies, cuts made by humans and candida alike.

For Neel Ahuja (2015),

queering in this sense emerges by tracing an affective materiality that interrupts anthropocentric body logics and space-time continuums rather than a sovereign stance of negation in relation to Law, including the law of compulsory reproduction...[It is] an inquiry into the unrealized lifeworlds that form the background of the everyday. This requires thinking askance the human and thinking death, animality, and vulnerability in an age of many extinctions. (373)

Others have re-oriented towards the queer microbiopolitics in which I am interested, including Paxson and Ahuja’s own sensitive discussion of mosquito-borne malarial infection, in which he folds queer theory back on itself, resisting what he calls “the anti-relational stance against reproduction in queer theory” (367). Eben Kirksey (2015) urges a multispecies ethnography that attends to the response-ability of microbes, since they “interact with our classification practices...torqued as taxonomic scientists care for them by isolating distinct strains, culture them on sterile media, and store collections in refrigerators” (764). Spanier (1991) observed that molecular biology text books described bacteria engaged in plasmid transfer as male or female, depending on whether they were the source or recipient of the plasmid. She notes the gender/sex conflation and the heteronormativity underlying such descriptions and argues that these ideologies are “embedded in studies of life at the microscopic level” (177).

I am particularly interested in the queer microbiopolitics of CandidaHomo ecologies because the infections attributed to C. albicans are almost exclusively induced by human action. What we do to our bodies encourages C. albicans reproduction and proliferation, including antibiotics, prosthetics, feminine hygiene products, dietary choices, hormone adjustment, immune suppression, biomedicalisation, latex and silicone sex toys and prophylactics. I want to attend to C. albicans in this rollercoaster of “attraction and feeling, debility and death” (Ahuja 2015, 370), over which C. albicans has little control but is attributed a voracious malevolence. I am not suggesting that having thrush, balanitis or candidemia is pleasant or desirable. In

fact, I recognise the discomfort and possible threat to life that these present. However, I also try to reconfigure the material-semiotics of the cuts made and untangle who is response-able. For, a queer reading of space reveals a distributed agency of desire that extends beyond individual or even multiple human bodies to incorporate nonhuman nature, inanimate objects, surfaces, and smells...The ‘sexual body’ is no longer one human subject but an array of different elements that dispels any attachment to ‘residual humanism.’...Heterotopic alliances involve or at least imply a coalescence of interests—even if not explicitly acknowledged—between disparate groups or individuals concerned with the defence of marginal or interstitial spaces. (Gandy 2012, 738, 740)

I am interested in the possible heterotopic alliances that emerge from the marginal and interstitial spaces of the CandidaHomo ecology and how they might teach us how to eat better together.

**Candida and contemporary microbial art**

The “discovery” of the microbiome has generated an explosion in scientific research that explores who is there, why they are there, what they do there and when and how they got there, i.e., the biological and evolutionary dynamics between the different microbial species and the host body. The notion of the human as a multiple, porous entity rather than an autonomous, contained individual has also captured the imagination of contemporary artists in the last twenty years, including exhibitions such as *Gut Instinct* at the SciArt Centre,42 *The Secret World Inside You* exhibition at the American Museum of Natural History, *Micropia* science gallery,43 and the *Invisible You* permanent exhibition at the Eden Project.44 Microbial artworks walk the lines between science communication, Romanticism, vitriolic pathogenism, speculative design and figuration (both allegorical and Harawayan). Some artists are interested in the poetic possibilities of this notion and produce representational and/or speculative works that express the agency of the microbiome, including Alexandra Daisy Ginsberg, Rebecca D. Harris, Rogan Brown and Rachel Mayeri. Others are interested in scientific accuracy and work with living organisms and microbiologists to produce work that conveys the lived experiences of the microbes and the humans—the ars erotica of human-microbial ecologies—including Anna Dumitriu, Joana Ricou, Francois-Joseph Lapointe, Sarah Craske and Kathy High.

The vast majority of microbial artwork is representational, using non-microbial materials to represent the appearance and/or experience of the microbes and/or host. The spatiotemporal scale differences between human and microbe make representation challenging. Much of it conveys the sublime beauty of the microbial world at a macroscopic scale, for example, the exquisite glass sculptures of Luke Jerram; perpetuates the militaristic war rhetoric of immune discourse, for example, *Horde* by David Bickley; or are

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42 http://www.sciartcenter.org/gut-instinct.html
43 https://www.micropia.nl/en/
speculative designs depicting possible futures, for example, Alexandra Daisy Ginsberg’s *E. chromi* or Michael Burton’s *The Race*.

A small number of microbial artworks, however, use living microbes as media. Making and displaying artworks that contain living microbes presents unique challenges for artists and institutions used to painted still-lifes and landscapes. Living artworks requiring care or maintenance place extra strain on institutional resources and these institutions are likely to have policies that consider nonhuman living organisms to be pests that might destroy work or objects. In addition, the display of living microbes associated with disease is a minefield of institutional biosafety regulation, material containment and public health and anxiety management. This is equally true for art galleries, science galleries and science museums. However, it is worth noting that the American Society of Microbiology’s annual “microbial art” competition dictates that the artwork must use living microbes. The artworks entered in this competition are almost exclusively “created” by microbiologists, not artists, and the living artworks are not displayed in public—photos of the “final” works are submitted and distributed.

“Microexploitation” artworks use the microbes as artistic tools, like paint, with little to no regard for the lived experiences (or consent) of the organisms. Although the artist may have cared for the creature in order to manipulate it, the aesthetic outcomes of these works tend to have little to do with the organism itself. Why use yeasts to create portraits of human faces (qua Zachary Cofer or Jeff Tabor) or abstract geometries? What microbiopolitics are at play here? These works are representationalism, traditional figuration. The organisms are equivalent to the mineral pigments of paint or silver nitrate on photographic paper. The artists do not look back and do not consider the response-ability of the organisms with which they create their representations. These works enact an unreflective microbiopolitics that exploits the performative reproduction of the organisms.

I have been unable to find any contemporary visual artwork that explicitly uses *C. albicans* or deals with its microbiopolitics. Several artists have made bread, yoghurt or beer from vaginal cultures, including Toi Sennhauser, Cecilia Westbrook and Zoe Stavri, but these works do not specifically discuss candida. They discussion of human sexual politics rather than exploring the microbiopolitics of food production and consumption. The cheeses made from human breast milk in Miriam Sumin’s *Lady Cheese Shop* would likely contain *C. albicans*, however, the work activates human sex and gender politics rather than

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45 Although some recent projects look at the requirements for curating, collecting and conserving living artworks.
46 Refer to chapter 3 and the conclusion for discussion of these challenges.
47 Recently, science galleries have appeared globally. These institutions are mixtures of science museums and art galleries and tend to host short term exhibitions rather than collections.
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microbiopolitics. Christina Agapakis and Sissel Tolaas’ *Self-made* microbiome cheeses do explore the microbiopolitics of production and consumption, however, do not specifically examine *C. albicans*.

The only contemporary art about candida I have been able to find is the pop song, *Virus*, by Björk on her 2012 album, *Biophilia* (Björk 2011b). This song explores symbiosis and the reliance of viruses on hosts for reproduction. Although the title refers to viruses, not candida, Björk has attributed the song’s inspiration to her recurring oral thrush infection:

> i’d been fighting this candida issue in my throat and i had to really change my diet and use different medication and it sort of seems to pop up and its kinda hilarious. It’s like I have this new neighbour that i have to sort of learn to live with. And obviously you know this fungus is inside all of us and it’s never about eliminating it. You have to kind of just live with it. (Björk 2011a)

The song’s lyrics and accompanying video poetically embrace the broader complexity of symbiotic relationships. The song tells the story of a sensuous, irresistible seduction, with lyrics such as

> I knock on your skin
> And i am in
>
> The perfect match, you and me
> I adapt, contagious
> You open up, saying welcome.

In the album manual, essayist Nikki Dibben (2011) expresses a common trope of horror about antagonistic symbioses (parasites), especially those that take over or change host behaviour, when she declares the song to be “an alarming analogy for love between humans!” However, the evocative lyrics and gentle, sweet instrumentation of the song do not convey such horror. Rather, they combine violence with sympathy and imply that the seduction is mutual—the “virus” cannot survive without the host and is as compelled to consume the host as the host is to be consumed (Björk 2011b, 12–15):

> Like a flame that seeks explosives
> As gun powder needs a war
> I feast inside you
> My host is you

*Virus* reflects the complex attraction and repulsion of the *CandidaHomo* ecology. It escapes anthropocentrism, telling the story from the perspective of candida not human. It conveys the sensuality of candida experience and insinuates the deadly effects of antifungals in the final repeated lyric “my sweet adversary.” *Virus* is a uniquely nuanced and compassionate figuration of the microbiopolitics of the *CandidaHomo* ecology that has been inspirational.
CONTRIBUTION TO KNOWLEDGE & SIGNIFICANCE

This is the first study that synthesises the biological, cultural, political, evolutionary, aesthetic and ethical implications of considering the human body as an ecology. The thesis makes several disciplinary and methodological contributions to understanding CandidaHomo naturecultures, including the following disciplinary contributions:

1. This is the first study discussing *C. albicans* outside microbiology or health discourse. As a member of the human ecology that has particular associations with both human gender and sexuality, its absence in other scholarship is a significant omission.

2. This research is the first to explore *C. albicans* through contemporary visual art-making. Previous representations of *C. albicans* have been materialised only through scientific experimentation or through music. Contemporary art provides affective and response-able experiences that elicit reconsideration of the microbiopolitics of CandidaHomo ecologies.

3. This research expands the discussion of gender and sexuality biases in evolutionary theories, which have focused on animals (and some plants), to include fungi and microbes. It challenges the heteronormativity and animal-centrism of these discussions, arguing that *C. albicans* contributes to queering the apparatus of evolutionary theory.

4. This research contributes to discussions of the ambiguous and ambivalent relationships between queer theory and biology, evident in queer theory’s emphasis on discourse. It also expands discussions of human-microbe sexualities and positions the human body as a queer ecology.

5. This research draws attention to the role of *C. albicans* in the co-evolutionary ecology of the human body. *C. albicans* research has, for the most part, not considered sexual and kin selection, focusing on the Red Queen and natural selection pressures. I demonstrate that sexual and social selection are also relevant and encourage the complexity of evolutionary pressures within the CandidaHomo ecology to be reconsidered.

It also makes the following methodological contributions:

1. This research describes an interdisciplinary research methodology for examining the complexity of naturecultures and companion species by combining Donna Haraway’s figurations and cat’s cradles, Karen Barad’s agential apparatuses and practice-led research.

2. It describes the possibilities of scientific experimentation and contemporary art-making as practice-led, response-able research methods and synthesises performative representation, scientia sexualis, ars erotica and instruction painting.
3. Contemporary art is offered as both research method and material-semiotic resolution of research.

**Key Terms & Definitions**

**Apparatus** The physical and/or sensual equipment and the theoretical or conceptual frameworks from which an *intra-action* emerges (Barad 2007). Apparatuses perform *agential cuts* and are *material-discursive*.

**Ars erotica** Practices that value sex as a human experience, appreciating and preserving actions which can bring about pleasure (Foucault 1990). See *scientia sexualis*.

**Candida** Common name for *Candida albicans*. Used in this thesis in the cultural and aesthetic discussions to indicate the shifting material-semiotics between disciplines.

**Candida albicans** The binomial nomenclature (scientific name) for the single-celled species of *yeast* that is a *commensal* of 50–80 percent of *humans*. Compromised immunity can result in infections commonly known as *thrush* or candidiasis and candidemia or systemic infections of tissue or blood. See *C. albicans, candida*. Used in this thesis in the scientific discussions to indicate the shifting material-semiotics between disciplines.

**CandidaHomo** A neologism that describes the naturecultural entanglement of candida and human.

**Cat’s cradle** A research methodology adapted by Donna Haraway (1994, 62) from the traditional string game, which she uses to “reconfigure what counts as knowledge in the interests of reconstituting the generative forces of embodiment.”

**Commensalism** The sharing of the same environment by two organisms where one species benefits and the other is unaffected. The term is derived from the Latin “commensalis,” which means to share a table (Ene and Bennett 2014).

**Companion species** The interdependent development, cohabitation and *co-evolution* of species (Haraway 2003). Coined by Haraway in *The Companion Species Manifesto: Dogs, People, and Significant Otherness*, companion species is a *figuration* that looks at the historical, social, biological, cultural, behavioural, ecological and evolutionary entanglements of species.

**Ecology** “The scientific study of the interrelationships among organisms and between organisms, and between them and all aspects, living and non-living, of their environment” (Allaby 2015a). Evolutionary concepts including *adaptation* and *natural selection* are cornerstones of ecological theory.

**Evolution** Descent with modification (Darwin 1859); *microevolution* refers to “evolutionary change within species, which results from the differential survival of the constituent individuals in response to natural selection” (Allaby 2015d) and *macroevolution* describes speciation “i.e. the development of new species, genera, families, orders, etc. There is no agreement as to whether macro-evolution results from the accumulation of small changes due to microevolution, or whether macro-evolution is uncoupled from micro-evolution” (Allaby 2015c).

**Evolutionary ecology** “Ecology that takes account of the evolutionary histories of organisms and of the relationships between them. It includes the evolution of life histories and of behaviour, as well as of the evolution of communities” (Allaby 2015b).
Evolutionary theory An explanation for the origins of species variation (Darwin 1859); “Evolutionary theory is the area that focuses on further development and refinement of the modern synthesis of evolution and genetics. Notable topics include the appropriate level of selection, the relative importance of natural selection and other mechanisms, and the rate of evolution at genotypic and phenotypic levels.” See evolution; evolutionary ecology

Figuration The act of shaping into a particular figure; the resulting figure or shape; a research methodology developed by Donna Haraway (1992) to “reveal the underlying assumptions of specific discourses” (Bastian 2006, 1030) and a tactic for resisting allegorical representation and creating new tropes and agency.

Heteronormativity “the institutions, structures of understanding, and practical orientations that make heterosexuality seem not only coherent—that is, organized as a sexuality—but also privileged...its privilege can take several (sometimes contradictory) forms: unmarked, as the basic idiom of the personal and the social; or marked as a natural state; or projected as an ideal or moral accomplishment. It consists less of norms that could be summarized as a body of doctrine than of a sense of rightness produced in contradictory manifestations—often unconscious, immanent to practice or to institutions” (Berlant and Warner 1998, 348).

Homo sapiens The binomial nomenclature (scientific name) for the only extant human species; See H. sapiens; human.

Human Common name for Homo sapiens.

Microbiopolitics The creation of categories of nonhuman biological agents; the anthropocentric evaluation of such agents; and the elaboration of appropriate human behaviours given our entanglement with microbes engaged in infection, inoculation, and digestion. Coined by Heather Paxson (2008).

Response-ability The responsibility to “enable responsiveness,” particularly in scientific experiments (Schrader 2010, 298).

Queer “a politics of difference...that uses experiences of oppression and desire as a means of collective political affiliation” (Davis 2005, 23); “A political statement, as well as a sexual orientation, which advocates breaking binary thinking and seeing both sexual orientation and gender identity as potentially fluid. The term is a simple label to explain a complex set of sexual behaviors and desires; used as an umbrella term to refer to all LGBTQI people.” See queer theory, queer ecology.

Queer theory A complex field of poststructuralist critical theory that deconstructs the normalizing practices and institutions that privilege heterosexuality and discriminates against those outside this system of power, and more broadly identifies hegemonic social norms and taxonomies and how and why these norms emerged. Queer theory focuses on mismatches between sex, gender and desire (Jagose 1996). See queer, queer ecology.

Queer ecology A loose, interdisciplinary constellation of practices that aim to disrupt prevailing heterosexist discursive and institutional articulations of sexuality and nature, and also to reimagine evolutionary processes, ecological interactions, and environmental politics in light of queer theory (Sandilands 2016). See queer, queer theory.

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48 www.nature.com/

49 www.vanderbilt.edu/lgbtqi/resources/definitions
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**Scientia sexualis** Describes the ordered system of knowledge for producing the “uniform truth” of sex (Foucault 1990). See *ars erotica*.

**Thrush** Fungal infection of the human mucosa caused by overgrowth of *C. albicans* (Berman and Sudbery 2002); see *Candida albicans*; *C. albicans*, *candida*.

**Thesis Overview**

This thesis is a cat’s cradle that forms figurations, apparatuses and heterotopic alliances to transform the microbiopolitics of the *Candida Homo* ecology (Figure 10). This cradle is made and remade to “learn something about how worlds get made and unmade, and for whom” (Haraway 1994, 69). The cradle weaves the apparatuses of *C. albicans* biology, evolutionary theory, queer ecology and art-making. The thread maps the different disciplinary personae and holds their intermittent (ir)resolutions. Although the cradle maps the conceptual complexity of this project, it also performs the interdisciplinary tensions, frictions and leakages experienced and created during the practice-led research and the construction of this thesis. In each chapter, the distinct apparatuses resolve into artworks generated during this research.

![Figure 10: Cat’s cradle of the thesis. Adapted from Furness Jayne (1906, fig. 741).](image)

Each chapter is a cradle in and of itself, examining a different material-semiotic apparatus of the *Candida Homo* ecology: chapter 1 reproduces sexuality, chapter 2 transforms bodies and environments and chapter 3 touches on eating well together. Each chapter is also a formal material-semiotic figuration, reflecting the textual conventions of the various disciplines. The science sections of each chapter—*C. albicans* biology and evolutionary theory—are written in the third-person, the text is interspersed with diagrams and scientific images and *C. albicans* and *H. sapiens* are referred to by their scientific binomials. The discussions of queer theory are first-person cultural analyses with few images and candida and human are referred to by their common names. Written predominantly in first-person, the artistic resolutions are dominated by images of artworks and references to candida and human oscillate between common and scientific names.
Chapter 1, *Queer Progeny: Re–producing sexual selection in the CandidaHomo ecology*, unwinds the strands of sex and reproduction, sexual selection and sexual orientation (Figure 11). I consider sexuality to be the first principle of a queer ecology and so review the multiple reproductive strategies of *C. albicans* that facilitate genetic recombination and adaptation. Although progeny are predominantly generated via asexual reproduction, *C. albicans* engages in facultative, condition-dependent sexual reproduction, which improves survival in its unpredictable environment (Berman and Hadany 2012). However, the sexual selection pressures in the *CandidaHomo* ecology have not been studied, which may be because the field of microbial sexual selection is very recent (Xu 2004).

![Diagram of sexual selection and reproduction](image_url)

**Figure 11.** Cat’s cradle of chapter 1, *Queer Progeny: Re–producing sexual selection in the CandidaHomo ecology*. Adapted from Furness Jayne (1906, fig. 753).

Heterosexual and gender biases are evident in the dominant model of sexual selection and are prevalent in emerging models of fungal sex, which includes hermaphroditism and multiple mating types, and facultative sex, which describes predominantly asexual reproducers that can switch to sexual reproduction (Aanen, Beekman, and Kokko 2016). These reproductive strategies do not reflect the two-sexes paradigm of animal-centric sexual selection. I trace the influences of dominant sexual selection theories in the configurations of sex and sexuality in queer theory and tug at the threads of biological determinism, sexual dimorphism and heredity. I also slip *C. albicans* into human sexuality and pull asexuality through the strands to unpick the compulsory sexuality within queer theory. Finally, the strands of candida reproduction, sexual selection and queerness rewind through discussion of my artworks *Translational Ambiguity Tolerance* (2015) and *The Tangled Field: After McClintock* (2016), which re-produce the material-semiotics of *CandidaHomo* sexuality.

Chapter 2, *Queer Affordances: Trans*forming natural selection in the CandidaHomo ecology, explores *C. albicans* in its environment, untangling the threads of bodies and environment, natural selection and trans* theory (Figure 12). Performativity—iterative, unconscious response-ability—is proposed as the second principle of a queer ecology and the *CandidaHomo* ecology is framed as an *affordance landscape* (Walsh 2014a), which describes the co-formation of environment and body that enables some possibilities for both
environment and body and forecloses others. A *CandidaHomo* affordance landscape describes how environmental conditions, including nutrients, temperature, pH, antibiotics, hormones and the host immune system, transform *C. albicans* bodies and how these bodies transform their environments in turn.

**Figure 12**

Figure 12 Cat’s cradle of chapter 2, *Queer Affordances: Trans*forming natural selection in the *CandidaHomo* ecology. Diagram adapted from Furness Jayne (1906, fig. 746).

Natural selection is the dominant explanation for this transformation and adaptation within evolutionary theory, however, its mechanisms are highly contested. As discussed, gene-centrism and random gene mutation dominated twentieth-century evolutionary theories. Plasticity-first theories, which assert that evolution is driven by environmental and behavioural factors, have emerged in the last forty years and reflect a broader ecological turn (West-Eberhard 2009). They are supported by the extraordinary phenotypic plasticity of *C. albicans*. Drawing on the controversies in natural selection theories, I trace a legacy of gene-centrism in queer discourse and argue that this has influenced the material-semiotics of gender. I then discuss the possibilities offered by trans* theory as a recent off-shoot of queer theory that examines the intersections of biology, gender and power for reconfiguring bodies in both evolutionary and queer theory. Finally, the threads of performativity, natural selection and trans* theory are entangled with a discussion of my artworks, *Ereignis, Gelassenheit und Lichtung: A love story* (2015) and *Control of Cell Morphology in vivo* (2015), which trans*form the material-semiotics of the *CandidaHomo* ecology.

The figuration in chapter 2, *Queer Affordances* is rewoven in chapter 3, *Queer Kind: Caressing kin selection in the CandidaHomo ecology* (Figure 13), which explores the tactile, social world of *C. albicans*. I argue that community is the third principle of a queer ecology and review the social intimacies and tangibility of communication in the nonvisual *CandidaHomo* ecology. As discussed, in neo-Darwinian evolutionary theories, relationships with others are driven by genetic heredity, competition and individualism. Social behaviours that benefit others have been explained through gene-centric, heteronormative kin selection, where beneficial behaviours are performed only by relatives. However, genetically unrelated, interspecies sociality is the default mode of living on the planet, including within the human body (Kiers and West 2015). *C. albicans* cohabits with the hundreds of other microbial species of the human microbiome in
multispecies biofilms. Queer families of choice offer a more expansive understanding of kinship, although legacies of heteronormative theories of kin selection linger in queer kinships. Luce Irigaray’s understanding of eros as a sensual, ethical proliferation of difference is discussed and proposed for reconsidering the formation of interspecies kinships. Finally, the threads of *C. albicans* sociality, kin selection, queer kinship and eros are interwoven with discussion of my artworks *Surface Dynamics of Adhesion* (2015) and *The Unsettling Eros of Contact Zones* (2015), which embrace the material-semiotics of *CandidaHomo* kind.

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**Fig. 7.49.**
Figure 13 Cat’s cradle of chapter 3 *Queer Kind: Caressing kin selection in the CandidaHomo ecology*. Adapted from Furness Jayne (1906, fig. 749).

The cat’s cradle formed at the beginning of this thesis is finally restrung in *Conclusion: Confessions, commensalism and dispersals* (Figure 14). I draw together the diverse figurations of the *CandidaHomo* ecology teased out in each chapter and describe how the microbiopolitics of *CandidaHomo* companion species have reformed. The cradle threads a confession, disperses to settle on some other surface, in some other niche or maybe to be engulfed by marauders and concludes with a slight polemic and a call for commensalism.

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**Fig. 7.51.**
Figure 14 Cat’s cradle of *Conclusion: Confessions, commensalism and dispersal*. Adapted from Furness Jayne (1906, fig. 751).
Figure 15 C. albicans diversity. Image selection from *Translational Ambiguity Tolerance*. Photographs by author.
1 QUEER PROGENY: RE-PRODUCING SEXUAL SELECTION IN THE CANDIDA HOMO ECOLOGY

1.1 INTRODUCTION

1.1.1 Introduction

Sex is a ubiquitous, yet highly ambiguous term. In the biological sciences, the definition of sex is complex and disputed (Leonard 2005; Aanen, Beekman, and Kokko 2016). In a broad sense, sex is any process that combines genes of more than one progenitor to produce genetically unique progeny (Xu 2005; Sagan 2013a), which encompasses both eukaryotic and microbial sex, and it is synonymous with reproduction (Bell 2005). However, Parker and Pizzari (2015, 136) assert that “sexual reproduction is a composite phenomenon that can be subdivided into a number of components—fusion, recombination, fission, and the male-female phenomenon.” Regardless, it is a foundational category in biological and social taxonomies and is a distinct driver of evolution (Parker and Pizzari 2015). Queer, however, dislocates sex and reproduction by insisting that sex is about pleasure not reproduction (Davis 2005). It is intercourse, arousal and physical intimacy. So, sex is generation of progeny and reproductive and non-reproductive pleasure—biological, technological and social.

Heteronormative biases in evolutionary theory and biology (Ah-King 2009; Hird 2010a) are challenged by the plurality of C. albicans reproductive strategies, which include asexuality and several sexual strategies (Ene and Bennett 2014). This fecundity takes place within the human body, which is usually thought of as reproducing via heterosexual exchange of gametes. Dominant evolutionary theories understand H. sapiens to be sexually dimorphic individuals who reproduce through the act of sex (Bell 2005). However, this discussion demonstrates that an ecology of sex and reproduction occurs within the human body, including the constant asexual reproduction of H. sapiens cells (Bell 2005; Hird 2006a).

In this chapter, I explore the material-semiotics of sex and reproduction in the CandidaHomo ecology. C. albicans reproduction provides a lens to discuss the assumptions about sex and reproduction embedded in evolutionary and queer theories. Consequently, this chapter unwinds the strands of sex, reproduction, sexual selection and sexuality to trace the influences of sexual selection theories on understandings of what sex is, how it is done, who does it and what it is for (Figure 16). By examining C. albicans reproductive biology, I reconfigure sexual selection theories and who and what counts as queer. This discussion interrogates biases of sexual dimorphism, heterosexuality and gene-centric reproductivity and explores the possibilities offered by reconfiguring the CandidaHomo ecology as a pluralist and dynamic site of more–than–human flourishing.
The Unsettling Eros of Contact Zones

Figure 16: Cat’s cradle for chapter 1, Queer progeny, indicating strands of *C. albicans* reproduction, sexual selection, sexuality and art-making. Adapted from Furness Jayne (1906, fig. 753).

1.1.2 Context

*C. albicans* is (in)famous for its intersection with human sexuality. Although it is best known for causing vaginal infections, it is also associated with nipple infections in breastfeeding women and oral thrush and nappy rash in breastfeeding infants (Noble, Gianetti, and Witchley 2016). It is highly sensitive to oestrogen and infections are associated with oral contraceptives and the latex and silicon used in condoms and sex toys. Oral thrush infections are also extremely common in HIV patients, due to suppressed immunity and antibiotic treatments (Poulain 2015). Consequently, candidiasis is synonymous with human sexual activity. In fact, candidal balanitis (or penis infection) is exclusively described as a sexually transmitted infection (Lisboa et al. 2010). Human bodies generate conditions ideal for *C. albicans* procreation and candidiasis is the result of its reproductive diversity.

For more than a century, microbiologists believed that *C. albicans* was an obligate asexual, cloning itself to produce genetically identical “mothers” and “daughters” (Heitman, Sun, and James 2013). However, multiple sexual reproductive strategies, where genetic recombination occurs following cell and nuclear fusion, have been identified in the last twenty years (Noble, Gianetti, and Witchley 2016), including “opposite-sex,” “same-sex” and *ménage à trois* mating (Figure 17). Discovery of the diverse sexual strategies has radically reconfigured assumptions about *C. albicans* reproduction and the role of sex in host-pathogen relationships. However, sexual selection pressures experienced by *C. albicans* have yet to be considered.

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50 These terms indicate gender bias towards an organism that has no gender and are discussed in section 1.2.
Figure 17 Reproduction in *C. albicans*. Inset, a scanning electron micrograph of a *C. albicans* mating zygote is shown. Parental opaque cells (yellow arrows) form mating projections (white arrows) and subsequently fuse and generate daughter cells (white asterisk). Reprinted by permission from Macmillan Publishers Ltd: *Nat Rev Micro* (Ene and Bennett 2014, Fig. 1), copyright (2014).

Sex is a discrete feature of evolutionary theory, although its definition is debated. Dominant sexual selection theories emerged from studies of animals and rely on heterosexual and gender biases that reflect hegemonic cultural beliefs about sex, reproduction and sexuality. Although debated, these theories are based on assumptions about mammalian reproduction (Gowaty 2003), including that sex occurs between two individuals of different sexes; these sexes are morphologically different; the individuals are of the same species; partner choice occurs because of competition and conflict; sex is only about reproducing one’s genes; different sexes are attracted to each other to produce the “best” offspring; different sexes behave differently; and this behaviour is genetically determined. However, Aanen, Beekman, and Kokko (2016, 2) argue that biases towards the familiar have led evolutionary theorists to assume “how sex ‘ought’ to occur.” Lehtonen and Kokko (2014, R305) assert that “there are so many ways of making offspring and combining the genetic material of different individuals that it may be futile to hope for a single definitive definition.” They conclude that sex is not necessary for reproduction since genes can recombine through several other mechanisms, including conjugation, transduction and transfection. Further, individuals engaging in sex do not have to be “opposite” sexes (Heitman, Sun, and James 2013; Beekman et al. 2016) and sex can be for more than reproduction, including social bonding, affiliation and conflict resolution (Bailey and Zuk 2009; Ah-King 2013c).
Dominant animal-centric sexual selection theories struggle to account for the diverse reproductive strategies and sexual behaviours of plants, fungi and microbes (Hird 2006a; Beekman et al. 2016). Andersson and Iwasa (1996) noted that sexual selection in botany was relatively recent, Nieuwenhuis and Aanen (2012) note that very little attention had been given to fungal sexual selection and Bell (2005) observes that there are almost no studies of microbial sexual selection. Although fungal reproductive strategies have long been recognised as extraordinarily diverse and include self-fertilisation (“selfing”), ménage à trois encounters and hermaphroditism (Heitman, Sun, and James 2013; Nieuwenhuis and James 2016), the sexual selection pressures have been given little attention. Fungal species have “mating types” rather than sexes and some species have multiple mating types—some have hundreds and notably, the zygomycete, *Schizophyllum commune*, has more than 20,000 (Kothe 1996; Hird 2006b).

Facultative sex, or asexual reproduction with infrequent rounds of sex (Dacks and Roger 1999), is the most common reproductive strategy of fungi and microbes, like *C. albicans*. However, animal-centric sexual selection theories based on studies on the obligate sexual reproduction of familiar species have typically considered asexual and sexual reproduction to be mutually exclusive (Burke and Bonduriansky 2017). Consequently, they have not considered the possibility that asexually reproducing cells may have a role in sexual selection. However, the distinctions between asexual and sexual reproduction are often unclear (Bell 2005; West-Eberhard 2014). Several recent studies in yeasts have found that sexual conflict can occur between vegetative (asexual) and mating competent individuals (Bell 2005; Xu 2005; Zeyl et al. 2005), opening up the possibility that asexual reproduction may be an important player in sexual selection, particularly in unicellular organisms whose asexual cells are one of at least three co-existing reproductive cell types. Despite this diversity, heteronormative and gender biases persist in discussions of fungal sexual selection (see Nieuwenhuis and Aanen 2012; Heitman, Sun, and James 2013). Rather than expanding the vocabulary of sexual selection to accurately describe the variety and diversity of reproductive behaviours and sexes, fungal sexual selection theory continues to rely on descriptors of sex, sexuality and sexual dimorphism and behaviour developed in animal sexual selection. *C. albicans* reproductive strategies have not yet been considered through sexual selection theories and therefore provide an opportunity to consider a more inclusive, nonanimal-centric, nonheteronormative model.

Considering *C. albicans* as queer resonates through the *Homo* ecology and establishes sex as more than reproduction. Queer theory dislocates sex and reproduction, emphasising the importance of multiplicity and diverse sexual and reproductive configurations (Davis 2005; Ah-King 2009). It refuses to reduce sexual behaviours to a biological sex, arguing that these behaviours are learnt and may not necessarily be sexual. It also draws attention to other possibilities for sexual behaviours, including pleasure and intimacy (Brown and Rasmussen 2010). However, considering asexuality reveals sexuality to be the limit of queer theory and traces of sexual selection theory in queer theory. Reconfiguring the human body as a more-than-human...
orgy opens queer and evolutionary theories to reconsider “how sex ‘ought’ to occur” (Aanen, Beekman, and Kokko 2016, 2). It also turns back to C. albicans biological research, encouraging it not to rely on heteronormative and animal-centric evolutionary theories.

1.1.3 Chapter overview
Contemporary scientific understandings of C. albicans reproductive strategies and their evolutionary implications are reviewed in this chapter. The heteronormative, gene- and animal-centric biases in sexual selection theories are examined and alternatives are discussed that understand sex and sexuality to be responsive and dynamic within and between species, populations and individuals. I examine the limit of queer theory and compulsory sexuality and explore the traces of sexual selection theory and queer theory/
Exploring the entanglement of C. albicans reproduction with H. sapiens sexuality enables a carnal, more–than–human reconfiguration of sexuality. Finally, two artworks, Translational Ambiguity Tolerance (2015) and The Tangled Field: After McClintock (2016), are discussed as material-semiotic resolutions of this chapter’s cradle. These works are apparatuses of scientia sexualis and ars erotica and reconfigure sex and reproduction in the CandidaHomo ecology.

1.1.4 Key terms and definitions

**Asexual** Reproduction that is exclusively by mitotic propagation (Tibayrenc and Ayala 2012); absence of sexual recombination (Schmid et al. 2016); in humans: a lack of sexual attraction or desire for others (Bogaert 2015).

**Clonality** Reproduction through simple fission or budding; absence of genetic recombination (Xu 2004).

**Facultative sex** Asexual reproduction with infrequent rounds of sex (Dacks and Roger 1999).

**Mating type** Fungal mating types are genetically defined...and regulate sexual compatibility of the gametes (or haploid structures that function like gametes), and gametes of the same mating type cannot form zygotes” (Nieuwenhuis and Aanen 2012, 2399).

**Recombination** The breakage and reunion of genetic materials in genomes (Xu 2004).

**Reproduction** in culture: the process of making a copy (Benjamin 1968); in biology: processes that replace or increase the number of cells or organisms in populations (Xu 2004).

**Sex** the process that produces genetically unique progeny (Sagan 2013b); process of genetic recombination that involves meiosis and gametes (Vreeburg, Nygren, and Aanen 2016); physical contact between individuals involving sexual stimulation; either of the two main categories (male and female) into which humans and many other living things are divided on the basis of their reproductive functions (Parker and Pizzari 2015); see sexual dimorphism; sexual reproduction; sexual selection

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The Unsettling Eros of Contact Zones

**Sexual dimorphism** Morphological and functional asymmetry at the gametic and organism level (Hadjivasiliou, Iwasa, and Pomiankowski 2015).

**Sexual reproduction** Processes that produce genetically unique progeny through sex (Sagan 2013b); “a composite phenomenon that can be subdivided into a number of components—fusion, recombination, fission, and the male-female phenomenon” Parker and Pizzari (2015, 136).

**Sexual selection** variation in reproductive success among members of the same sex and species (Gowaty 2003); relationship between a trait and its effect on fitness through sexual competition” (Shuker 2010, e12).

1.1.5 Contribution to knowledge

The discussion in this chapter makes the following contributions to understanding sex and reproduction in the *CandidaHomo* ecology:

1. This research observes that sexual selection has yet to be considered by *C. albicans* research. Although the sexual selection pressures on *Saccharomyces cerevisiae* sexual reproduction have been examined (Rogers and Greig 2009), *C. albicans* sexual reproduction has distinct differences that are likely to affect selection pressures. I argue that considering facultative sexual selection may provide interesting insights into the dynamics of the *CandidaHomo* ecology and *C. albicans* biology.

2. This is the first study discussing *C. albicans* sexuality and reproduction outside microbiology or immunology. Neither feminism or queer theory or scholars of “leaky bodies” have considered the microbiopolitics of *C. albicans*. Myra Hird (2006b; 2010b) has discussed the human body as a queer reproductive ecology, arguing that not only do human cells reproduce asexually, we are host to constant microbial orgies. However, she does not specifically mention *C. albicans*. As a member of the *Homo* ecology that has particular associations with both human gender and sexuality, its absence in discussions of gender and sexuality is a significant omission.

3. This research expands the discussion of gender and heteronormative biases in sexual selection theories, which has to date focused on animals (and some plants), to include fungi and yeast. I challenge the animal-centrism of these discussions and argue that *C. albicans* provides us with a timely opportunity to queer the language of sexual selection.

4. This research folds sexual selection theory into queer theory, demonstrating its reliance on compulsory sexuality and revealing traces of sexual selection theories.

5. Finally, this research is the first to explore the sex and sexuality of *C. albicans* through contemporary art-making. Previous representations of *C. albicans* sexuality have been materialised through scientific experimentation. The artworks that emerged during this research do not deny the external ecology or human manipulation but celebrate the queer fecundity of candida itself.
1.2 Queering *Candida* Reproduction

1.2.1 Asexual (clonal) reproduction

The most common reproductive strategy of *C. albicans* is asexual reproduction, which is described as a parent cell growing a bud (offspring) from its body (Herman and Soll 1984). When the bud is of a similar size to the parent, a septum forms between the cells, which separate, and a budding scar is left on the parent cell (Figure 18). The parent cell can produce many buds, which then go on to produce their own buds. Numerous studies over the twentieth-century describe the budding process (Herman and Soll 1984), including how many buds a parent produces during its lifetime, and what determines bud location and the relative size of parents and buds. Individual cells propagate and form colonies. Asexual (or clonal) reproducers typically form white, domed colonies when grown on agar (Figure 19). Colony (or population) size is constrained by farnesol, a molecule secreted by individual cells (Hornby et al. 2001). Asexual reproduction was long thought to be the only mechanism by which *C. albicans* reproduced (Bougnoux et al. 2008). An asexual cell replicates through mitosis, which is a process of nuclear division that occurs when a parent cell divides to produce two identical cells (Miko 2008). For *C. albicans*, both of its diploid chromosomes are copied in the progeny (Ene et al. 2016). Hence, parent and progeny should be genetically identical, i.e., clones. However, aneuploidy and loss of heterozygosity (LOH) are common in *C. albicans* (Forche et al. 2011) and consequently, genes and traits can differ between parents and progeny, providing opportunities for adaptation (Zhang et al. 2015).

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52 It is important to note the terms “mother” and “daughter” are commonly used to describe the cells involved in asexual reproduction (Herman and Soll 1984; Heitman, Sun, and James 2013; Heitman et al. 2014). Such terminology assigns genders and sexes to organisms that have neither. Although more recent papers tend to refer to “parent” cell rather than “mother” and “offspring” or “progeny” rather than “daughter,” they also slip between the two even within the same paper (for example, Berman and Sudbery 2002; Sudbery, Gow, and Berman 2004), indicating a conflation of sex roles and gender (refer to Section 1.3.2).

53 The phenotype of colonies depends on the population structure and the relative composition of yeast, pseudohyphae and hyphae. This is discussed further in chapter 3.

54 Human somatic cells also reproduce asexually through mitosis.

55 Aneuploidy is “a change in chromosome copy number that does not parallel a change in the entire haploid or diploid genome” (Ene and Bennett 2014, 242).

56 Loss of heterozygosity is “homozygosis of alleles due to either recombination or whole-chromosome loss” (Berman and Hadany 2012)
1.2.2 Sexual reproduction

After more than a century of thinking C. albicans reproduced asexually, Hull and Johnson (1999) identified a “mating-type locus” (MTL), drawing on previous findings in Saccharomyces cerevisiae and using emerging gene sequencing technology (Figure 20). Although sexual reproduction had never been observed in clinical samples or laboratory strains (Zhang et al. 2015), the MTL indicated that C. albicans had genes that would enable it to reproduce sexually. However, it was unclear how C. albicans would reduce its diploid genome to the haploid state believed necessary for sexual recombination.
C. albicans mating was induced \textit{in vitro} in 2000 and a previously observed morphological transition between the typical “white” yeast cell form and an “opaque” cell form\textsuperscript{57} was linked to the process (Figure 21), although the mechanisms were unknown (Hull, Raisner, and Johnson 2000; Magee and Magee 2000). The well-known white yeast cell reproduces asexually and is not able to mate with another cell, only opaque cells are “mating-competent” (Soll 2003). Therefore, \textit{C. albicans} mating requires the morphological transition from white to opaque. Although a similar MTL is present in several other yeast species, the white-opaque transition is unique to \textit{C. albicans} and the closely related \textit{Candida tropicalis}, both of which are human pathogens (Ene and Bennett 2014).\textsuperscript{58} Since the discovery of \textit{C. albicans} sexual mating, research into its mechanisms and implications for the \textit{CandidaHomo} host-pathogen relationship has increased exponentially.

\textsuperscript{57} So-called because of the phenotype of the colonies formed by these cells (Soll 2003). Opaque cells are longer than white cells, form larger, flatter, grey-coloured colonies and have a distinct physiology (discussed further in chapter 2).

\textsuperscript{58} Unlike \textit{C. albicans}, the white-opaque transition in \textit{C. tropicalis} is independent of MTL control, which suggests that the transition has other physiological functions (Ene and Bennett 2014). Unlike \textit{C. albicans}, the white-opaque transition in \textit{C. tropicalis} is independent of MTL control, which suggests that the transition has other physiological functions in both species (Ene and Bennett 2014).
Several excellent reviews of the research into *C. albicans* sexual reproduction have been published in the last ten years that provide increasingly comprehensive descriptions of its complex mechanisms.59 Although *C. albicans* is still considered predominantly clonal, sexual mating does occur, albeit rarely (Schmid et al. 2016).60 The majority of *C. albicans* cells are diploid (2N), i.e., they have two copies of the chromosome and are heterozygous at the MTL, i.e., one chromosome (MTLa) contains an “a” gene at the MTL and the other chromosome (MTLα) contains “α” genes at the MTL, as shown in Figure 20. Therefore, the majority of cells have both a and α genes. Stress, such as hypoxia and starvation, causes cells to lose this heterozygosity and become homozygous at the MTL, i.e., the cells will have only a/a or α/α genes at the MTL (Ramírez-Zavala et al. 2008; Berman and Hadany 2012). Depicted in Figure 22, these white homozygotes then transition to mating-competent opaque homozygotes (Ene and Bennett 2014). The white-opaque transition is a heritable epigenetic switch regulated by the transcriptional regulatory protein WOR1 and occurs with a frequency of $10^4$ to $10^5$ per cell generation, while the transition from opaque to white occurs with a frequency of $10^3$ to $10^4$ (Slutsky et al., 1987; Lan et al., 2002; Lockhart et al., 2002).

![Figure 22 Mating in *C. albicans*. Reproduced by permission from Heitman et al. (2014, fig. 1).](image)

59 Including Heitman (2009); Soll (2009); Alby and Bennett (2010); Heitman (2010); Jones Jr and Bennett (2011); Ene and Bennett (2014); McManus and Coleman (2014); Soll (2014); Tomasini et al. (2014); Bennett (2015); Scaduto and Bennett (2015); and Zhang et al. (2015); Noble, Gianetti, and Witchley (2016); Schmid et al. (2016). Refer to Gow, Brown, and Odds (2000) for comparison.

60 Schmid et al. (2016) estimated minimum “productive” mating frequencies to be once every 2,000–167,000 generations, although they argue that frequencies could be 10 times higher.
Bennett (2015, 11) notes that opaque cells homozygous for a or α genes are able to produce “sex-specific pheromones that induce mating responses in cells of the opposite sex.” The “opposite sex” referred to is the different mating type (a or α) and the “sex-specific pheromones” are the pheromones that facilitate mating between different mating types. An a cell produces a-pheromone, which attracts an α cell; an α cell produced α-pheromone, which attracts an a cell. The process of attraction, cell and nuclear fusion and subsequent reproduction are depicted in Figure 23. In the presence of mating pheromones, cells form “mating projections,” which fuse. The nuclei of both cells fuse and form a tetraploid (4N) a/a/α/α zygote. These zygotes propagate and the progeny reduce to a variety of possible recombinant diploids (2N) and aneuploids (Figure 24) through concerted chromosome loss\(^{61}\) or loss of heterozygosity (Bennett 2015; Hickman et al. 2015).

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\(^{61}\)Concerted chromosome loss refers to a poorly understood process that coordinates the loss of chromosomes, reducing tetraploids to diploids (Berman and Hadany 2012).
Mating between opaque cells of different mating types as described, i.e., an a cell and an α cell, is called heterothallism and produces both homozygous and heterozygous recombinant progeny (Figure 25a). Heterothallism describes the production of “gametes that are only compatible with gametes of a different mating type and not with gametes of the same mating type” and is a common mating strategy in multicellular fungi (Nieuwenhuis and Aanen 2012, 2394). Homothallism, or mating between cells of the same mating type, a/a + a/a, has also been observed in C. albicans (Figure 25b), although it is less common (Alby, Schaefer, and Bennett 2009). This strategy is variously called “same-sex” mating, “unisexual” reproduction and “selfing” in the literature. Two opaque homozygous a cells fuse and produce diploid and aneuploid homozygotes. The majority of a cells produce Bar1 protease, which degrades the small amounts of α-pheromone they might produce (Alby, Schaefer, and Bennett 2009). However, some a cells lack this enzyme and continue to produce α-pheromone, enabling homothallic reproduction.
Figure 25 Reproductive interactions between white and opaque cells in a population, including heterothallic and homothallic mating and sexual biofilm formation. (Scaduto and Bennett 2015, fig. 2), adapted by permission from Elsevier.

Additional rare reproductive strategies are being still being discovered and researchers note that more are definitely possible. For example, Alby, Schaefer, and Bennett (2009) observed homothallic mating between two a/a cells occurring in the presence of an α/α cell. In this ménage à trois mating, conjugation of two a/a cells is facilitated by α-pheromones secreted by an adjacent α/α cell (Figure 25b). Further, although C. albicans mating usually generates tetraploids (4N), which become diploid, Hickman et al. (2013) have observed the generation of haploid (N) cells. These cells, which have only one set of chromosomes, undergo the white-opaque transition and mate to produce diploid progeny.

Finally, mating pheromones produced by homozygous opaque cells can promote adhesion and biofilm formation in adjacent white cells, leading to the formation of “sexual biofilms” (Ene and Bennett 2014; Palková and Váchová 2016). Sexual biofilms contain a basal layer of unicellular homozygous cells upon which a layer of filamentous cells is formed (Figure 25c) and are more permeable and less drug-resistant than “conventional” biofilms generated by MTLα/α cells. Scaduto and Bennett (2015) propose that the permeability of sexual biofilms facilitates mating by providing an environment that concentrates pheromone gradients and allows the passage of mating projections (Figure 25c). Therefore, sexual biofilms co-locate mating-competent cells and improve mating efficiency (Ene and Bennett 2014). Cottier and Mühlenschlegel (2012) also note that anaerobic conditions accumulate at the base of such biofilms and prevent the production of the hormone farnesol, which kills opaque cells under aerobic conditions. Such

62 Biofilms are aggregated, structured communities embedded in a matrix of extracellular polysaccharides (Jabra-Rizk et al. 2016). Conventional (nonsexual) biofilm formation is discussed in chapter 2.
biofilms rarely form in *in vitro* conditions and are poorly understood. However, Zhang et al. (2015) propose that the anaerobic conditions within the gastrointestinal tract of humans could promote sexual biofilm formation and therefore *C. albicans* mating.

1.2.3 Evolutionary implications
Mating-competency in *C. albicans* is thought to be rare and its function is still unclear (Zhang et al. 2015). As discussed, mating has rarely been observed *in vivo* and researchers continue to speculate as to why *C. albicans* would retain and replicate genes that enable mating but rarely use them, given the high cost of doing so (Soll 2009; Ene and Bennett 2014). Consequently, several recent papers explore the evolutionary functions of mating in this predominantly asexual reproducer (Forche et al. 2008; Bennett 2009; Butler et al. 2009; Xie et al. 2013; Zhang et al. 2015). Berman and Hadany (2012) have demonstrated that stress induces condition-dependent sex, which provides a selective advantage. Ene and Bennett (2014) conclude that, although rare, sexual reproduction in *C. albicans* generates stable “excess” heterozygosity (multiple gene copies) and aneuploidy (multiple chromosome copies), which enables rapid response and adaptation to highly variable host conditions. Although aneuploidies are usually detrimental, they have been shown to increase *C. albicans* resistance to antifungal drugs (Ene and Bennett 2014). Ene and Bennett (2014) also propose that unisexual mating enables sexual reproduction in the absence of an opposite-sex partner and the resultant genetic recombinations and chromosomal aneuploidies could facilitate adaptation.

The evolution of sexual reproduction in *C. albicans* is discussed as evidence of the “Red Queen hypothesis,” which proposes that hosts and pathogens are engaged in cycles of responsive adaptation and describes why sexual reproduction might have evolved (Ene and Bennett 2014). Zhang et al. (2015) found that *C. albicans* mating is under natural selection as it generates genotypes that increase population fitness. They also identified the following costs: mating-competent cells are slower growing than clonal cells and therefore produce fewer progeny, decreasing reproductive success; MTL-homozygotes may become extinct when competing for limited resources with faster growing MTL-heterozygotes; the act of mating yields fewer new cells; mating may “fail” if unfit progeny result; competition with parents and ancestors for limited niches and resources; low abundance increases chance of extinction; and delayed accumulation of faster growing progeny. Although Whiteway (2009) has asked how a *C. albicans* cell finds/chooses a partner, sexual selection pressures on *C. albicans* remain unexplored.

1.2.4 Asex, parasex or true sex?
Slippages between “sex” and “mating type,” “opposite-sex” and “different mating type,” and “same-sex” and “same mating type” are ubiquitous throughout *C. albicans* research papers and facilitate incorporation of the yeast (and other organisms with multiple reproductive or facultative strategies) into animal-centric

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63 An exception being on mouse skin.
sexual selection models. Conflation of “same-sex,” “unisexual” and “selfing” is also common. “Unisexual” distinguishes mating between two cells of the same mating type from “asexual” reproduction, which involves the production of progeny from a single parent cell. Although “selfing” is used to describe unisexual or “same-sex” mating, it more accurately describes asexual reproduction, where self replicates self. Further, the ménage à trois strategy is described as mating between two a/a cells that occurs in the presence of an α/α cell. The semantics here suggest that rather than mating between three, the α/α cell is present but not really part of the mating. This framing reflects heteronormative and gene-centric biases in sexual selection theories (Hird 2006a), discussed further in section 1.3.

Description of C. albicans mating frequently slips between “parasexual” and “sexual” and “sex” and “true sex,” indicating the instability of the term “sex” in the biological sciences. C. albicans production of recombinant progeny through conjugation and nuclear fusion is commonly qualified as “parasexual” reproduction (Forche et al. 2008; Robinson 2008; Berman and Hadany 2012; Ene and Bennett 2014; Bennett 2015; Hickman et al. 2015; Zhang et al. 2015; Schmid et al. 2016) or not “true” sex (Odds et al. 2007; Bougnoux et al. 2008). Parasexual reproduction is a “form of reproduction in which transfer of genetic material and recombination occurs without meiosis or the development of sexual structures” (Ene and Bennett 2014, 239; emphasis added). Loidl (2016, 308; emphasis added) argues that “parasexuality allows organisms that are sexually incompetent to undergo recombination via the random assortment of parental chromosomes.”

The term “parasexual recombination” was first introduced in 1956 to describe the recombination of genes by asexual fungal species, specifically Aspergillus nidulans and A. niger and was subsequently adopted by fungal biologists to describe the diverse (“non-conventional”) reproductive strategies of fungi (Clutterbuck 1996). Parasexual recombination emerged from heteronormative neo-Darwinism and broader cultural conditions that privileged sexual reproduction. The semantics of parasexuality indicate that the metonymy of sex and meiosis persists, evident in the description that C. albicans sex is not “true” sex without meiosis. Further, Berman and Hadany (2012, 197; emphasis added) describe parasex as a “a non-conventional life cycle involving alternation of generations,” which implies that either sex or asex are the conventional strategies.

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64 These slippages are also evident in studies of fungal sexual selection as discussed in section 1.3.3.
65 These biases are also evident in a resistance to consider plant-insect-plant ménage à trois as sex (Hird 2006a)—the insect is described as mediating, but not participating in plant sex (Beekman et al. 2016).
The Unsettling Eros of Contact Zones

1.3 Queering Sexual Selection Theory

1.3.1 Is it sex?
For much of the twentieth century, asexual reproduction or long-term clonality was thought to accumulate deleterious mutations that resulted in individual, population and species extinction (Tibayrenc and Ayala 2012; Ene and Bennett 2014). This phenomenon, called Müller’s ratchet, was theorised in the 1930s to explain the advantages of sexual reproduction and was thought to have driven the evolution of asexual reproducers into sexual reproduction. However, gene sequencing shows that many asexual lineages, including yeasts, are ancient, contradicting the presumption of extinction within Müller’s ratchet. It is now thought by many that asexual reproduction was the only mode of reproduction for almost the entire history of life on the planet (Margulis and Sagan 1990; Hird 2009; Ambur et al. 2016; Lenormand et al. 2016). Organisms avoid Müller’s ratchet through genetic recombination, which occurs in both sexual and asexual reproduction, albeit via different mechanisms.

In the biological sciences, the definition of sex is complex and incorporates reproductive strategy, gamete size, genetic recombination and behaviours and characteristics associated with reproduction (Leonard 2005; Xu 2005). For example, Parker and Pizzari (2015, 136) assert that “sexual reproduction is a composite phenomenon that can be subdivided into a number of components—fusion, recombination, fission, and the male-female phenomenon.” Defining sex is difficult due to this plurality. Xu (2004, 775) observes that “in two edited books on the evolution of sex (Michod and Levin 1988; Halvorson and Monroy 1985), no two chapters or authors had exactly the same definition.”

For much of the twentieth-century, sex was defined as “meiosis followed by the fusion of meiotic products from different individuals” (Lehtonen and Kokko 2014, R305; emphasis added), usually of the so-called opposite sex—Parker and Pizzari’s (2015, 136) ”male-female phenomenon.” Such definitions were informed by neo-Darwinian theories of sexual selection invested in heteronormative Mendelian inheritance and gametes as the mechanism by which inheritance is possible (Walsh 2014b). In most animals and plants, gametes are generated by meiosis, the process “that generates haploid cells from diploid cells” (Brandeis 2018, 802). The fusion of these haploid cells from different individuals results in genetically novel progeny. Although some eukaryotic species reproduce clonally, meiosis is considered by many to be

66 “each component being subject to selection” (Parker and Pizzari 2015, 136).
67 Keller (2012, 528) argues that “the lexicons of genetics, developmental biology, evolution, and ecology are replete with overlapping kind-terms...Such overlaps persist over long periods of time without exerting significant pressure on the community to divide. In fact, researchers are rarely troubled by the coexistence of multiple meanings of many of the terms they rely upon; they are confident that, despite such polysemy, they have no trouble ‘knowing what they mean’.”
68 Further, these gametes tend to be anisogamous, the implications of which are discussed in section 1.3.2.
fundamental to eukaryotic sexual reproduction (Lenormand et al. 2016; Nieuwenhuis and James 2016) and hence, meiosis and sex have been synonymous.

However, the identification of frequent and ubiquitous genetic recombination by bacteria through lateral gene transfer demonstrated the semantic entanglement of sex, reproduction and meiosis (Xu 2004; Bell 2005; Michod, Bernstein, and Nedelcu 2008). Consequently, sex has come to be most broadly defined as any process that combines genes of more than one progenitor to produce genetically unique progeny (Xu 2005; Sagan 2013a). Lehtonen and Kokko (2014) describe the ambiguities and tensions in biological definitions of sex as follows:

Perhaps the broadest definition of sex is the coming together of genes from different individuals. By this definition, both eukaryotes and prokaryotes do have sex, the latter in the form of conjugation, transformation and transduction. There are also more specific definitions of sex, such as meiosis followed by the fusion of meiotic products from different individuals. This narrower statement avoids one clear disadvantage of the broadest definitions: if any form of uptake of DNA is sex, it becomes hard to draw the line and explain why we do not consider that humans have sex with the HI virus if it inserts its genome to take advantage of our cells. Alternatively, sex can be contrasted with known features of asexual reproduction: when asexual organisms are said to not regularly go through a sexual cycle that involves meiosis and changes in ploidy levels, it is implied that sex involves those things. All definitions of sex that include meiosis, however, imply that prokaryotes do not have sex. (R305)

They conclude that “a single definitive definition” of sex may be impossible, due to the variety and diversity of “ways of making offspring and combining the genetic material of different individuals” (R305).

Nevertheless, all definitions include two aspects as fundamental: (1) some mechanism of genetic recombination and (2) outcrossing (two different individuals) (Xu 2004; Michod, Bernstein, and Nedelcu 2008; Lively and Morran 2014; Brandeis 2018). The most common and fervent debates revolve around the mechanism of recombination (see for example, Parker and Pizzari (2015) and Brandeis (2018)). Although there are discussions about what constitutes an individual (Leonard 2005; Nieuwenhuis and Aanen 2012; Constable and Kokko 2018), outcrossing between two sexually dimorphic individuals remains the dominant paradigm (Lehtonen, Kokko, and Parker 2016).

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69 Lateral gene transfer involves conjugation (cell fusion), transduction (introduction of DNA by a virus) and transformation, which is the incorporation of exogenous DNA from the environment into the bacterial genome (Ambur et al. 2016; Ram and Hadany 2016). Contemporary genetic engineering uses all these processes, particularly transformation, which is a key process in DNA cloning.

70 These discussions are driven primarily by fungal biologists since the majority of fungi are hermaphrodites (Nieuwenhuis and James 2016). Discussed further in section 1.3.3.

71 See Leonard (2005), Nieuwenhuis and James (2016) and Constable and Kokko (2018) for discussions about multiple fungal mating types; West-Eberhard (1979), Hird (2006a) and Beekman et al. (2016) for discussions of sexual polymorphisms; Ah-King and Nylin (2010), Ah-King and Hayward (2014) and Ah-King and Gowaty (2015) for discussions of sex as a reaction norm; and Bell (2005) and Zeyl et al. (2005) for discussions of strategies that involve both vegetative and sexual reproduction. This is by no means an exhaustive list.
Asexual reproducers have evolved diverse strategies to recombine genes, including horizontal gene transfer (Ambur et al. 2016) and condition-dependent sex (Ram and Hadany 2016). Genetic recombination generates novel multi-locus combinations, some of which may increase adaptation (Michod, Bernstein, and Nedelcu 2008). Tibayrenc and Ayala (2012) have also suggested that recombination repairs damaged DNA and removes deleterious mutations. Michod, Bernstein, and Nedelcu (2008) concur, arguing that this mundane action of repair may in fact be the ancestral mechanism of sexual reproduction rather than the more romantic and modernist “novelty.” Further, Tibayrenc and Ayala (2012) propose that eukaryotic pathogens such as *C. albicans* may have retained an ancestral ability to restrain recombination, which might otherwise disrupt gene combinations advantageous in hostile conditions. This proposition is supported by Zhang et al. (2015), who found that the restricted mating frequency of *C. albicans* maximises survival and minimises the costs of sexual reproduction.

Logically, the costs of sexual reproduction outweigh the benefits, as sex has a two-fold cost for individuals, i.e., (at least) two individuals are required to produce a single offspring and (at least) 50% of a parent’s genes are lost (*qua* Maynard-Smith and Williams) (Heitman, Sun, and James 2013; Lively and Morran 2014). Ram and Hadany (2016) have described additional costs of sexual reproduction, including the production of males and male gametes, conflict between sexes and duration or failure to find suitable mates. Heitman, Sun, and James (2013, 3) add the “lesser appreciated but well-established cost” of destroying genomic configurations that have “run the gauntlet of adaptive Darwinian selection.” In fact, Ram and Hadany (2016) argue that dominant evolutionary models of sex, which claim that all individuals reproduce with the same probability, cannot account for the costs of sex.72

The Red Queen hypothesis is considered to be the best explanation to date for the evolution of sex. Proponents argue that sex evolved through host-pathogen competitive co-evolution (Heitman, Sun, and James 2013; Sagan 2013a; Ene and Bennett 2014). For hosts and pathogens, it is argued, the adaptive possibilities gained by the rapid generation of multi-locus combinations outweigh the costs of sexual reproduction. This explanation is commonly used to explain the retention of sexual reproduction by *C. albicans* (Ene and Bennett 2014). Consequently, *C. albicans* is increasingly being used as a model organism to explain the evolutionary origins of sex, which McDonald, Rice, and Desai (2016) argue is largely still a mystery, given the efficiency of asexual reproduction.

Although some eukaryotic metazoa reproduce asexually, the majority are obligatorily sexual despite the high cost of its maintenance (Xu 2004; Burke and Bonduriansky 2017). Aanen, Beekman, and Kokko (2016) note that this is the case for those species most familiar to us and our knowledge of sex and sexuality has

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72 Although Lehtonen and Kokko (2014, R306) argue that “costs, as well as benefits, depend on how broad one’s definition of sex is.”
been largely informed by these. Consequently, sexual selection theories have been biased towards a heteronormative obligately sexual model (Da Silva and Bell 1992).\textsuperscript{73} However, facultative reproductive strategies, where individuals can switch between sexual and asexual modes, are ubiquitous in microbes and fungi and common in eukaryotic metazoa (Xu 2004; Nieuwenhuis and James 2016). In fact, Nieuwenhuis and James (2016) argue that true asexuality is rare.\textsuperscript{74} However, sexual and asexual reproduction have largely been treated as mutually exclusive strategies (Burke and Bonduriansky 2017). This separation is evident in the ambiguity of “parasex” and the uncertainty as to why \textit{C. albicans} has sex (“true” or not).

Consequently, until recently, sexual selection has given very little attention to the facultative sexual strategies of fungi and microbes (Bell 2005; Nieuwenhuis and Aanen 2012; Constable and Kokko 2018). Although it is unclear how effective or important sexual selection is for these organisms (Bell 2005; Nieuwenhuis and Aanen 2012), it is important to consider to provide a more diverse and comprehensive understanding of sex, sexuality and evolution. Further, introducing facultative sex to discussions of \textit{C. albicans} reproduction could provide additional models for considering why it maintains sex and the sexual selection pressures it experiences.

1.3.2 Sexual Selection

The Red Queen hypothesis may explain the origins of sex through host-pathogen co-evolution, but it is a model of natural selection, not sexual, and does not explain how sexual selection might work in the \textit{Candida Homo} ecology. Darwin introduced sexual selection to explain the seemingly frivolous and expensive use of resources for reproduction that did not seem to correlate with competitive, scarcity-driven natural selection (Subramaniam 2014).\textsuperscript{75} Connected to natural selection’s philosophy of scarcity and competition, Darwin (1871, 256) described sexual selection as the “advantage which certain individuals have over other individuals of the same sex and species, in exclusive relation to reproduction.” West-Eberhard (2014) argues that Darwin envisioned sexual selection to be the social environments that improved reproductive success, whereas natural selection described the non-social. Consequently, sexual selection should be defined as “social competition for mates or fertilisation success...as contrasted with non-interactional definitions” (502).

In the broad sense, sexual selection is “an aspect of natural selection having to do specifically with variation in reproductive success among members of the same sex and species” (Gowaty 2003, 904). However, Nieuwenhuis and Aanen (2012) observe that many definitions of sexual selection are commonly used and Leonard (2005) lists twelve distinct definitions drawn from the literature. For example, many consider sexual selection to be any process that leads to the differential mating success of individuals. Although such

\textsuperscript{73} For example, see Gowaty (2009) for discussion of gender perception bias.
\textsuperscript{74} Vrijenhoek (1998) has observed that only 1 in 1000 animal species are obligately asexual.
\textsuperscript{75} The peacock’s tail and stag’s antlers are exemplary (West-Eberhard 2014).
processes could include a range of cooperative mechanisms, Andersson and Iwasa (1996, 53) argue that “competition over mates is the unifying aspect of all forms of sexual selection.” The consensus definition is that “sexual selection is the relationship between a trait and its effect on fitness through sexual competition” (Shuker 2010, e12).

Already linked by Darwin, the adoption of Mendelian inheritance by population geneticists in the Modern Evolutionary Synthesis placed gene-centric sexual reproduction at the centre of evolutionary theory. Mendel’s elegant experiments explained trait inheritance as resulting from the combination of genes from two progenitors, male and female. Other combinations of progenitors or mechanisms of trait inheritance such as behaviour or immunity were treated as anomalies and “true” sex was defined as genetic recombination through meiosis and the fusion of gametes (Walsh 2014b). Sex became a function of genetic replication and species survival, rather than for comfort, pleasure, intimacy or developing community. Although for Darwin, sexual selection was sensual and excessive (Grosz 2008), the conflation of sex, genetic reproduction and conflict sucked the joy out and sexual selection became about competition, scarcity and efficiency. Consequently, nonhuman sex is viewed almost exclusively through an evolutionary lens, where its function is for the reproduction of individuals and species, not pleasure (Aanen, Beekman, and Kokko 2016).

For Darwin, sexual selection occurred via mate choice (intersexual) and mate conflict (intrasexual) (Gowaty 2003) and Andersson and Iwasa (1996) note that these mechanisms have received the most interest. However, given the complexity of sexual reproduction and behaviours, selection could occur at any or all of a variety of levels, including sperm competition, mate location (scrambles), endurance, coercion, infanticide, cryptic female choice and parental investment (Andersson and Iwasa 1996; Leonard 2005). Nieuwenhuis and Aanen (2012) provide criteria for determining if sexual selection is occurring, which include whether: sexual reproduction occurs, competition for mates exists, heritable variation is exhibited by traits that influence the competitive ability to access mating partners, these traits are costly and competition actually occurs in nature.

However, Hoquet (2015) argues that “to the epistemologists eye sexual selection is a somewhat fuzzy concept.” He suggests that there are several sites of uncertainty: (1) is sexual selection about access to mates or fertilizable gametes?, (2) what does competition for mates encompass?, (3) is individual viability or gene transmission subject to selection?, (4) are “good genes” or high-quality offspring important and how is this determined? and (5) is heritability important? Given that the literature discusses these same issues, this uncertainty is a feature of the field. In fact, Leonard (2005, 351) argues that “defining sexual selection as the product of competition with conspecifics for reproductive opportunities is clear in

76 Including the pollinator of the peas in Mendel’s experiments.
principle, however identifying and measuring it in practice is far from simple.” In fact, she observes that “sexual dimorphism and secondary sexual characters are often used as proxies for evidence of sexual selection and/or as part of the definition of sexual selection” (349).

The Darwin-Bateman two-sexes paradigm correlates sexual behaviour (gender) with biological phenotype (sex) (Ah-King 2011; Hoquet 2013). As Aanen, Beekman, and Kokko (2016) argue, these assumptions are drawn from the unconscious biases of human evolutionary theorists towards the familiar, i.e., they are heteronormative and animal-centric. Gowaty (2003, 905) notes that “ideas about [sexual behaviour] in mammals were easily extrapolated to other organisms, even invertebrates, because biologists define sex in terms of gamete size [anisogamy].” A heteronormative sexual conflict model, based on anisogamy and a mammalian-derived designation of larger gametes as female and smaller gametes as male, emerged from this paradigm and became fundamental to sexual selection theory. For example, Andersson (1994) argues that anisogamy is essential for sexual selection to act and Parker and Pizzari (2015) include a “male-female phenomenon” in their definition of sexual selection. In this model, conflict arises between the sexes because of an innate asymmetry between the sexes in their investment in gametes (Nieuwenhuis and Aanen 2012; Madjidian, Karlsson Green, and Lankinen 2013; Burke and Bonduriansky 2017). Shuker (2010) argues that

> while it is clear that males and females have to cooperate to some extent in order to mate...both theory and (to a lesser extent) experiment have moved us to view the context in which reproductive behaviour evolves as one primarily driven by sexual conflict rather than sexual cooperation. (e15)

However, he notes that “the key of course is the phrase ‘to some extent’ ” (e15), recognising that the extent of cooperation varies depending on species and context.78

Given their animal-centrism, sexual selection theories tend to be heteronormative, driven by sexual dimorphism and gene-centric reproduction (Ah-King 2009; Bailey and Zuk 2009). For example, Ah-King and Ahnesjö (2013, 463) note that “most models of sexual selection assume that mate choice is genetically determined, which is contradicted by evidence of mate choice changing.” Beekman et al. (2016) observe that most studies of sexual selection have focused on animals with separate sexes and obvious adaptations that function in the context of reproductive competition. Yet, many sexual organisms are both male and female at the same time, often lack sexual dimorphism and never come into

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77 Anisogamy is the “size dimorphism of gametes: one gamete type is larger (e.g. ova) than the other (e.g. spermatozoa), and gametic fusion (now) occurs only between the larger and the smaller gametes” (Lehtonen, Kokko, and Parker 2016).

78 Refer to Gowaty (2009) for discussion of cooperation and sexual selection, in which she considers, albeit briefly, that “sexual orientation might be about...the fitness-enhancing advantages of within- and between-sex coalition-building for the achievement of common goals” (409). Refer also to Roughgarden and Akçay (2010), who call for a rejection of competition based sexual selection in favour of a cooperative model.
direct contact at mating…[They] are often dismissed as ‘unusual’, simply because they have been less studied and their sex life happens to be rather different from ours. (1–2)

The gender and heterosexual biases of sexual selection have been discussed by many, including Hrdy (1986); Bagemihl (1999); Grosz (1999); Hird (2002); Wilson (2002); Gowaty (2003); Roughgarden (2004); Hird (2006a); Ah-King (2007; 2009); Gowaty (2009); Parisi (2010); Roughgarden and Akçay (2010); Ah-King (2013b; 2013a); Ah-King and Ahnesjö (2013); Hoquet (2013). Drawing on feminist and queer scholarship that resists the biological essentialism of sex and sexuality, Bagemihl (1999) and Roughgarden (2004) demonstrated the bias in sexual selection towards heterosexuality as the only natural sexuality and described numerous examples of nonhuman “unusual” behaviours. In Biological Exuberance, Bagemihl (1999) argues that such behaviour is so prevalent among nonhumans that it must provide some evolutionary advantage.

Roughgarden (2004) extended Bagemihl’s provocation and argued that sexual selection theory should be radically reworked to focus on cooperation, not conflict. She draws on Lynn Margulis’ theories of symbiosis to insist that cooperation between individuals and species is the foundation of evolutionary adaptation and much more common than conflict. Her position is highly controversial and has been refuted by mainstream and feminist biologists alike, who argue that her alternative model fits existing sexual selection theory and misappropriates West-Eberhard’s understanding of social selection (Gowaty 2009; Shuker 2010). Despite the controversy, studies of “unusual” behaviours (both reproductive and nonreproductive), including polyandry, hermaphroditism, ménage à trois and facultative, fungal and microbial sexuality, have proliferated and enriched the sexual selection field.

Ah-King and Nylin (2010, 236) observe that “it is a paradox that all biologists are aware of variation in sex determination, sex change and alternative reproductive strategies, and still we continue to present this variation in terms of a two-sex norm and the deviations from this norm as alternatives and sex role-reversals.” They propose a gender-neutral model of sex and sexual reproduction as reaction norms,

79 See for example, Bailey, Dunne, and Martin (2000); and Zietsch et al. (2008); Rice, Friberg, and Gavrilets (2013); Ngun and Vilain (2014). The gender biases are discussed further in chapter 2. For excellent reviews of feminist responses, see Gowaty (2003) and (2009), Alaimo (2010); Brilmyer (2017).
80 Beekman et al. (2016, 2).
81 By arguing that heterosexuality is not “natural,” queer biologists challenge the heteronormativity of sexual selection theories and advocate for the acceptance of human homosexuality. They examine the heteronormative biases in ecology and evolutionary biology, introducing pleasure, non-reproductivity and bonding into sexual selection theories. However, they risk essentialising divergent sexualities in order to denaturalise heterosexuality. While Bagemihl and Roughgarden may “play” in ecology and evolutionary biology to “dissolve binary oppositions,” they tend to denaturalise heterosexuality by naturalising homosexuality.
82 (Beekman et al. 2016, 2).
83 For examples, see Xu (2004); Leonard (2005); Hird (2006a); Michod, Bernstein, and Nedelcu (2008); Ah-King (2009); Bailey and Zuk (2009); Hird (2009; 2010a); Hird and Giffney (2012); Nieuwenhuis and Aanen (2012); Ah-King (2013c; 2013a); Ah-King and Gowaty (2015); Aanen, Beekman, and Kokko (2016); Beekman et al. (2016); Ram and Hadany (2016); and Burke and Bonduriansky (2017).
responsive to environment and context, rather than genetically determined. Gowaty and Hubbell (2009) also provide a model for adaptively flexible reproduction, including polyandry, male coercion and sequential and simultaneous hermaphroditism. Understanding sex and reproductive strategies as flexible reaction norms assumes that diverse sexualities and reproductive strategies (even within species) are “primordial.” This model of “phenotypic variation via ecological regulation of gene expression” (Ah-King and Hayward 2014, 7), where sex could be considered as spectra of “resilience potentials” (9), describes the reproductive strategies of C. albicans well. What possibilities are foreclosed by not considering the “unusual” facultative, fungal and microbial sexuality and isogamous species, such as C. albicans?

1.3.3 Fungal sex and sexual selection

Fungi such as C. albicans are crazy sexual beings, notoriously diverse in their sexual behaviours and capable of multiple reproductive strategies, including sequential and simultaneous hermaphroditism, sexual polymorphism, ménage à trois and selfing (Lee et al. 2010; Nieuwenhuis and Aanen 2012). Recent reviews of sexual selection in fungi demonstrate the complexity and flexibility of fungal sex and that sexual behaviour varies widely between and within species and individuals (Nieuwenhuis and Aanen 2012; Gladieux et al. 2014; Beekman et al. 2016; Vreeburg, Nygren, and Aanen 2016). Despite (or perhaps because of) this complexity, the sexual selection pressures experienced by fungi have only recently been considered. Fungi are described as having “mating types” rather than “sexes” and most are isogametic (Nieuwenhuis and Aanen 2012), i.e., the gametes are morphologically similar, rather than anisogamous. Mating types produce distinct pheromones to attract mates and recognise each other through pheromone signalling (chemotaxis), which can get complicated since these signals may be dispersed over time and space. Many species have “more than two, sometimes up to hundreds, different mating types” (Nieuwenhuis and Aanen 2012, 2398). Fungal sexual selection studies, therefore, focus on pheromone signals as traits that influence mating success and adaptation rather than the visual or behavioural traits more common in animals and insect-pollinated plants (Hadjivasiliou, Iwasa, and Pomiankowski 2015; Beekman et al. 2016).

Mating is highly regulated and for the most part only possible between different mating types as self-fertilisation is prevented by pheromone signalling (although homothallism also occurs) (Nieuwenhuis and James 2016). Mating type genes regulate different aspects of mating, including mating competence and mate attraction and recognition, and can therefore be subject to sexual selection (Nieuwenhuis and Aanen 2012). However, as Leonard (2005) observes, identifying reproductive success can be complicated in hermaphroditic species, since the common measure of number or quality of offspring can be difficult to

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84 Parker and Pizzari (2015, 153) describe intersexual competition between males and females as “primordial”.
85 (Beekman et al. 2016, 2).
86 Mushrooms are the sexual organs of some species of fungi, however, most species do not produce such overt displays.
apply. She also notes that sexual conflict is indirect in species with multiple mating types because each individual competes with all others. Additionally, the scope for competition in yeasts, such as *C. albicans*, is limited as they can only mate once (Beekman et al. 2016). Further, Nieuwenhuis and Aanen (2012, 2340) observe that since the majority of species are isogamous, “the gametes have no inherent differences in investment so asymmetry is unlikely.”

Despite these challenges, fitness differences between mating types and alleles have been observed (Jackson and Hartwell 1990a; Jackson, Konopka, and Hartwell 1991; Rogers and Greig 2009; Smith 2011; Nieuwenhuis and Aanen 2012; Tazzyman et al. 2012; Smith, Pomiankowski, and Greig 2013; Hadjivasiliou, Iwasa, and Pomiankowski 2015; Du et al. 2017; and Constable and Kokko 2018). For example, in chytrids, the limiting fertilising gamete can choose which gamete to fertilise, based on the pheromones produced (Nieuwenhuis and Aanen 2012). Strong signallers have a better chance of being detected and fertilised. Similarly, *S. cerevisiae* has been shown to prefer “high quality” signallers (Jackson and Hartwell 1990a; Rogers and Greig 2009; Smith, Pomiankowski, and Greig 2013). It is likely that *C. albicans* would also preferentially mate with stronger signallers, although this as not yet been examined.

Although Beekman et al. (2016) describes numerous species for which reproduction is separated in time and space, where mating partners interact indirectly, Nieuwenhuis and Aanen (2012) reflect the dominant view that multiple individuals need to meet to compete. This seems to be true for *C. albicans* and so traits that improve cell proximity, such as construction of sexual biofilms, and pheromone signal reception or strength may be subject to sexual selection. However, as Nieuwenhuis and James (2016) observe, mating requires more than merely finding a partner. Xu (2005, 1600) notes that “sexual mating in eukaryotes is a highly complex and interactive process. Current evidence suggests that in [the yeast] *Cryptococcus neoformans*, pheromone production, secretion, and reception; conjugation tube formation; cell size change; cell-cell recognition; and fusion are controlled by multiple signal transduction pathways.” *C. albicans* mating involves all these processes and more, including the white-opaque morphological switch, the switch to mating competency, the post-mating process of reduction from tetraploidy to diploidy/aneuploidy through concerted chromosome loss, sexual biofilm construction, the mechanisms of *ménage à trois* and homothallic mating.

Although some fungal species have multiple mating types, the vast majority have only two, which are usually isogamous (Billiard et al. 2011; Hadjivasiliou, Iwasa, and Pomiankowski 2015). They are formally designated as plus (+) and minus (-), A and B or a and α, as for *C. albicans*, rather than male or female. This nongendered nominative system was specifically adopted in the 1940s for the study of single-celled protozoa. Spanier (1991, 182) argues that the researchers were convinced that male and female were inappropriate terms and nongendered terminology would “generate more accurate and productive research.” This system is largely maintained for unicellular facultative reproduction—not *C. albicans* or
*C. neoformans* are referred to as male or female and none of the literature on microbial sex uses male or female. However, “male” and “female” are commonly used to describe mating types in the fungal sexual selection literature (see Lee et al. 2010; Nieuwenhuis and Aanen 2012; Heitman et al. 2014; Beekman et al. 2016; Nieuwenhuis and James 2016; Vreeburg, Nygren, and Aanen 2016), reinforcing a heteronormative sexual dimorphism.

Gowaty (2009) argues that

> many mainstream evolutionary biologists feel the field has moved on from the old ideas (1) that sex roles are fixed, (2) that females do not behaviorally compete and are coy and passive, (3) that males do not have fitness-enhancing mate preferences, or (4) that there are only two rigidly defined genders. (417)

Although this may be the case in animal biology, animal-centrism and heteronormative gender and sexual biases pervade fungal sexual selection literature. Nieuwenhuis and Aanen (2012, 2398) explicitly emphasise that fungi are useful models for sexual selection “because of the high diversity in fungal life cycles, mating systems and ecology.” They further note that the majority of fungi are isogamous and many “mate as hermaphrodites” (2398). However, the terms “mating type” and “sex” are often used interchangeably to refer to gametes (Lee et al. 2010; Heitman, Sun, and James 2013), implying that there are no inherent differences between mating types and sexes. Heitman, Sun, and James (2013, 7) observe that for some “the distinction between sexes and mating types is more semantic than substantive whereas to others this is dogma that is not open to debate.” For example, they (2013, 7) state “there are a few fungi that do have clearly demarcated sexes” and Lee et al. (2010, 316) describe the chromosomes containing the MAT locus as “sex chromosomes.”

Despite being imprecise, this conflation is not of itself problematic, except that it privileges animal-centric “sex” over mating type and elides the unique characteristics of mating types. In fact, it is believed that mating types are distinct from gametes (sexes) as mating types are determined by the mating-type locus and many species have no genetic sex determination (Heitman, Sun, and James 2013; Vreeburg, Nygren, and Aanen 2016). Hadjivasiliou, Iwasa, and Pomiankowski (2015) also observed asymmetric pheromone signalling in isogamous species, supporting the proposal that mating types have are functionally distinct from gametes and sexes.

Although dimorphic designations may be somewhat understandable for anisogamous species, they are routinely used to describe the mating types of isogamous species, including *S. commune* (which has 20,000 mating types) (Vreeburg, Nygren, and Aanen 2016). Male and female are also used to describe species that do not have gametes, where fertilisation occurs through mycelial fusion (Nieuwenhuis and Aanen 2012; Heitman, Sun, and James 2013), or isogametic species, such as *Neurospora crassa*, in which the male is the fertilizing partner...and the recipient that makes the protoperithecia is designated the female partner.”
The Unsettling Eros of Contact Zones

(Heitman, Sun, and James 2013, 7). Heitman, Sun, and James (2013, 10) further describe the facultative heterothallic mating of *C. neoformans* as “heterosexual reproduction,” reinforcing a heteronormative paradigm.

Isogamous mating types exhibit different, sometimes asymmetrical, reproductive behaviours that are most apparent in chemotaxis (pheromone signalling to attract a mate) (Hadjivasiliou, Iwasa, and Pomiankowski 2015). These are invariably described as “sex roles” and are “parse[d]...into only two categories” (Ah-King and Ahnesjö 2013, 461): male and female. In animal sexual selection, “sex roles” are part of Parker & Pizzari’s (2015) “male-female phenomenon,” i.e., the asymmetry is attributed to anisogamy and differential investment and “sex” and “sex roles” have been considered synonymous (Ah-King and Ahnesjö 2013). The relatively straightforward designations of the larger gamete as female and the smaller as male are “intuitively associated to [sic] stereotypic [human] female and male sexual strategies” (Ah-King and Ahnesjö 2013, 461). Gowaty (2003, 907) argues that “the “facts” about males and females have been so intuitively obvious that only a few ever asked if the “facts” were correct.” A range of discrete, complex behaviours, morphologies and physiologies are usually collapsed under the idea of sex role, including mate choice, mating competition, courtship, parental care, mating pattern, territory defence and selection intensity. Gowaty (2003, 906) notes that despite objections, anisogamy “continues to be a compelling explanation for sex differences.” However, the study of yeasts demonstrated that sexual selection can act on isogamous individuals and therefore anisogamy is not strictly required (Beekman et al. 2016).

Despite the predominance of isogamy, fungal sexual selection has adopted this “compelling explanation” and its associated “stereotyped, idealized and traditional expectations of female and male behavior” (Ah-King and Ahnesjö 2013, 463). Some use sex and sex role synonymously, although most researchers are careful to distinguish between sex as gamete size and sex role as behaviour. Mating types are described as “acting” or “behaving” in a sex role, rather than the mating type “is” that sex. As in animal biology, highly complex mating behaviours are collapsed into self-evident stereotypical sex roles, where the female is invariably described as a passive recipient and the male is an active donor. For example, Beekman et al. (2016, 8) describes “donation of nuclei in the male, and reception of nuclei in the female role,” Nieuwenhuis and Aanen (2012, 2401) assert that “female gametes can produce pheromones as a signal for chemotaxis, to attract male gametes or hyphae (the antheridia) to initiate fertilization” and Vreeburg, Nygren, and Aanen (2016, 1) describe “each cell being a gamete that simultaneously can behave as a female, i.e. contributing the cytoplasm to a zygote by accepting nuclei, and a male gamete, i.e.

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87 Hadjivasiliou, Iwasa, and Pomiankowski (2015) are a notable exception, although their phrase, “gamete roles,” conflates mating type and gamete.

88 As discussed, these designations were extrapolated from mammalian biology (Gowaty 2003).

89 Refer to (Gowaty 2003; 2009) for a review.
donating nuclei to the zygote.” This slippage between mating type, sex and sex role indicates an implicit acknowledgement that sex is an inappropriate/incorrect description of mating type.

Furthermore, parental investment stereotypes pervade the literature. For example, Vreeburg, Nygren, and Aanen (2016) reinforce the sacrificial female trope when they argue that the mating type acting in the female role accepts the nucleus “to become fertilized and reproduce sexually...exposes itself to risks and potential costs. At ‘gamete fusion’, the nucleus of the receiving monokaryon is providing a soma to the nucleus of its mating partner, while its partner provides a nucleus only” (3). Likewise, Du et al. (2017, 6) conflate mating type with parental behaviour in their study of black morel mushrooms, describing “maternal” tissue as that being fertilised by a “paternal” partner and the “one feeding the fruiting body.” Additionally, although they note that “mating types are not linked to either role (i.e. male or female)” (2399), Nieuwenhuis and Aanen (2012, 2397) argue that “fungi compete to fertilize, analogous to ‘male-male’ competition, whereas they can be selective when being fertilized, analogous to female choice.” Such descriptions indicate that fungal sexual selection studies are adopting “facts” about males and females from mainstream animal sexual selection and “not asking if they are correct.”

Consequently, the potential of fungal diversity to challenge the heteronormativity of sexual selection is elided by the “pars[ing of] continuous variation into only two categories” (Ah-King and Ahnesjö 2013, 461). The fungal capacity to differentiate gamete/sex from behaviour uncouples sex and sex roles. For example, although they rely on sexual binaries, Du et al. (2017) argue that “sexual identity, i.e., which mating type acts as male or female, is not defined.” Similarly, Hadjivasiliou, Iwasa and Pomiankowski’s (2015) observation that pheromone signalling is distinct from morphology offers potential for de-essentialising nonhuman sexual behaviours. Further, Beekman et al.’s (2016, 3) observation that the mating partners of some species can influence the sex roles of others supports Ah-King and Nylin’s (2010) model of reaction norms and Gowaty and Hubbell’s (2009) model of adaptive flexible sexuality. It also demonstrates the performative nature of biological sex, discussed further in chapter 2. Although they conflate gamete, mating type, Hadjivasiliou, Iwasa, and Pomiankowski (2015) gesture towards nonheteronormativity in fungal biology by referring to “asymmetric gamete roles” rather than “sex roles.” They engage a nongendered and nonbinary language and enable consideration of a more diverse theory of sexual selection.

Studies of *S. cerevisiae* and *C. albicans* have contributed significantly to knowledge of the diversity and complexity of fungal mating, due to their ease of care and observation (Heitman, Sun, and James 2013). As

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90 (Gowaty 2003, 907)
discussed, these yeasts have two isogamous mating types. Even so, *C. albicans* complicates conflation of mating types, sexes and sexual reproduction as the morphological change to the opaque cell form is necessary to make it competent to mate. They engage in a type of sexual polymorphism, where asexually reproducing cells become morphologically distinct from the sexually reproducing cells, which are differentiated by pheromone production rather than morphology. Once white cells switch to opaque, the isogamous a and α mating types produce different pheromones but have no obvious sex roles. In heterothallic mating, asexual cells become mating competent, produce different pheromones and both cell and nuclei fuse together. Neither cell is donor or recipient, male or female. In fact, both signal and respond, donate and receive. In homothallic mating, cells producing the same pheromones fuse and *ménage à trois* mating requires three cells.

Although no studies of sexual selection in *C. albicans* have been conducted to my knowledge, sexual selection in *S. cerevisiae* has been investigated (Jackson and Hartwell 1990b; a; Jackson, Konopka, and Hartwell 1991; Pagel 1993; Rogers and Greig 2009; Smith 2011; Reding, Swaddle, and Murphy 2013). It is important to note that, unlike *C. albicans*, *S. cerevisiae* can undergo meiosis, does not require a morphological transition for mating and is haploid, with only 1 copy of its chromosomes. However, like *C. albicans*, it has two isogametic mating types, a and α, and individuals recognise mates via pheromone signalling. Beekman et al. (2016) observe that for yeasts the scope for competition between mates is restricted because they only mate once. However, they argue that competition is still possible since mate quality varies and many cells will remain unfertilized at low densities because mates are difficult to locate and at high densities cells are unable to move to find mates.

Consistent with Beekman et al.’s conclusion, studies have demonstrated that *S. cerevisiae* mating is subject to sexual selection. Both mating types respond to mating partners emitting the strongest signal (Jackson and Hartwell 1990a), indicating that “the yeast mating pheromone is...an exaggerated sexual trait” (Smith 2011, 41) upon which sexual selection can act. Numerous subsequent studies have found preferences for strong signalling (Rogers and Greig 2009; Smith 2011; Tazzyman et al. 2012), Jackson, Konopka, and Hartwell (1991) found evidence for a novel role of α-pheromone receptors in partner discrimination and Smith, Pomiankowski, and Greig (2013) identified a preference for larger mate size. Rogers and Greig (2009) posited that signal strength might indicate high-quality individuals, even though strong and weak signallers had equal fecundity and vegetative fitness.

Like those of their multicellular fungal kin, *S. cerevisiae* studies rely on the discourse of animal-centric and heteronormative sexual selection models. In an early study, Jackson and Hartwell (1990b) found that

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91 Could this this sexual polymorphism be considered similar to honeybees, where one “sex” has two different phenotypes differentiated by their ability to reproduce sexually? What are the implications if honeybee sexes are reimagined as three, like candida—“asexual,” “male” and “female”?
mating between a and α cells was induced by the production of α-pheromone by a cells, which induced a-pheromone production by neighbouring α cells. a cells then chose a mating partner based on the α-pheromone they had induced. Jackson and Hartwell concluded that mating was driven by the a cell, consistent with the dimorphic sex roles of animal-centric models. However, they subsequently found that both cells respond equally to each other’s pheromones (Jackson and Hartwell 1990a). These experiments provide excellent examples of perception bias (Gowaty 2009): the researchers based their experimental design on animal-centric models of anisogamy and sex roles and assumed the yeast cells would engage in an asymmetrical mating relationship, where one mating type would “act” to induce a response in the other. Their description of this incorrect asymmetrical interaction as “courtship,” i.e., “an a cell courts an α cell using a-pheromone” (1990b, 2202) connotes particular heteronormative human behaviours and the term has persisted in subsequent studies (Rogers and Greig 2009).

Further, in a study of pheromone production as sexual display, “one of the haploid yeast mating types, MATa, was designated the signalling (typically the ‘male’ role), and the other, MATα, as the receiver (typically the ‘female’ role)” (Rogers and Greig 2009, 544). This designation referred to an experimental study of the courtship song of the male fruitfly Drosophila pseudoobscura, a sexual display where the male is “the signalling” (Rogers and Greig 2009). Where to begin?: firstly, the researchers have designated a false asymmetry since both mating types signal equally; secondly, this asymmetry is unnecessarily associated with the “male-female phenomenon;” and thirdly, the behaviours are collapsed with disputed, conservative and heteronormative anisogamous sex roles.

Similarly, a study of mate choice conducted by Tazzyman et al. (2012) conflates mating type and sex and incorrectly assigns gender to the isogametic cells: “in many sexual signalling systems, the costly handicap mating signal evolves in one sex (usually the males), and the preference trait evolves in the other sex (females)” (1464). Thirteen years after Jackson and Hartwell’s biased experiment and despite Gowaty’s (2009, 417) claim that “many mainstream evolutionary biologists feel the field has moved on,” Smith, Pomiankowski, and Greig (2013, 326) used the “standard model of sexual selection (i.e., male-male competition and female choice)” to examine the effects of size on competitive mating success in S. cerevisiae. As Gowaty suggests, these “facts” have since been disputed in animal sexual biology but clearly are being reinforced by fungal sexual biology. Although C. albicans pheromone signalling may be subject to sexual selection in similar (and other) ways to those demonstrated in the studies of S. cerevisiae sexual selection,92 future C. albicans studies would be remiss to adopt such language and biases.

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92 It is worth noting that only two or three research groups are conducting research into S. cerevisiae sexual selection, including the Lang Lab at Lehigh University, Pennsylvania and the Galton Lab at University College London. Because the field is so small, any perception biases will likely become confirmation biases and be perpetuated within the group and by other groups through reference to the dominant groups papers. Consequently, the designation of S. cerevisiae mating types as male and female by the dominant researchers may become normative for the field.
1.3.4 Facultative sex and sexual selection

Although *C. albicans* sexual reproduction may be subject to sexual selection, the frequency with which it engages in sexual reproduction is extremely low. As discussed, sexual selection has typically considered asexual and sexual reproduction to be mutually exclusive (Burke and Bonduriansky 2017) and asexual reproduction has been considered to be exclusively subject to natural selection, understandable given the lack of competition for access to mates. However, the distinctions between sexual and asexual reproduction or between social (sexual selection) and non-social (natural selection) interactions are not always clear (Bell 2005; West-Eberhard 2014). Consequently, recent models of facultative sexual selection consider the relationships between asexual (vegetative) and sexual reproduction.

Typically, sexual reproduction has been considered antagonistic to vegetative fitness as the production of sexual traits is costly and the duration of the sexual cycle is longer. Da Silva and Bell (1992) argue that

the notion of antagonism between vegetative and sexual life-cycle components has always been central to the theory of sexual selection...because...although sexual traits that might increase mating success are likely to reduce vegetative performance...Therefore, a negative correlation between mating success and viability is expected...However it is difficult to study this antagonism in multicellular organisms, because of the complex relationships between vegetative and sexual structures borne by the same individual. In unicellular protists these complications are stripped away, and overall fitness can be partitioned cleanly into two components, vegetative increase and mating success. (227)

The negative correlation between mating success and viability has been observed in *C. neoformans* (Da Silva and Bell 1992; Bell 2005; Xu 2005), *S. cerevisiae* (Zeyl et al. 2005; Lang, Murray, and Botstein 2009; Reding, Swaddle, and Murphy 2013) and the basidiomycete *Heterobasidion parviporum* (Vreeburg, Nygren, and Aanen 2016). This expected negative correlation between asexual and sexual reproduction underlies the fervent interest in explaining the prevalence of facultative sexual reproduction and the maintenance of (para)sexual reproduction by *C. albicans*.

However, discussion of facultative sex tends to focus on the causes and mechanisms of the switch between strategies rather than interactions between individuals. Although the frequency and costs of facultative sex are largely unknown for most species (Xu 2004; 2005), Constable and Kokko (2018, 1172) note that “ecological conditions select for sex rate in a given facultatively sexual species” and Xu (2005) asserts that the costs are context dependant. Like asexual reproduction, these discussions tend to be framed by natural selection and competition between individuals for resources (Bell 2005). For example, Zhang et al. (2015) concluded that *C. albicans* mating is under natural selection.

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93 Sexual reproduction is characterised by intention (“choice”) and action (“conflict”), whereas asexual reproduction is passive. Thanks to Ionat Zurr for bringing this to my attention.
Despite the focus on natural selection, asexual reproduction is thought to be an important player in facultative sexual selection, particularly in unicellular organisms whose asexual vegetative cells are one of at least three co-existing reproductive cell types. Several studies of facultative sex have found that sexual conflict can occur between vegetative (asexual) and mating competent individuals. For example, Xu (2005) found that the presence of mating individuals reduced the capacity of vegetative cells of *C. neoformans* to reproduce. They further observed that “the greater the mating ability, the greater the reduction in vegetative fitness” in other cells and concluded that this reduction “constitutes one type of cost of sex” (1598). Da Silva and Bell (1992) found that the ability of the unicellular alga *Chlamydomonas reinhardtii* to mate was nearly lost in experimental lines that were propagated asexually and a subsequent study by Bell (2005) demonstrated that “the response to sexual selection was so great that not only did gametogenesis become two orders of magnitude more efficient, but the mating system changed from heterothallic to homothallic and gametogenesis occurred spontaneously rather than in response to the usual nitrogen starvation signal” (Zeyl et al. 2005, 2109).

Similarly, Zeyl et al. (2005) observed increases in sexual proficiency in asexually evolved lines of *S. cerevisiae* under sexual selection, implying heritable selection for sexual mating over asexual reproduction. However, they also observed a positive correlation between vegetative and mating fitness in one experimental population. They argue that sexual selection could act on any of the “numerous yeast genes known to have roles both in mitotic growth and in... mating...[or] “a regulatory mutation may cause the expression in both phases of the life cycle of other genes previously restricted to the sexual or the asexual phase” (2114). Da Silva and Bell (1992, 228) also suggest that “intra-sexual competition or mate choice may create a positive correlation between vegetative growth and mating success.”

Two mechanisms have been described which would result in improved mating success and viability of vegetative cells. Da Silva and Bell (1992, 227) argue that “a positive correlation is possible under antagonistic evolution, such as that between parasites [or pathogens]” and Zeyl et al. (2005, 2114) assert that “early stages of adaptation to an environment may select for improvements to both sexual and asexual fitness.” These suggestions are consistent with the Red Queen hypothesis and observations that facultative sex is beneficial for organisms in unpredictable environments such as the human body (Xu 2005; Stelzer and Lehtonen 2016). Zhang et al. (2015) found that *C. albicans* mating generates genotypes that increase population fitness, maximising asexual reproduction and minimising the costs of sexual reproduction. Although their study was focused on natural selection, their findings are consistent with Da Silva and Bell’s and Zeyl et al.’s mechanisms. Zhang et al. (2015) also identified the following costs of mating: mating-competent cells are slower growing than clonal cells and therefore produce fewer progeny, decreasing reproductive success; MTL-homozygotes may become extinct when competing for limited resources with faster growing MTL-heterozygotes; the act of mating yields fewer new cells; mating may “fail” if unfit
progeny result; competition with parents and ancestors for limited niches and resources; low abundance increases chance of extinction; and delayed accumulation of faster growing progeny. These costs are consistent with opportunities for sexual conflict identified by Da Silva and Bell (1992), Bell (2005), Xu (2005), Zeyl et al. (2005) and Beekman et al. (2016), which suggests that facultative sexual selection may act in the CandidaHomo ecology.

Recent studies of fungal, microbial and facultative sex have confirmed Beekman et al.’s (2016) assertion that

we may miss a suite of more subtle mechanisms that profoundly affect sexual selection if we stick to studying the usual suspects...[and] the lessons learned from moving out of one’s comfort zone and venturing into the lesser-known realms of sexual selection can provide critical insights into the mechanisms of (gamete-level) sexual selection in more familiar taxonomic groups. (2)

Given the extraordinary complexity of C. albicans reproduction, including pre- and post-mating, mating itself, the multiple possible mating configurations, niche construction by asexual cells that improves mating efficiency between mating competent cells, the cohabitation of asexual and mating competent cells and other “subtle mechanisms,” it is remarkable that studies of sexual selection in C. albicans have not yet been undertaken. However, this may be due to the absence of models of facultative sexual reproduction in C. albicans literature. The mechanisms, frequency and costs of (para)sex have been comprehensively studied in C. albicans and consequently, C. albicans is an ideal model for studies of facultative sex and sexual selection. Furthermore, facultative sex is an ideal model with which to consider the C. albicans reproduction. “Venturing into the lesser-known realms of [facultative sex and C. albicans could] provide insights”\(^\text{94}\) for animal-centric and heteronormative sexual selection models.

1.4 QUEERING QUEER

For the most part, feminists, queers and people of colour have been understandably reticent to look to biology and evolutionary theory. They have worked hard to uncouple biology and behaviour, nature and nurture, pleasure and reproduction, wary of abuse and discrimination justified by social Darwinism, biological essentialism, eugenics and “bad science” (Spanier 1995, 58; Owen 2014; Brilmyer 2017). In particular, queer theory disarticulates biological sex, i.e., the behaviours that lead to reproduction, and cultural sex, i.e., the unconscious and learned performance of sexed and sexual behaviours, which has come to be known as gender (Halperin 2003; Davis 2005). Most importantly here, it challenges assumptions that heterosexuality is “primordial”\(^\text{95}\) and draws attention to the pleasures and intimacies of sexual behaviours, which dominant sexual selection models overlook in their fervour for competition and genetic

\(^{94}\) (Beekman et al. 2016, 2).

\(^{95}\) (Parker and Pizzari 2015, 153)
replication (Gowaty 2009). Although Elizabeth Grosz infamously insists on the generative power of sexual
dimorphism, she argues that queer

is a refusal to link sexual pleasure with the struggle for purpose...it represents a desire to enjoy, to
experience, to make pleasure for its own sake, for where it takes us, for how it changes us, to see it
as one, but not the only, trajectory or direction in the lives of sexed bodies. (Grosz 1994a, 153)

Consequently, queer theory has been described as “hedonistic activism” and a “sensorial basis to cultural
critique.” (Morland 2009, 287). I propose sexuality as the first principle of queer theory. I further argue that
queer theory is oriented towards sexual desire and that this orientation is haunted by dominant
heteronormative theories of sexual selection.

1.4.1 Queer CandidaHomo ecologies
The sex and sexuality of candida and human are intimately entangled. We acquire it during birth or very
soon after through breast feeding or skin contact. However, we do not notice it until it proliferates, then
uncontained reproduction causes inflammation, irritation, discharge and sometimes death. Its ability to
switch from asexual to sexual reproduction enables it to adaptively respond to unpredictable
environmental conditions and it occupies almost every ecological niche in the human body, including the
skin, vagina, penis and mouth. Candida and thrush are overwhelmingly associated with women, although
the sex of humans does not seem to be a factor determining the prevalence of commensal populations of
C. albicans in the intestines and oral cavities of healthy individuals (Moreira et al. 2001) and C. albicans is a
commensal on the penises of 20 percent of healthy men (Lisboa et al. 2010).96

75 percent of women are likely to suffer from candidiasis at least once in their lives and 5–10 percent have
recurring vulvovaginal candidiasis (Noble, Gianetti, and Witchley 2016). Women are eight times more likely
than men to be diagnosed with an infection (Martins et al. 2014). C. albicans is especially responsive to the
fluctuating pH, glucose and estrogen in vaginas (Noble, Gianetti, and Witchley 2016) and contraceptive use
is a predisposing factor (Martins et al. 2014). However, men are more likely to contract chronic infections of
dentures and systemic, nosocomial infections, i.e., 55–70 percent of patients with candidemia are men
(Jaggi et al. 2014; Khalid et al. 2014; Prakash et al. 2015; Chapman et al. 2017). Studies of oral thrush in
denture wearers observe that men have poorer oral hygiene habits, which is a risk factor for infection
(Moreira et al. 2001; Prakash et al. 2015). It may be that men’s infections are under-reported or
underdiagnosed (Lisboa et al. 2010). Overall, men are less likely to attend medical services and infections
may only be observed once hospitalised.

96 The scientific literature does not discuss nonbinary, intersex or trans.
A gender bias is also evident in the framing of candida infections. Although *Candida*-associated vulvovaginal infections are considered to be a ubiquitous aspect of women’s lives, penis infections (candidal balanitis) are almost exclusively attributed to sexually transmitted infections (Martins et al. 2014), despite the scarcity of information about the prevalence and incidence of candidal balanitis (Lisboa et al. 2010; Behzadi, Behzadi, and Ranjbar 2015). Reasons for this scarcity are unclear but may be the result of research bias and/or the classification of balanitis as a sexually transmitted infection (STI), evident in a significant disparity in candidal balanitis studies compared to vulvovaginal candidiasis.97

The majority of studies claim that candidal balanitis has been transmitted from women, despite several studies that found no association (Lisboa et al. 2010). Some medical help websites openly claim that women *cause* infections in men: “men can get a yeast infection by having unprotected sex with a woman with candidal vaginitis” (“Men Get Yeast Infections, Too!” 2015), despite no conclusive experimental or clinical evidence. In fact, Rivers et al. (2013) observe that the contribution of sexual transmission is unclear and Lisboa et al. (2011, 145) argue that “the relevance of sexual transmission should not be emphasised.” While it is important to note that this is a risk factor, causation is complicated—if most of us acquire it as infants, surely it is possible that men are transmitting it to women and obviously, men who have sex exclusively with men are not getting it from women.

The vast majority of candida research assumes heterosexual partnerships to be the norm (Schmid et al. 1993; Reed et al. 2000).98 Only two studies have been conducted to determine if candida is sexually transmitted between women who have sex with women (WSW) and the results were contradictory (Bailey et al. 2008; Rivers et al. 2013). Studies of sexual transmission between men who have sex with men (MSM) are exclusively focused on the comorbidity of oral candida infections and HIV/AIDS. Oral thrush is an early indicator of an HIV infection and studies indicate that 45–55 percent of HIV+ patients have oral thrush, which is attributed to their suppressed immune systems. I have been unable to find any studies that discuss *C. albicans* infections in polyamorous, nonbinary, intersex or trans people.

Despite the comorbidity of candida and HIV, queer explorations of the cultural intersections of disease and sexuality in the wake of the HIV epidemic have not looked to candida. This aversion may be due to queer theory’s ambivalence with actual bodies and biology. O’Rourke (2014, 5) argues that “queer theory does not—despite what it tells itself—like the icky, sticky, yucky, viscous, gloppy, gunky, mascara-streaked, wet, bloody, sweaty, pissy, shitty, leaky, seeping, weeping, sploshing, spurting, spasmimg, milky. It needs to carefully mop up the messy, the dirty, the sexually disgusting.” Wiegman (2012) attributes this elision to a

97 A literature search of the PubMed database for “candida balanitis,” “candida and penis” and “candida and vagina” yielded 83, 90 and 4,962 results respectively; for “candida and men” and “candida and women,” 456 and 1,984 respectively.

98 PubMed search results: candida and heterosex* [55]; and homose* [101; only 1 in the last decade]; and bisex* [20]; and gay [25]; and lesbian [7]; and WSW [2]; and HIV [2,011].
shift in focus from sex to gender and from a critique of heteronormativity to a desire for homonormativity as described by Lisa Duggan (2002) and others. However, Karen Barad (2007) argues that an ambivalence about the biology of sex has existed in queer theory from the get-go.99 This ambivalence is partly due to the discursive focus of gender theory and partly a reaction to concerns about biological essentialism inherent in sexual orientation and identity politics (Chasin 2013; Gupta 2015). For example, Hilary Radner (2008, 99) writes that “Foucault asks us to step back and consider our own libidinal investments as a product of history rather than nature,” as if historical/cultural libidinal investments are differentiable from biological libidinal investments. Considering the sexuality and reproduction of the CandidaHomo ecology as naturecultural and more–than–human re-orientes to the materiality of biology and history and of knowledges and social practices that describe “how sex ‘ought’ to occur.”100

In particular, the asexuality of candida prompts me to consider whether asexuality might be the limit of queer theory. For example, Subramaniam and Willey (2016) ask “of all the complexities of the human body, why do we privilege sexuality?” Their response is that

all biological theories of sexualities have their roots and are deeply invested in (neo)Darwinian theories of evolution, where reproductive success and fitness is the holy grail. This has led to the privileging of heterosexuality, the “queerness” of homosexuality, the unnaturalness of monogamy for men, and the naturalness of monogamy for (white) women, the “primitiveness” of the non-Western world, to name just a few. (514)

Their response is entirely reasonable given that sexual selection theory is one of these naturecultural knowledge practices that entangles biology and sex and its development during the nineteenth century along with other scientific and medical practices, clinics and institutions structured scientia sexualis and biopower. As has been discussed, sexual selection privileges and naturalises sexual dimorphism, sex roles and heterosexuality and this normalisation has been interrogated by feminist and queer biologists and STS scholars, notably Elizabeth Grosz, Elizabeth A. Wilson, Sarah Blaffer Hrdy, Patricia Adair Gowaty, Barbara Smuts, Mary Jane West-Eberhard, Evelyn Fox Keller, Sandra Harding, Donna Haraway, Ruth Hubbard, Elizabeth A. Wilson, Myra Hird, Malin Ah-King, Anne Fausto-Sterling, Joan Roughgarden, Bruce Bagemihl, Banu Subramaniam, among many others.101

Similarly, the emerging field of queer ecologies interrogates material-discursive constructions of nature and sexuality more broadly. In fact, queer theory is founded on sexual multiplicity and variation and rejection of sexual dimorphism. However, when Subramaniam and Willey (2016) ask “why we privilege sexuality?,” their response indicates that they are actually asking why we privilege “sexual reproduction.” This is

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99 A similar ambivalence is evident in feminism and has been comprehensively discussed.
100 (Aanen, Beekman, and Kokko 2016, 2)
101 Refer to Brilmyer (2017) for an excellent review of the relationships between feminism and Darwin.
entirely consistent with queer theory and feminism’s uncoupling of sex and reproduction. However, “why privilege sexuality?” is not precisely the same as “why privilege reproduction?” Subramaniam and Willey do not question the existence of sexuality itself.

1.4.2 Queering sexuality

Teresa de Lauretis, who coined the term “queer theory” in 1991,

hoped both to make theory queer (that is, to challenge the heterosexist underpinnings and assumptions of what conventionally passed for “theory” in academic circles) and to queer theory (to call attention to everything that is perverse about the project of theorizing sexual desire and sexual pleasure). (Halperin 2003, 341)

Queer theory does more than this, however. It provides an apparatus with which to examine “knowledges and social practices that organize ‘society’ as a whole by sexualizing—heterosexualizing or homosexualizing—bodies, desires, acts, identities, social relations, knowledges, culture, and social institutions” (Seidman 1996, 13). Queer theory interrogates “sexuality as an inescapable category of analysis, agitation, and refunctioning” (Berlant and Warner 1998, 564). Consequently, interrogations of candida research and sexual selection theory as knowledge practices that describe sexual practices are crucial for queer theory to consider.

It is also crucial to consider queer theory itself as a knowledge practice that describes sexual practices and this self-interrogation of “its exclusionary operations” is an important aspect of the theory (Eng, Halberstam, and Muñoz 2005, 3). As Hannah McCann (2016, 239) observes, “queer theory affords a way of critiquing and extending the limits of sexual identity, while simultaneously providing these identifications as a source of inspiration and motivation for discussion.” Although queer theory is a dynamic field, it is dominated by an orientation towards anti-normativity. Many have discussed the reasons for this reactionary orientation (Eng, Halberstam, and Muñoz 2005; Jagose 2015; Wiegman and Wilson 2015), tracing it to early theorists such as Sedgwick, Butler, Warner and Halperin, who were informed by Foucault’s discussion of the scientific and biopolitical mechanisms of normalisation of sexuality and bodies (Jagose 2015),

102 Leo Bersani’s (1987) so-called anti-social assertion that sex is the site at which queers refuse sex shame and are refused heterosexuality (Caserio et al. 2006; O’Rourke 2014; Hammers 2015) and Lee Edelman’s (2004) rejection of hetero-productive logic (Halberstam 2008; Davis 2015; Hammers 2015). Hammers (2015) argues that

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102 Annamarie Jagose (2015) notes that Teresa de Lauretis conceived queer theory as a response to the whiteness of lesbian and gay studies and saw it as a tool to broadly “counter dominant discursive formations” rather than the explicitly anti-normative framing subsequently adopted. She argues that the problem with defining queer theory with respect to normativity is that the norm doesn’t exist. Consequently, we end up, at best, chasing ghosts and, at worst, become normalised ourselves (refer to Chen (2012)).
queer desire...exposes as fiction hetero-productive logic as it eludes/disrupts representation/meaning altogether. In essence, queer sexuality is constitutive of perversion and refusal, and is as such incompatible with sociality (Bersani, 1987)... queer theory’s singular fixation on desire as it not only marks that domain of queer but claims this territorial domain—that which is refusal, thus queer—by way of gender’s erasure...Desire is thus, unlike gender, a “uniquely valuable source of antinormative potential” (Dean, 2000: 27)—that which most strongly resists heteronormativity since sexuality is “resistance to normalization itself” (Dean, 2000: 87). (840)

The paradox and misogyny inherent in this rejection of gender has been discussed eloquently by many, including Butler herself (Hammers 2015). What interests me here is the metonymy of desire and sex and the underlying assumption of white masculinity and its associated sexual behaviours.

The recent “coming out” of human asexuality (described broadly as the absence of sexual desire) reveals a regime of compulsory sexuality and the reliance of queer theory on desire for another (Cerankowski and Milks 2010; Scott and Dawson 2015; Wong 2015). Recent scholarship about asexuality (Cerankowski and Milks 2010; Przybylo 2011; Gupta 2013a; Cerankowski and Milks 2014; Owen 2014; Gupta 2015; Scott and Dawson 2015; Wong 2015) provides one of the most exciting challenges the exclusionary operations of queer theory by revealing an assumption of sexual desire. As the definitions of queer theory indicate, the field, although founded on a challenge to “compulsory heterosexuality,” has understood sexual desire as a condition of being human. Although Vares (2017) notes the recent emergence of queer and feminist scholarship, many asexuality scholars have drawn attention to the absence and occasional active rejection of asexuality by queer theorists (Przybylo and Cooper 2014; Vares 2017). For example, Gupta (2013b) observes that some lesbian, sex-radical, and queer scholars hypersexualise lesbian women in response their desexualisation, claiming that lesbian women are more sexual than other women. Milks (2014) asserts that within U.S. feminist and queer discourse, if asexuality is addressed at all (and it typically is not), it is generally viewed in pejorative terms as either/both conservative and repressed; or it is used as a pejorative itself, with judgments like “repressive” and “conservative” attached to its use. These attitudes toward asexuality position it on the wrong end of the narrative of sexual liberation—the obsolescent beginning to which no one wants to return.” (107–108)

Understanding a body as naturally sexual or desiring suggests homonormative assumptions about sexual behaviours.

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103 Although as described by the scholars, there are diverse definitions and experiences.

104 Compulsory heterosexuality was introduced by Adrienne Rich (1980) and describes the mechanisms by which heterosexuality is structured and enforced. Heteronormativity emerged from compulsory heterosexuality (Berlant and Warner 1998).

105 Following criticisms that white masculinity underpinned queer theory by queer women and people of colour, Lisa Duggan (2002) argued that queer practices and theory were increasingly complicit with neoliberalism and capitalism and in danger of becoming “homonormative.”
Compulsory sexuality identifies and challenges the cultural assumption that all people are sexual. It interrogates “the social norms and practices that both marginalize various forms of nonsexuality, such as a lack of sexual desire or behavior, and compel people to experience themselves as desiring subjects, take up sexual identities, and engage in sexual activity” (Gupta 2015, 132). The term was coined by Hilary Radner (2008), who provocatively asks

What is the opposite of “sexuality”? Is it celibacy? Or is it new configurations of libidinal investment that may eschew the erotic altogether? Today, then, it perhaps makes more sense to talk about “compulsory sexuality” and the reasons for which it is nearly impossible to “think” its opposite. (98)

Kristina Gupta (2015) provides a comprehensive review of the evidence for compulsory sexuality, including feminist scholarship on compulsory heterosexuality, media sexualisation and the absence of representation of nonsexual relationships, institutional bias (sexology, psychology and law (Emens 2014)) and the desexualisation of particular groups as a method of social control. Rather than understanding sexuality as essential, “compulsory sexuality can instead be conceptualized as a system that simultaneously privileges sexuality while marginalizing nonsexuality, that regulates the behavior of sexual and nonsexual people, and that contributes to the production of both sexualities and nonsexualities” (Gupta 2015, 145).

Therefore, considering sexuality as a compulsory system requires examination of the “knowledges and social practices” that describe, privilege, regulate and produce sexualities. The two practices that interest me here are sexual selection theory and queer theory. Gupta (2015, 135) identifies both as being complicit in defining the norms of sexuality when she argues that “society’s definition of the human and the normal are tied to the sexual, but not necessarily entirely to the heterosexual.” As discussed, Neo-Darwinian sexual selection theories have underpinned contemporary Western definitions of “the human and the normal.” Given that sexual desire is definitive for queer theory, it becomes entangled with sexual selection, in refusal and in kind. Cynthia Barounis (2014, 184) argues that “queers...find themselves complicit in a much broader set of compulsory systems governing erotic identification.”

1.4.3 Sexual selection and queer theory
The entanglements between sexual selection and queer theory are evident in queer sexuality as “unmarked, as the basic idiom of the personal and the social;...marked as a natural state; or projected as an ideal or moral accomplishment...and a sense of rightness produced in contradictory manifestations—often unconscious, immanent to practice or to institutions” (Berlant and Warner 1998, 348). I am not arguing

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106 Kristina Gupta (2015, 132) argues that “the question of whether asexuality is outside of sexuality or is simply another form of sexuality is not a useful question, as it reflects the assumption that both sexuality and asexuality are definable identities.”
107 (Seidman 1996, 13)
108 Here I refer to Lauren Berlant and Michael Warner’s (1998) description of heteronormativity and so also provide further evidence for Lisa Duggan’s (2002) homonormativity.
here in support of sociobiology or biological essentialism in either sexual selection or queer theory. What I am interested in is exploring the traces of sexual selection theory through queer theory’s naturalisation of sexual desire and sexual behaviours, even if they are anti-normative. Gupta (2015, 134) argues that “according to Foucault, the subject is, necessarily, a sexual subject.” However, given Foucault’s interrogation of bio-power, I wonder if it might not be more correct to say that, for Foucault, the subject is, inevitability or inescapably or unavoidably, a sexual subject. Consequently, sexual subjectivity is in inevitable, inescapable, unavoidable polylogue with the knowledge practices that describe that subjectivity.

However, to my knowledge, the legacies of sexual selection (or evolutionary theory more broadly) in queer theory and queer ecology have not been explicitly examined, except as refusal of social Darwinism, biological essentialism and heteronormativity. Several have gestured towards their entanglement, for example, Luciana Parisi (2004) discussion of “abstract sex” pushes the limits of what we consider reproduction to be, Myra Hird (2010b) discusses bacterial indifference and infers the role of asexual reproduction in past and future planetary survival, Ah-King and Hayward (2014) discuss the sexual and morphological agential potential of endocrine disruption and plastic pollution and, of course, Haraway argues for companion species co-evolution.

The reticence to look at the traces of sexual selection may be due to Foucault’s rejection of Darwinian genealogy (Solinas 2017) and queer theory’s discursive heritage. It may also be inattention to or misinterpretation of contemporary sexual selection theories that understand sex as flexible reaction norms. For example, Atterton (1994) categorically distinguishes between biological and cultural evolution and only recognises Mendelian inheritance, which neo-Darwinism frames as heterosexual. He further asserts that the temporal magnitude of biological evolution is “vastly greater” than that of cultural evolution (12), which is consistent with understandings of metazoan evolution but not fungal or microbial. However, there are several scholars who are familiar with both contemporary sexual selection and queer theory, including Malin Ah-King and Myra Hird.

Nevertheless, the entanglement of queer and sexual selection theories is particularly relevant for understanding queer ecologies, especially given that nonhuman sexuality is almost exclusive framed through sexual selection theory. There are several aspects of queer theory that resonate with sexual selection theories, including compulsory sexuality, sexual fitness, variation as constitutive of sexuality, the involvement of more than one individual, sex role stereotypes of the passive female and active male, sexual coercion and sociality.

**Compulsory sexuality**

As discussed, sex is fundamental to both sexual selection and queer theory. Although dominant sexual selection theories have argued that sex is synonymous with reproduction, queer sexual selection studies
demonstrate that sex without reproduction or for pleasure occurs in many species. Furthermore, fungal, facultative and microbial sexual selection demonstrate that reproduction can occur in the absence of sex and that asexual reproduction is the most common and ancient strategy. As Hird (2012) points out, life on earth exists because of asexual reproduction. Although queer theory uncouples sex and reproduction, it understands sexual acts as constitutive of being human—as natural (Gupta 2017, 1003). For example, Love (2011, 180) writes that “it’s hard for me to imagine a form of queerness that does not maintain its ties to a specific form of sexual identity.”

Fitness

Implicit in these comments is an “assumption that so-called normal and healthy human subjects are sexual subjects and that normal and healthy romantic relationships involve sexual activity” (Gupta 2015, 140). In sexual selection, sexual fitness is identified by the number or health of offspring produced. Several scholars have observed the connection between queer sexuality and health or ability (Jagose 2013; Barounis 2014). Healthy queer sexuality includes orgasm, particularly for women (Jagose 2013) and does not include frigidity (Barounis 2014). Of course, gay male sex, in particular, has a complex relationship with health, given the legacy of HIV/AIDS. For example, Michael Warner (1999) asserted that overcoming sexual shame is necessary to participate in queer community. However, Barounis (2014, 189) suggests that this commonly-held queer ethic “might unwittingly institute [its] own set of regulatory norms that implicitly promote sexuality as the (compulsory) key to personal growth, community well-being, and even global health.” This ethic of healthy sexual liberation is inherited from sex-positive feminism (Cerankowski and Milks 2010; Milks 2014), Leo Bersani’s (1987) call to refuse sex shame (Caserio et al. 2006; O’Rourke 2014; Hammers 2015) and early twentieth century understandings of active (hetero)sexuality as important for healthy bodies and relationships (Barounis 2014).109

Variation

Sexual variation is fundamental to the fitness of the queer community. Erica Chu (2014, 83) observes that in order to “counter the master narratives of compulsory heterosexuality and respectable gayness [queer narratives] promote an understanding of what Michael Warner calls “sexual variance.” For example, Parisi (2010, 163) argues that “all forms of sex—bacterial sex, endosymbiosis, sexual reproduction, parthenogenesis, algorithmic sexes, engineered cloning, nano and synthetic sexes—are events that expose sexual difference to a multiplicity of actual sexes, ontologically irreducible to the model of the two.” This sexual variance is inherited from Foucault’s strategies of resistance to biopower. Atterton (1994) and Solinas (2017) both argue that Darwinian evolutionary theories are evident in the variation and plurality central to Foucault’s understanding of the “agonistic” struggle to survive in environments, which

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109 Gupta (2015, 143) notes that Foucault “rejected sexual liberation as a goal.”
110 “a relationship which is at the same reciprocal incitation and struggle” (Dreyfus and Rabinow 1983, 222)
manifests in the “body exceed[ing] the limits of disciplinarity” (Atterton 1994, 14). Chu (2014, 83) argues that queer narratives of sexual plurality have rendered asexuality invalid or abnormal or, worse, assimilationalist: “for many LGBQs, not being sexually active or not voicing sexual attraction is associated with involuntary entrance into the closet and is therefore aligned with assimilating into normative society or trying to pass as straight.” However, Gupta (2015, 148) argues that this plurality could be a strategy for challenging the unearned privileges that accrue to sexual people and sexual relationships and by eliminating discrimination against nonsexual people and nonsexual relationships. It certainly could be supported by Ah-King and Nylin’s Ah-King and Nylin (2010) models of sex as reaction norms, Gowaty and Hubbell’s (2009) adaptively individual flexibility or facultative sexual selection.

The sex that is not one
Wiegman (2012, 341) provocatively asks “at the heart of the antinormative enterprise, then, is a deceptively simple but as yet unanswered, perhaps, unanswerable, question: What is the sex that queers so queerly have? Or more pertinently, what is the queer sex that queers so nonnormatively have?” Hammers (2015) argues that the perverse and resistant sex/desire on which queer theory is founded is gay male anal penetration. Since one cannot anally penetrate oneself, “the sex that queers so queerly have” is not with self, it is with an other.” This other oriented sex is evident in the metonymy of sex and desire, which is either used synonymously or as “sex/desire.” Drabinski (2014, 325) hails this orientation towards an other when she asserts that “we identify with Hernandez, identify with…how the self puts the self ‘out there,’ feels that naked desire, and yearns for it to be returned.” She assumes that we all put ourselves “out there” and yearn for desire to be returned.

Similarly, Hammers (2015) asserts that “social recognition is crucial to modes of desire” (841) and describes queer desire as a “binding mechanism, generative of alternative socialities, wherein bodies are themselves emergent formations entangled with, and dependent on, other bodies” (849). Likewise, Gayatri Gopinath (2005, 5) argues that “all too often [queer] diasporas are narrativized through the bonds of relationality between men.” Similarly, the calls for same-sex marriage equality privilege monogamy over polygamy and singleness (Butler 2002; Davis 2005; Scherrer 2010). Further, the descriptions of an asexual person as either “someone who prefers not to have sex” or “someone who does not experience sexual attraction” indicate the orientation towards an other of sex/desire (Milks 2014). These definitions also demonstrate a tension between a/sexual attraction as a preference or a biological experience. In addition, “by redefining some

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111 She refers to the call by trans* studies scholars for a proliferation of representations of gender categories in the expectation that such a proliferation will reduce pressure on all people to conform to specific ways of doing gender.
112 Ironically, other oriented sex is the biological definition of hetero-sex. See “heterothallism.”
113 The distinctions between asexuality and Hypoactive Sexual Desire Disorder (HSDD) as a person who is distressed about their lack of sexual attraction are discussed elsewhere (Chasin 2015).
sexual activities as nonsexual, asexually identified individuals disrupt the socially constructed distinction between the “sexual” and the “nonsexual.” (Gupta 2017, 992–993)

**Queer sex roles**

Despite the plurality and intersectionality on which queer theory was founded, several scholars have discussed the white masculinity at the heart of queer studies (Muñoz 1999; Eng, Halberstam, and Muñoz 2005; Gopinath 2005; Puar 2007; Kuntsman and Miyake 2008; Eng 2010; Parker 2011; Chen 2012; Muñoz 2015). The anti-normativity of queer theory is founded on a gay male being penetrated rather than penetrating during anal sex. Bersani (1987, 220) argued that “a particular sexual act—especially when the sexual act is associated with women but performed by men...has the terrifying appeal of a loss of the ego, of a debasement.” O'Rourke (2014, 8) concurs, asserting that “this openness to being penetrated by the other which founds sexuality as relational is potentially self-shattering.” (O'Rourke 2014, 8) “penetration (making a hole in the body) is foundational for [hetero]sexuality and in not privileging penetration but rather being penetrated...sexuality is dephallicized.”

Therefore, in true Freudian tradition, being penetrated debases you if you are a man—you lose your phallus and become woman. Hence, de-phallacisation is the mechanism by which heterosexuality is negated. However, this description is not just Freudian, it disturbingly reflects and reinscribes the heteronormative sex acts and roles of the active male and passive female described by neo-Darwinian sexual selection theories. Similarly, although Dean (2014) opens queer sex to the possibility of having a vagina and nonpenetrative sexual acts such as sucking, being penetrated (receiving) is passive and penetrating (giving) is active:

> in order to have sexuality you need a hole—prototypically a mouth for sucking (or an anus or a vagina, each of which performs its own version of sensual sucking). However, sucking represents a way of converting the passive position of being penetrated into an active position, or possibly a way of equivocating the distinction between active and passive. (273)

Framing queer sex around the phallus obviously undermines the sexuality of women and other people without phalluses and many other erotic configurations. However, Hammers (2015, 844) notes that the liberatory potential of “self-shattering” powerlessness is central to queer sexual discourse, which forecloses the experiences of other sexualities but more importantly elides the unpleasureable use of powerlessness as a method of social control Cvetkovich (2010).

Sexual coercion is one of the mechanisms of sexual selection which may not seem to apply to queer theory. However, sexual coercion underlies compulsory sexuality. Chasin (2013, 415) observes that “feminist researchers have long known that expectations governing female (hetero)sexuality can be so strong that women routinely agree to unwanted sexual contact (with men) even in the absence of direct pressure from
a partner [male coercion].” The queer community is not exempt from such pressure, as Gupta (2015) observes:

some sexual minority communities have developed sexual norms that place pressure on individual community members to engage in sex. For example, stigma is often directed toward lesbians if they are in relationships that either permanently or temporarily involve little sexual activity, and the identification of lesbian bed death as a problem within lesbian communities may have increased sexual pressure on some women. Scholars are also beginning to investigate gay men’s experiences of unwanted sexual activity and the norms, both internal and external to gay communities, that place pressure on gay men to engage in sex. (1376–1377)

Further, “some gay and lesbian individuals have been diagnosed with a desire disorder for failing to express an “appropriate” level of desire for a same-sex partner” (Gupta 2015, 137).

**Queer sociality**

As West-Eberhard (2014) argues, sexual selection is an important aspect of social selection. Similarly, sex/desire is the basis for queer community. Despite its claim to anti-sociality, queer sex is, for the most part, relational and oriented towards others. Halperin (1995) asserts that queer sex is radical because it produces queer relations that reconfigure heteronormative familial and social structures. Therefore, the site of queer resistance is not in the self-shattering, emancipatory queer sex act but in queer relationships and queer community. As Davis (2005, 23) suggests, “queer politics uses experiences of oppression and desire as a means of collective political affiliation.” However, Cerankowski & Milks (cited in Barounis 2014) observe that

while asexuality certainly fits the model of sexual non-normativity, and might therefore be embraced as “queer,” the political valorization of sexual culture as the key to solidifying the bonds of queer community might also have an exclusionary effect on those who do not see sexuality as central to their lives. (183–184)

So, the queer *Candida Homo* ecology encourages consideration of limits of queer theory, which I have argued is sexuality itself. Consideration of sexuality as the limit inspires exploration of the legacy of sexual selection in queer theory. This legacy is evident in compulsory sexuality, association with fitness and variation, orientation towards an other and others and lurking heteronormative sex roles. Foucault “urges us to give up seeing one discourse on the side of power and another discourse, resistance, opposite it and always in a position of subordination” (Atterton 1994, 13). Maybe queer theory isn’t so anti-normative or anti-biological after all. Similarly, Davis (2005) urges us to not take our sexuality so seriously. In any case, candida reminds us that it’s not just us in this body after all.
1.5 The Work of Art in the Age of Candida Homo Reproduction

Having explored the reproductive strategies of C. albicans, the controversies in sexual selection theories and relationships between queer theory and sexual selection theories, I discuss two artworks as material-semiotic resolutions of the sexual microbiopolitics of the Candida Homo ecology. Translational Ambiguity Tolerance (2015) explores the diversity of candida sexuality and The Tangled Field: After McClintock (2016) examines reproduction, heredity and lineage. Generated during the research process, these artworks manifest and explore the complex and unstable flourishings between candida and humans and reconsider the implications of framing the world in rigid sexual and reproductive dualisms. They remind us that sex can be pleasurable, extraordinary and often ruthless and is rarely if ever, limited to individuals or even the same species.

1.5.1 Translational Ambiguity Tolerance

Translational Ambiguity Tolerance is a small artist’s book in the form of a pack of 52 cards, each with different digital micrographs of candida cells and colonies (Figure 26). The images on the cards depict the reproductive diversity of candida cells and colonies: asexual and sexual, selfing and ménage à trois. The artwork is a cat’s cradle: the cards are unbound pages of a book that enables remixing and re-storying, pairing and re-combination. In an exhibition, the installation is an intimate, domestic mise en scène where the viewer is invited to sit with another human in lounge chairs under the soft lighting of a domestic lamp (Figure 27). The cards are spread on the table in front of them, exposed to the human gaze. A certificate of authenticity accompanies the pack (Figure 28), openly declaring it to be an artwork. However, the accompanying explanatory text is minimal, jargonistic and slightly confusing. The opacity of the work challenges viewers to consider candida sexuality as complex more—than—human ars erotica rather than scientia sexualis.

Figure 26 Translational Ambiguity Tolerance, 2016, digital micrographs on card, dimensions variable. Photo by author.
Translational Ambiguity Tolerance is more—than—human pornography. The viewer is positioned as a voyeur, able to look at the images of candida sexuality without being seen by the organisms themselves. To see each card, the viewer(s) fondles the images. She(they) wear(s) cotton gloves inherited from the previous
viewer and passed on to the next (Figure 29). The gloves hold the traces of all the hands and microbes that have been on them and are sites of micro-reproduction. The cards are small enough to hold in one hand, but two hands are needed to shuffle, view and exchange and the cards acquire their own microbiomes through repeated handling. This is eosexual *ars erotica*,\(^\text{114}\) where the viewer(s) are implicated in the viewing as the viewer(s) whole body(ies) is(are) required to play. This is a social, familial bonding activity, pleasurable and purposeless. Just as genes reshuffle to improve fitness, viewers shuffle the cards to make a “better” hand. However, unlike a pack of playing cards or scientific diagram, there is no apparent order or hierarchy. Only disorder results from play. The images then are about *ars erotica*—experience and pleasure rather than knowledge.

![Figure 29 Translational Ambiguity Tolerance in play, 2015. Photo reproduced by permission from Megan Schlipalius.](image)

Scale poses a challenge in microbe-human interactions. Some sort of imaging device is necessary for us to see and study their bodies, usually a microscope of some kind. Vision technology and microbiology have co-evolved since Antonie van Leeuwenhoek developed a microscope during the mid-1600s that was of sufficient magnification to enable him to see the “animalcules” (bacteria) in water from his pond (Lane 2015).\(^\text{115}\) Van Leeuwenhoek was deeply involved in the emerging scientific revolution of the seventeenth century.

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\(^{114}\) Ecosexuality is an orientation directed toward the non-human (Stephens 2010; Kelley 2011; Morris 2015).

\(^{115}\) Van Leeuwenhoek developed a more precise technique for grinding lenses, which improved the magnification of existing microscopes from 20/30X magnification to 200X.
Queer Progeny century, responsible for new imaging technologies and identifying and describing bacteria and a prolific, though controversial, member of the Royal Society. Ford (1992, para. 2) suggests that, “in his method of analysing a problem, Leeuwenhoek was able to lay many of the ground rules of experimentation and did much to found, not only the science of microscopy but also the philosophy of biological experimentation.” Lane (2015) argues that van Leeuwenhoek was the first even to think of looking—certainly, the first with the power to see. Using his own deceptively simple, single-lensed microscopes, he did not merely observe, but conducted ingenious experiments, exploring and manipulating his microscopic universe...[and] opened a world that others could not comprehend. (1)

Consequently, he is considered to be the “father” of microscopy and microbiology and, as Ford and Lane both argue, his philosophy firmly established imaging technologies as central to the comprehension of the “unseen world.”

Lane’s description of van Leeuwenhoek drips with sublime reverence for the micro-colonisation enabled by van Leeuwenhoek’s technology, consistent with the European colonising and categorising project. He argues that van Leeuwenhoek was not content to “merely observe” and notes that his exploration and manipulation were “ingenious” and opened not just a “world” for comprehension by the human but a “universe.” Lane leaps between the incomprehensible spatial and temporal scales enabled by the nascent scientific gaze of the microscope. This is Barad’s intra-active apparatus—the performative emergence of knowledge and matter. However, although the observational device is celebrated, it is rendered invisible (Haraway 1997b), even in the same sentence, i.e., the device is so simple that it is elided in favour of the sublime immensity of the “microbial universe,” incomprehensible except to the genius of the experimenter.

The invention of microphotography in the mid-nineteenth century combined the microscope with the emerging photographic technologies and ushered in a new age of verisimilitude in imaging and representation. Although its usefulness and accuracy were highly contested, microphotography was one of the earliest applications of photography in science because “photography could display for later analysis phenomena that were beyond the ability of ordinary human vision to resolve” (Breidbach 2002, 221). By

116 Possibly drawing an analogy with Gallileo’s invention of the telescope, which revolutionised understandings of the macrobial universe.
117 Also called photomicrography.
118 The opposing positions are evident in the arguments of Treviranus and Dorné (Breidbach 2002). Although both agreed on the need for objectivity, Treviranus argued that “illustrations should not show just what was perceived, but should emphasize the principal attributes one has to identify in a certain preparation” (224), whereas Dorné argued that “microphotography provided an accurate description of what had actually been observed” (224). Refer to Breidbach (2002) for a wonderful history of microphotography and photomicrography.
119 Darwin himself extensively used photography to illustrate scientific theory in The Expression of the Emotions in Man and Animals: “he became a prominent voice in scientific photography, and his efforts in the field helped shape
The Unsettling Eros of Contact Zones

the end of the century, microphotography had become one of the central techniques of bacteriology, in
large part because its ability to accurately record finer structural details of microscopical objects such as
bacteria was embraced by the founder of bacteriology Robert Koch, who “described the photograph as
being more important than the pictured thing itself” (Breidbach 2002, 222).

Koch was referring to photographic indexicality but also believed that an objective photograph could only
be produced by a skilled microscopist, who was able to successfully prepare the microscopic sample for
imaging and control the vagaries of the microscope and photographic chemistry. Live samples could not be
imaged by this early technology and so a specimen had to be killed, preserved and mounted prior to
imaging. Photographic chemistry was still largely guesswork so every image required preparation and
manipulation and microscopic cameras were still in development. Hence, the apparatus of comprehension
was being built and altered whilst being used to describe the bodies of the microbes. Breidbach (2002)
argues that

> Koch used microphotography not only to obtain proper illustrations of the objects under study but
> he used the mechanical device as an instrument to control and evaluate the skill of an
> observer...His claim for microphotography resulted in a critical evaluation of the technical
> limitations of the instrument used (the microscope) and the methodical knowledge of the observer.
> (221)

Therefore, microphotography was useful for making both the fine detail of microbes and the skill of the
scientist available for scientific analysis and comparison. notes that “photographs assumed a dual role.
They illustrated something, but they were also experiments in their own right. They became more than
mere pictures—they became data.” This is especially true for microphotographs, where measurements and
comparisons were only possible in the still image. In one of the many instruction manuals for
microphotography of the time, Fraenkel and Pfeiffer (1892) described the “absolute objectivity” of
photographs able to represent objects “as they are in reality” (quoted in Breidbach 2002, 238). However,
they also specified that there are specific properties of the microworld that need a “photographic eye,”
including “the need to focus on one plane of observation and the need for high contrasts in the
preparations used for microphotography.”

Standardisation of preparations led to the standardisation of microscopy in general and “the complex
observations of various microscopists developed into a series of conventions for representing the
microworld” still in practice today (Breidbach 2002, 238), including high-contrast black and white. Such
standardized pictorial representations “establish the proper way of looking at microscopic preparations”
(Karg and Schmorl cited in Breidbach 2002, 238) and the authoritative and “objective” microbiopolitical

photo history...Darwin became one of the first scientists ever to publish photographs in a scientific treatise and made
significant inroads in action photography” (Prodger 2009, xxiii–xxiv).
The images on the Translational Ambiguity Tolerance cards perpetuate this scientific objectification of microbial reproduction through surveillance and classification\textsuperscript{120}—a microbial scientia sexualis. They were produced over several years of laboratory experimentation, where I manipulated, imaged, traced and classified the bodies of many, many generations of candida that had been originally isolated from clinical human vaginal infections, purified in a laboratory and bred and bred and bred. These images were captured by containing and manipulating candida bodies to identify different reproductive strategies. The images include multiple viewing strategies from electron micrographs to live imaging, fluorescent stains to vibrant agar. The subjects range in scale from nanometres to millimetres, from single cells to colonies. The semiotics are recognisably scientific—bodies suspended in amorphous environments and scale bars. However, descriptions, labels, keys or captions to indicate the content are not provided. The viewer is challenged to interpret an unfamiliar and alien sexuality and bears witness to an incomprehensible more—than—human flourishing.

The title of the artwork, Translational Ambiguity Tolerance, refers to the biological phenomenon summarised in the Certificate of Authenticity. Usually, an organism’s RNA codon translates into a unique amino acid, which is combined with other amino acids and incorporated into a protein for use in the cell. The CUG codon in most organisms translates to the amino acid leucine. However, some species of the Candida genus have the unique ability to translate the standard leucine CUG codon into an alternative amino acid, serine (Rocha et al. 2011).\textsuperscript{121} Lethal for most organisms, this ability provides a selective advantage to these Candida species, including C. albicans, with no decrease in fitness (Santos et al. 1997; Santos et al. 1999; McManus and Coleman 2014). In fact, this ambiguous translation is well tolerated and precisely regulated by C. albicans, generating unique protein variants and providing the organism with significant functional plasticity in its morphology (Rocha et al. 2011, 14091). The discovery of this phenomenon in C. albicans provided evidence for epigenetic evolution, i.e., where protein folding affects the evolution of genome coding (Rocha et al. 2011). Translational ambiguity tolerance is thought to be a Red Queen escape strategy and evidence of the co-evolution of Candida and Homo. The material-semiotics

\textsuperscript{120} The surveillance, classification and manipulation of the sexual lives of domestic, wild and zoological animals is well documented and discussed. Refer to Matt Chrulew (2011); Matt Chrulew (2014); Eben Kirksey (2015); Dinesh Wadiwel (2016); and Adam Zaretsky (2016), among many others.

\textsuperscript{121} Species able to tolerate this translational ambiguity are classified as the CTG clade (Rocha et al. 2011).
of this phenomenon, articulated in the title of this artwork, invite viewers to examine their own tolerance for ambiguity, especially when translating the unfamiliar and incomprehensible.

1.5.2 The Tangled Field: After McClintock

The Tangled Field: After McClintock (Figure 30) is a kinetic sculpture that responds to geneticist Barbara McClintock’s discovery of genetic regulation (“controlling elements”) as an evolutionary mechanism. McClintock (with her colleague Harriett Creighton) showed that genes “jump” around chromosomes and “control” the genes around them to produce specific characteristics (Creighton and McClintock 1931; McClintock 1950; 1956; 1961). Her discoveries that some genes (now called transposons) move around in the genome and affect the expression of other genes revolutionised evolutionary and molecular biology. However, her findings were highly criticised for several decades because they challenged the orthodoxy of the linear genome, the central dogma and Mendelian inheritance (Keller 1983; Pray and Zhaurova 2008). McClintock’s “controlling elements” posited a mechanism for what is now called phenotypic plasticity and presaged epigenetics (Döring and Starlinger 1984). The Tangled Field presents a range of abnormal/deviant colony morphologies caused by candida “controlling elements”: its regulatory network. As discussed, candida has a complex and sensitive regulatory network that allows it to control its reproductive strategies and morphology without genetic mutation. The reversible transition between white and opaque cells is an example of this regulation, as is the ability to rapidly change its reproductive strategy between asexuality and sex. The artwork also draws from the method outlined by Homann et al. (2009) in “A Phenotypic Profile of the Candida albicans Regulatory Network.” This method traces the changes in colony morphology and other traits associated with the regulation of candida virulence and antifungal drug resistance, just as McClintock traced the evolution of maize (Zea mays) through its various chromosomal and phylogenetic characteristics.

122 Thomas Morgan (1922, 194) speculated that “genes are arranged in linear order in the chromosomes...they must be supposed to...remain unchanged through long periods. More than this we need not postulate.” McClintock and Creighton (1931) confirmed Morgan’s claim that genes are positioned on chromosomes. However, their findings challenged his assumption of linearity and fixity.

123 The morphological plasticity of C. albicans is discussed further in chapter 2.
Unlike McClintock or Homann et al., who intentionally manipulated their organisms through sex or environmental stress, the organisms in The Tangled Field are descended from morphologically distinct colonies that arose spontaneously in an early batch of experimental cultures (Figure 31). I isolated, identified and maintained these “deviant” isolates, which comprise multiple cell forms, including white and opaque mating-competent yeasts and hyphae and pseudohyphae from both opaque and white cells.¹²⁴ For The Tangled Field, the isolates were grown under various conditions described by Homann et al. (2009), including different nutrient, temperature, pH and carbon sources, to encourage morphological regulation.

¹²⁴ Hyphae and pseudohyphae are discussed further in chapter 2.
They were also grown on red blood agar, black charcoal agar and yellow and colourless transparent agars for aesthetic contrast (Figure 32).

Figure 31 Diverse C. albicans cultures on sheep’s blood agar, including white and opaque cell forms. Photo by author.

Figure 32 C. albicans “deviant” cultures embedded in resin for The Tangled Field sculpture, 2016. Photo by author.

Like Translational Ambiguity Tolerance, this artwork is both scientia sexualis and ars erotica. The development of the work was a scientific exploration of the different reproductive strategies of candida that controlled and observed the chemical and physical processes by which candida reproduces. The sculpture consists of thirteen “abnormal” candida cultures grown on agar plates and embedded in resin discs (Figure 32). These discs hang at the ends of several cascading metal arms. The sculpture is suspended from the ceiling and breezes generated by human movement cause the arms and plates to rotate and oscillate gently. Although the height and diameter of the sculpture vary slightly as the sculpture moves, it is
suggestively figurative (Figure 33). The hand-size discs containing the candida cultures glisten in the light and bubbles in the resin subtly imply breath (Figure 34). As Haraway (1997a, 11) observes, “figurations are performative images that can be inhabited. Verbal or visual, figurations can be condensed maps of contestable worlds.” Helmreich (2014, 55) argues that “the microbiome is a new figure on the landscape of biology, gathering up concerns, longings, anxieties, and hopes, new ideas about species, disease, and community.” The Tangled Field is a figuration of microbial heredity, an intergenerational cat’s cradle of candida woven together by metallic thread.

Figure 33 The Tangled Field: After McClintock, 2016, installation detail. Photo by author.

Figure 34 The Tangled Field: After McClintock, 2016, installation detail. Photo by author.
The Unsettling Eros of Contact Zones

The appearance of the work as a phylogenetic tree resonates with scientific, eugenic and animal husbandry representations of lineage and descent, locating the viewer in this frame of reference. The work is lit from above to cast a shadow on the ground below (Figure 35), which collapses the three-dimensional sculpture into a single plane, visually reminiscent of contemporary phylogenetic diagrams (Figure 36). The shadow is gently animated by the movement of the sculpture and the sculpture above cannot be ignored—subtle and insistent reminders that genes have bodies. The ambiguous visual references unsettle, compelling a cognitive shift in the viewer and drawing attention to the complex pleasures and discomforts of eros.\textsuperscript{125}

Figure 35 Shadow cast by \textit{The Tangled Field} sculpture, 2016, installation view. Photo reproduced by permission from Kate O’Sullivan.

\textsuperscript{125} These are discussed further in chapter 3.
Figure 36 Phylogenetic diagram showing *C. albicans* clonal clusters “generated by eBURST analysis of MLST data.” Adapted by permission from Odds et al. (2006, fig. 2).

The almost imperceptible movements of the sculpture and its shadow subtly destabilise the linear hierarchies of a phylogenetic tree and echo McClintock’s mobile or “jumping” genes. Reminiscent of the modernist kinetic sculptures of Alexander Calder, which are concerned with form, movement and space and childhood mobiles designed for play and pleasure, the arms and disc rotate and oscillate so that they seem to displace each other. The viewer must move close to distinguish the colonies within the resin, increasing air disturbances and causing the discs and arms to move more erratically. The air bubbles, light reflections and movement resist the fixation of colony morphology by the resin. Hence, candida colonies, human viewers and environment are constantly adjusting: intra-active phenomena. All have agency, although unequal. *The Tangled Field* brings evolution into a time scale perceptible to human viewers and reminds us that our bodies are dynamic, biopolitical, more–than–human ecologies.

1.6 Conclusion

1.6.1 Summary

This chapter formed the cat’s cradle shown in Figure 37, unwinding the strands of sex, reproduction, sexual selection and sexuality that constitute the CandidaHomo ecology. The review of current *C. albicans* reproductive research demonstrated the diversity of *C. albicans* strategies. The discovery less than twenty years ago that some *C. albicans* cells are “mating-competent,” the subsequent exponential increase in research and the lists of questions to be answered that conclude many research papers indicate how little we know sex and reproduction, even within our own bodies. Such findings open up possibilities not just for understanding *C. albicans* but also for sexual selection biology. Further, the evolutionary dynamics involved in candida’s ability to vary its reproductive strategies have the potential to challenge the animal-centric heteronormativity of sexual selection.
As discussed, discussions of sexual behaviour, heredity and sexual selection have dominated by theories of gene-centric evolution and sexually dimorphic reproduction. The twentieth century was dominated by animal-centric and heteronormative neo-Darwinian sexual selection models that believed that two individuals of “opposite sexes” mate in a frenzy of genetic replication. The diverse sexualities of fungi and the facultative sexual strategies of microbes like *C. albicans* uncouple sex from reproduction and challenge heteronormative sexual selection. However, the disputed heterosexual and gender biases of sexual selection theory are being applied to studies of sexual selection in yeast and other microbes and so this study provides a timely urge for future considerations of the role of sexual selection in the *CandidaHomo* ecology to rethink biases and find new language to describe the extraordinary diversity of reproduction and sexuality.

Inspired by the asexuality of candida, I look back at queer theory to explore “its exclusionary operations” and potential traces of sexual selection. Asexuality unmasks a compulsory sexuality at the heart of queer theory, which is reminiscent of dominant theories of sexual selection. Traces of heteronormative sexual selection also lurk in the white, masculinity of queer theory. Considering sex as a facultative and flexible strategy may offer a way through this compulsory sexuality. Other traces of sexual selection theories linger in queer theory’s association between sexuality and health/fitness, its embrace of variation in response to selective pressures and its orientations towards an other and others. This is not is say that queer theory is essentialist. Rather its fundamental ethic to interrogate the systems that regulate sexuality requires self-examination of its own legacies. Foucault reminds us that we are never opposite power, but always already within it. Furthermore, more—than—human flourishing is always already happening, profligate, promiscuous fecundity, around us, on us, in us.

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126 (Eng, Halberstam, and Muñoz 2005, 1)
1.6.2 Takeaways

1. *C. albicans* has multiple reversible and heritable reproductive strategies that improve survival and adaptation to stressful environmental conditions. Sexual selection studies in *S. cerevisiae* suggest the possibility that *C. albicans* mating could be subject to sexual selection, opening up a new field of *C. albicans* research.

2. *C. albicans* sex is rare and much research speculates as to why it occurs at all. Research may benefit from considering the model of facultative sexuality, which describes predominantly asexual organisms that can switch to sexual reproductive strategies.

3. The synthesis of Darwinian sexual selection, Mendelian inheritance and population genetics in the mid-twentieth century established gene replication as the driver of sexual encounters. It also defined “sex” as reproduction through meiosis and intercourse between two individuals of “opposite” sexes for the purpose of producing a third “unique” individual. The definition of sex has expanded to include genetic recombination through mechanisms other than meiosis.

4. Dominant sexual selection theories are biased towards animals, heteronormativity, reproductivity and assumptions of “how sex ‘ought’ to occur.”\(^{127}\) They naturalise dominant cultural understandings of sexual dimorphism, heterosexuality, gender and competition between sexes.

5. The sexual selection pressures on the diverse and dynamic reproductive strategies of fungi and unicellular organisms, such as *C. albicans*, have only recently been considered and researchers tend to frame them within the animal-centric and heteronormative sexual selection theories. Adopting *C. albicans* as a model organism for sexual selection provides an opportunity to expand the animal-centric and heteronormative discourse of sexual selection theory and consider a role for asexual reproduction in sexual selection theory.

6. Gender and heteronormative biases in sexual selection theories have been challenged by feminist and queer evolutionary theorists, who argue that sexual selection theories should consider sex as a flexible reaction norm, responsive and variable to environmental and social conditions. They urge attention to cooperation, abundance, a continuum of reproductive strategies and technological and cultural influences.

7. Queer theory interrogates the structures that define and regulate sexuality and is oriented towards anti-normativity. However, asexuality demonstrates that queer theory reinforces “compulsory sexuality.”

8. Traces of sexual selection theory are evident in queer theory’s association between sexuality and health/fitness, sex role descriptions and its embrace of variation in response to selective pressures and orientations towards an other and others.

\(^{127}\) (Aanen, Beekman, and Kokko 2016, 2)
9. Artistic resolutions of candida sexuality and microbiopolitics open playful spaces of *scientia sexualis* and *ars erotica*—experiences that evoke more–than–human flourishings, our own sexualities and the ecologies that we are and are responsible to and for.

1.6.3 Re-stringing the cradle

And so, the cat’s cradle woven in this chapter gains momentum for the next figuration, since queer ecologies are more than reproduction, more than sex, more than desire. They are also about bodies in environments. Recently, evolutionary biologists have gone meta, reminding us that traits are the units of selection rather than genes, exploring nongenetic trait inheritance and environmental and social influences on trait variation (West-Eberhard 2009; Drury 2013; Jablonka and Lamb 2014). They have also explored how bodies influence their environments, building spaces to enhance survival (Day, Laland, and Odling-Smee 2003; Odling-Smee, Feldman, and Laland 2003; Barker and Odling-Smee 2014). Therefore, the next chapter, *Queer Affordances: Trans*forming natural selection in the *CandidaHomo* ecology, winds sexual selection into natural selection, sexuality into trans* embodiment and the facultative fecundity of *C. albicans* into phenotypic plasticity and niche construction.

Figure 38 Re-stringing the cradle Illustrations by Furness Jayne (1906, figs 747, 748, 750 & 752).

Figure 39 Timelapse of *C. albicans* cells in human serum over 24 hours. Photos by author.
2 Queer Affordances: Trans*forming Natural Selection in the CandidaHomo Ecology

2.1 Introduction

The intra-action between a body and its environment allows for some possibilities and forecloses others. Consequently, bodies and environments are in perpetual transformation. In the CandidaHomo ecology, bodies respond to pH, temperature, nutrients, the host immune system and antibiotics and environments are shaped and constructed by the bodies in them. C. albicans bodies are extraordinarily plastic, which allows C. albicans to adapt to unpredictable host conditions and has resulted its success as a human pathogen (Polke et al. 2015; Poulain 2015). Their morphologies and physiologies are highly responsive to environmental cues, reversible and heritable—nine different morphologies have been identified (Noble, Gianetti, and Witchley 2016). They also manipulate their environments, chemically and physically, creating conditions that improve survival (Nobile and Johnson 2015; Noble, Gianetti, and Witchley 2016; Palková and Váchová 2016).

Such adaptive plasticity sits uneasily in neo-Darwinian theories of natural selection, where bodies are subject to random genetic mutation and relatively stable environmental conditions (West-Eberhard 2009; Nieuwenhuis and James 2016). Numerous scholars and studies since the late-twentieth century (West-Eberhard 2003; M. J. West-Eberhard 2005; Mary Jane West-Eberhard 2005; Pigliucci, Murren, and Schlichting 2006; Whitman and Agrawal 2009; Mideo and Reece 2012; Bateson 2014; Ghalambor et al. 2015) have demonstrated that phenotypic plasticity enables natural selection to act on phenotypes as well as genotypes and may actually lead adaptation (Levis and Pfennig 2016). Further, evolution can occur in the absence of genetic change through the “ability of a genotype to express different phenotypes according to its environment” (Grenier, Barre, and Litrico 2016, 1). Things get complicated when the environment is another body, as it is for the CandidaHomo ecology.

In the previous chapter, Queer Progeny, I unwound the cradle of C. albicans sex and reproduction. I argued that sexuality is the first principle of a queer ecology and demonstrated that a re-examination of our biases and assumptions about “what sex ‘ought’ to be” is necessary to attend to more—than—human flourishing.

128 See also Donohue (2005); Pigliucci, Murren, and Schlichting (2006); Gluckman et al. (2009); Hunt et al. (2011); Grether (2014); Nishikawa and Kinjo (2014); Shaw et al. (2014); Ehrenreich and Pfennig (2016); Grenier, Barre, and Litrico (2016); Levis and Pfennig (2016); Cuypers, Rutten, and Hogeweg (2017); Koch et al. (2017); Mattenberger et al. (2017).

129 (Aanen, Beekman, and Kokko 2016, 2).
I wound the plurality of *C. albicans* reproductive strategies through sexual selection theories and queer theory to unsettle sex, sexuality and reproduction in the *CandidaHomo* ecology.

Of course, human bodies are always already malleable and transformative, as puberty, pregnancy and menopause demonstrate. However, morphologically and sexually ambiguous bodies have long been considered “unnatural.” The biopolitics of such unnatural bodies rely on the categorisation of bodies as biologically determined. In this chapter, *Queer Affordances: Trans*forming natural selection in the *CandidaHomo* ecology, I rewind the cradle woven in chapter 1 by exploring the plasticity of bodies and environment in the *CandidaHomo* ecology and proposing performativity as the second principle of a queer ecology. Consequently, this chapter untangles the threads of bodies, environment, natural selection and trans* theory to trace the influences of natural selection theories on understandings of what bodies are, what they do, why they do it and what they are for (Figure 40).

![Figure 40 Cat’s cradle for chapter 2 Queer affordances](image)

Figure 40 Cat’s cradle for chapter 2 Queer affordances, indicating strands of *C. albicans* phenotypic plasticity, natural selection, trans* theory and art-making. Adapted from the illustration by Furness Jayne (1906, fig. 746).

Examining the details of *C. albicans* phenotypic plasticity and niche construction allows me to entangle natural selection with trans* theory to explore the co-evolution of bodies and environments. I draw on trans* theory as an aspect of queer theory and an affective biopolitics of “bodily metamorphosis” (Steinbock, Szczygielksa, and Wagner 2017a, 2) to demonstrate that phenotypic plasticity is the norm rather than the exception for all bodies and is, in fact, necessary for coping with environmental change. Further, other bodies are essential for plasticity, especially in the *CandidaHomo* ecology. Microbial

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130 Among others, refer to Julia Kristeva, Elizabeth Grosz and Margrit Shildrick. See also McRuer (2006); Shail (2007); Smith (2007); Overend (2011)

131 The * in trans used here is derived from the Boolean search tool that searches for “any and all unknown terms” starting with trans (Halberstam 2016, 368). It includes people who identify as male and female and gender non-binary (Bettcher 2014). Its use is controversial, as it may preclude those who identify as genderqueer and live in opposition to any binary. Its use here is informed by trans* theory that attends to the more-than-human (Hayward and Weinstein 2015).
constructed biofilms coat every surface of the human body and manipulate the qualities of these surfaces. I reconfigure the Candida Homo ecology as a trans*formative site for more–than–human flourishing.

2.1.1 Context

C. albicans is able to transition between nine distinct cell forms in response to a range of chemical and physical environmental cues, including temperature, pH, carbon source, oxygen concentration and surface materials (Palková and Váchová 2006; Noble, Gianetti, and Witchley 2016). White yeast and hyphae are believed to be the most common cell forms. They are found in the majority of host niches and are able to tolerate the widest range of conditions. The opaque cell form enables mating and the others are adaptations to niche-specific conditions. Although little is known about the mechanisms of transition between forms, it is known that transitions are regulated by epigenetic and metabolic pathways and do not require genetic variation. C. albicans also actively manipulates its environment, producing ammonia to alter extracellular pH (Palková and Váchová 2016; Jones and Elliot 2017) and chemoattractants to evade immune cells (Höfs, Mogavero, and Hube 2016) and constructing biofilms that provide protection from microbial toxins, physical forces, immune cells and antifungals (Nobile and Johnson 2015). However, the natural selection pressures that affect C. albicans in the H. sapiens environment have only recently been considered and are poorly understood (Wartenberg et al. 2014; Scaduto and Bennett 2015; Zhang et al. 2015; Noble, Gianetti, and Witchley 2016).

Phenotypic plasticity—trait variation without genetic modification (Grenier, Barre, and Litrico 2016)—is fundamental to how organisms cope with environmental variation (West-Eberhard 2009). For example, Kull (2014, 288) describes plasticity as “a universal feature of all living beings.” However, neo-Darwinism has considered environmentally induced phenotypic plasticity to be non-heritable (Ghalambor et al. 2015). Vane-Wright (2014) summarises this position, when he argues that

what matters for evolution is the existence of mechanisms that can make the results of plastic shifts irreversible. Can this come about without natural selection? From a neo-Darwinian perspective, this would only be possible as some form of neutral evolution. So the question then becomes, can plastic changes become genetically fixed as a result of random changes in the genome? (229–230)

As discussed, the Red Queen hypothesis, which is the most common explanation for Candida Homo adaptation, does allow for some plasticity in an evolutionary “arms race” but the relationship between phenotype, genotype and environment is unclear (Masri et al. 2015).

Where gene-centric evolutionary theories propose that adaptation occurs because of random gene mutations, plasticity-first evolution suggests that variations in the phenotype of an individual drive

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132 Early medical mycologists believed that hyphae and yeast cells were different species (Barnett 2008).
Although this phenotypic variation may be caused by a genetic change, it is more likely caused by a non-genetic change, such as an epigenetic process, developmental plasticity, and environmental or behavioural changes (West-Eberhard 2002; Jablonka and Lamb 2014). West-Eberhard (2009) observes that twenty-first century theories of evolution reflect the “environmental turn” of the last forty years, shifting from gene-centric neo-Darwinism to plasticity-first “post-Darwinism.” However, this shift is still highly contested and gene-centrism, popularised in Dawkins’ (1976) The Selfish Gene, persists in natural selection theories and popular understandings of the biology of bodies in–the–world. 

Developed in response to queer theory’s ambivalent relationship with the biology of bodies (Richardson 2007; Bettcher 2014), trans* theory interrogates unresolved ambivalences between behaviour and biology and sex and gender and how these materialise in and are lived by bodies (Stryker 2004; 2006). It insists on the embodiment of gender, which is challenging for discursive queer theory (Bettcher 2014). Trans* embodiment is affective and relational (Hayward and Weinstein 2015) and as such, trans* is material-semiotic searching, displacement, movement, weaving, crafting; the intra-active mattering of bodies, human and more–than. Eva Hayward (2008) introduces “trans-speciation” as a possibility for linking human and nonhuman morphogenesis and argues that the human body is always already “trans-morphic” (81). I propose that CandidaHomo ecology is not just always already “trans-morphic” but is always already “trans-speciated,” in intra-active, multispecies trans*formation.

2.1.2 Chapter overview

In this chapter, contemporary scientific understandings of the phenotypic plasticity of C. albicans and the adaptive possibilities of that plasticity are reviewed. I discuss the mechanisms by which C. albicans responds to and forms its environment and current understandings of natural selection within the CandidaHomo ecology. Secondly, I describe dominant theories of natural selection and untangle genotype, phenotype and environment in contemporary evolutionary theories. Gene-centrism, body plasticity and environmental predictability are discussed and transformed into responsive and performative affordance landscapes. Thirdly, understandings of bodies in trans* theory are explored and used to transfigure CandidaHomo relationships. I briefly trace the influences of gene-centric natural selection on queer and trans* theories, arguing that these theories are haunted by notions of bodies as sexually dimorphic and essentialist. Finally, I discuss two artworks generated during this research as material-semiotic resolutions of these threads, apparatuses that tangle with the scientia sexualis and ars erotica of microbiopolitics. Control of Cell Morphology in vivo (2015) and Ereignis, Gelassenheit und Lichtung: A love story (2015)

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133 Refer to and Mideo and Reece (2012); Grenier, Barre, and Litrico (2016); Levis and Pfennig (2016) for excellent discussions of the relationship between phenotypic plasticity and evolution.

134 For example, one of my biology students recently described DNA as the “building blocks of life.”
transform the figurations discussed in this chapter and reconfigure the affordances of the *CandidaHomo* ecology.

### 2.1.3 Key terms & definitions

**Affordance** Affordances are opportunities for action; they are intrinsic emergent properties of organism/environment systems “that determine what can be done” (Stoffregen 2003, 124).

**Gender** in culture: the state of being male or female as expressed by social or cultural distinctions and differences, rather than biological ones; expressions of masculinity and femininity (Oakley 2016); “arguably numbering more than two” (Stryker, Currah, and Moore 2008, 12); in biology: gender refers to the sexually dimorphic gametes and is used to differentiate from sex as a process of reproduction (Ah-King 2013b).

**Natural selection** A *natural* process that results in the survival and reproductive success of individuals or groups best adjusted to their environment and that leads to the perpetuation of genetic qualities best suited to that particular environment. West-Eberhard (2014) argues that although natural selection pressures can be biotic and abiotic, they are non-social.

**Niche construction** The process by which organisms bring about changes in their local environments, many of which are evolutionarily and ecologically consequential (Scott-Phillips et al. 2014).

**Performativity** gender performativity refers to the conscious, unconscious and learned iterative behaviours and acts of gender presentation (Butler 1990); matter is *performativ*e in that it (re)produces itself through the effects of its own intra-active dynamic material relationships (Barad 2003).

**Phenotypic plasticity** The ability of individual genotypes to produce different phenotypes when exposed to different environmental conditions (Pigliucci, Murren, and Schlichting 2006).

**Phenotypic switching** A change in cellular or colony properties that seems to be heritable, but reverses at a rate that is much higher than could be caused by mutation (Berman and Sudbery 2002).

**Plasticity-first** The fixation of a novel phenotype precedes the fixation of the genotype (Koch et al. 2017); the plasticity-first hypothesis is a mechanism of adaptive evolution in which phenotypic accommodation is refined through genetic accommodation (Levis and Pfennig 2016).

**Trans* theory** Trans* theory examines the intersections of gender, sexuality, identity, embodiment and desire that do not readily reduce to heteronormativity (Stryker 2004); “A trope for reworking the relationality of male and female, of human and animal” (Hayward 2008, 68).

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136 “Natural Selection.” https://www.merriam-webster.com
2.1.4 Contribution to Knowledge

The discussion in this chapter makes several contributions to understandings of the phenotypic plasticity of bodies:

1. This is the first study to discuss the phenotypic plasticity of *C. albicans* outside microbiology or immunology. Although Alyssa Overend (2010) has discussed how *C. albicans* is gendered and engenders and reinforces understandings of leaky female and contained male bodies, her analysis occurs within a public health context. Overend’s research is concerned with the discursive construction of *C. albicans* by humans, rather than the embodied effects of *C. albicans* plasticity itself. I discuss the phenotypic plasticity and niche construction of *C. albicans* in the context of evolutionary ecology and trans* theory.

2. This research draws attention to the adaptive phenotypic plasticity and environmental manipulation of *C. albicans* as evidence for plasticity-first evolutionary theories.

3. This research argues that gene-centric and heteronormative biases embedded in dominant natural selection theories linger in ambivalences about the biology of gender and sex. Recent plasticity-first selection theories resonate with trans* theory that understands bodies as transformative. By arguing that the biology of bodies and environments at all scales are as intra-active and performative as gender, sex and sexuality, queer can be reconfigured as microbiopolitical flourishing.

4. Finally, two artworks are presented that explore how imaging and viewing technologies intersect with microbiopolitics. These works are the first to explore the performativity of the *CandidaHomo* ecology.

2.2 The Science of *C. albicans* Plasticity

2.2.1 Introduction

*C. albicans* is one of the most successful human pathogens, which is attributed to an extraordinary phenotypic plasticity (Pande, Chen, and Noble 2013; Polke et al. 2015; Poulain 2015). It is able to rapidly and reversibly transition between nine phenotypically (morphologically and physiologically) distinct cell forms, depicted in Figure 41. These transitions occur in response to complex and changing environmental conditions (Figure 42), including pH, temperature, carbon source, concentrations of nutrients, O$_2$ and CO$_2$, estrogen, serum and the host immune system (Noble, Gianetti, and Witchley 2016). The morphology and physiologies of the cells shift in response to the changing conditions, transitioning to survive inhospitable environments. These transitions do not rely on random gene mutations but occur via complex transcriptional regulation. A recent review conducted by Noble, Gianetti, and Witchley (2016) describes the
morphology, induction signals, function and host interactions of each cell form, which are summarised in Table 1.

Figure 41 C. albicans cell type transitions. Adapted by permission from Macmillan Publishers Ltd: Nat Rev Micro (Noble, Gianetti, and Witchley 2016, figs. 1 & 3), copyright (2016).

Figure 42 In vivo challenges for C. albicans in the human host. Reproduced by permission from Polke et al. (2015, fig. 1).
Table 1 Features of *C. albicans* cell types. Reproduced by permission from Noble, Gianetti, and Witchley (2016, 4).

<table>
<thead>
<tr>
<th>MTL locus Genotype</th>
<th>Yeast (white/a/a)</th>
<th>Hypha*</th>
<th>Pseudohypha*</th>
<th>Chlamydospore</th>
<th>White(a) and white(a)</th>
<th>Opaques/a and Opaques/u</th>
<th>Opaques/a</th>
<th>Grey/a</th>
<th>GUT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell shape</strong></td>
<td>Round-to-oval</td>
<td>Tube</td>
<td>Elongated ellipsoid</td>
<td>Round-to-oval</td>
<td>Round-to-oval</td>
<td>Ellipsoid</td>
<td>Ellipsoid</td>
<td>Ellipsoid</td>
<td>Ellipsoid</td>
</tr>
<tr>
<td><strong>Cell type</strong></td>
<td>Unicellular</td>
<td>Multicellular</td>
<td>Multicellular</td>
<td>Thick cell wall</td>
<td>Unicellular</td>
<td>Surface pimpl</td>
<td>Surface pimpl</td>
<td>Unicellular</td>
<td>Unicellular</td>
</tr>
<tr>
<td><strong>Special morphological features</strong></td>
<td>N/A</td>
<td>N/A</td>
<td>Indented cell-junctions</td>
<td>Nutrient scarcity</td>
<td>N/A</td>
<td>Surface pimpl</td>
<td>Surface pimpl</td>
<td>Small cell type</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>In vitro inducing signals</strong></td>
<td>Default cell shape under most in vitro conditions</td>
<td>37°C, N-acetylglucosamine, serum, immersion in agar, hypoxia, hypercarbca and alkaline pH</td>
<td>Hypha-inducing cues</td>
<td>Nutrient scarcity</td>
<td>37°C, glucose and alkaline pH</td>
<td>N-acetylglucosamine, hypercarbca and acidic pH</td>
<td>Mating</td>
<td>Nutrient abundance</td>
<td>Unknown</td>
</tr>
<tr>
<td><strong>Special functions</strong></td>
<td>Biofilm formation (conventional)</td>
<td>Thigmotropism; biofilm formation (conventional)</td>
<td>Biofilm formation (conventional)</td>
<td>High fitness in a neonatal mouse skin colonization model</td>
<td>Biofilm formation (sexual)</td>
<td>Mating</td>
<td>Unknown</td>
<td>High fitness in an ex vivo tongue infection model</td>
<td>Unknown</td>
</tr>
<tr>
<td><strong>Host interactions</strong></td>
<td>Virulence (bloodstream model); commensalism (mouth, skin, vagina and gastrointestinal tract)</td>
<td>Induced endocytosis; active penetration of host epithelial cells; virulence (mouth, vagina and bloodstream model)</td>
<td>Virulence (mouth, vagina and bloodstream)</td>
<td>High fitness in a neonatal mouse skin colonization model</td>
<td>High fitness in a neonatal mouse skin colonization model</td>
<td>Mating</td>
<td>Unknown</td>
<td>High fitness in an ex vivo tongue infection model</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

GUT, gastrointestinal induced transition; MTL, mating-type locus. *Note that the cell types listed are under certain environmental conditions, but these cell types have not been well characterized.*

2.2.2 Phenotypic plasticity

Although *C. albicans* is described as a yeast, yeast cells transition between pseudohyphae and hyphae and hyphae transition to chlamydospores (Noble, Gianetti, and Witchley 2016). White cells also transition to opaque and opaque to white as discussed in chapter 1. The cues and mechanisms of the transitions between yeast-pseudohyphae-hyphae and white-opaque-white are well characterised under *in vitro* conditions and increasingly under *in vivo* conditions. However, the other transitions, including the hyphae-yeast, hyphae-chlamydospore, white-opaque filamentation and the recently discovered grey and GUT transitions are still largely mysterious (Jacobsen and Hube 2017). The yeast-pseudohyphae-hyphae transitions are the most comprehensively studied and best described because yeast forms are the most common form found *in vivo* and *in vitro* and hyphae are associated with increased virulence (Noble, Gianetti, and Witchley 2016).  

[137] The overwhelming majority of evidence indicates that hyphae have much greater “virulence potential” than yeast cells, although yeast cells can be virulent (Noble, Gianetti, and Witchley 2016).
Yeast cells (Figure 43a) can be induced to transition to pseudohyphae and hyphae by growth at 37°C or in alkaline pH, in serum and N-acetylglucosamine,138 low oxygen (hypoxia) or high carbon dioxide (hypercarbia), by host immune cell signals and contact with a surface (Cottier and Mühlschlegel 2009). In these conditions, the components of the yeast cell wall restructure and the cell wall “evaginates” (Figure 43b). Pseudohyphae form if the evagination point constricts and forms a septum at the mother cell (Figure 43e–g). If the evagination point does not constrict, a germ tube forms (Figure 43b) and becomes the parent cell for subsequent generations, which form hyphal mycelia (Figure 43c). Early diagnostic tests relied on this unique ability of C. albicans to form germ tubes in the presence of serum (Mackenzie 1962; Andleigh 1964).139 Jacobsen and Hube (2017) argue that despite an exponential increase in morphological research since 2012, much remains to be discovered about yeast-hyphal transitions, including cues and regulation of hyphae-yeast transitions, mechanisms of hyphal branching and the relationship between hyphal growth and virulence.

Figure 43 Yeast, hyphal and pseudohyphal morphologies and transitions. All scale bars represent 10 µm. Reprinted from Sudbery, Gow, and Berman (2004, fig. 1), with permission from Elsevier.

The white-opaque-white transition (Figure 44) is highly sensitive to environmental cues and is well-characterised, due to its role in C. albicans mating (discussed in chapter 1). The transition from white to

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138 A derivative of glucose and a component of microbial and fungal cell walls.
139 The formation of chlamydospores, which form at the end of filaments in nutrient and oxygen poor conditions, was also used as a diagnostic test (Jansons and Nickerson 1970).
opaque is induced by acidic pH, ≥5 per cent CO₂ (hypercarbia) and N-acetylglucosamine, whereas the opaque to white transition is promoted by alkaline pH, low CO₂, glucose and mammalian body temperatures (Noble, Gianetti, and Witchley 2016). The cues trigger cell wall reconfigurations, causing white cells to elongate and enlarge (Figure 44A) and altering their physiology and metabolism. Soll (2014) draws attention to the intermediary form of the white-opaque transition (Figure 44B), which has not been studied but which he suggests may have a role in regulating the temporality of the transition. Opaque yeast cells form “mating tubes” in response to α-pheromones, which allow them to transition to hyphae under completely different conditions from those that induce the white yeast-hyphae transition (Si et al. 2013; Ene et al. 2016). Opaque cell filamentation is optimal at 25°C with sorbate rather than glucose as a carbon source and low phosphate. Filamentation conditions are mutually exclusive, i.e., white yeast cells cannot filament under the same conditions as opaque yeast cells.

Figure 44 Transitions between white and opaque cells involve a dramatic change in cellular phenotype and differences in the capacity to colonize skin. Adapted by permission from Soll (2014, fig. 1) under the terms of a Creative Commons Attribution License.

Three novel cell forms—opaque heterozygous, “grey” and “GUT”—that are functionally and genotypically distinct have recently been observed, although little is known about their transitional cues and mechanisms (Noble, Gianetti, and Witchley 2016; Palková and Váchová 2016). Almost nothing is known about the opaque heterozygous (a/α) cell form, which can be induced under the same conditions as opaque homozygous cells and grey cells (Figure 41), which are induced by high nutrient concentrations rather than the nutrient-poor, high CO₂ conditions that induce opaque transitions (Palková and Váchová 2016). Unique signals in the gastrointestinal tract, as yet uncharacterised, induce a transition between white and “gastrointestinally induced transition” (GUT) cells, which are morphologically and functionally unique (Figure 45A) (Pande, Chen, and Noble 2013). The GUT form is a commensal cell form sustained under gastrointestinal conditions that rapidly transitions to the white cell form when removed from these conditions. GUT cells are also phenotypically distinct from opaque cells (Figure 45B) and do not form mating filaments in response to α-pheromone (Figure 45C).
The transition between white and GUT cell forms confers enhanced fitness in the mammalian gastrointestinal tract and GUT cells are distinct from opaque cells. A. W indicates colonies with typical white morphology and unmarked colonies have the novel GUT morphology. Scale bars, 20 µm.; B. SEM of opaque and GUT cells. Scale bars, 1 µm; C. Growth in α-pheromone (αF) induces mating projections in opaque cells but not GUT cells. Scale bar, 20 µm. Adapted by permission from Macmillan Publishers Ltd: *Nature Genetics* (Pande, Chen, and Noble 2013, figs. 2 & 3), copyright (2013).

The phenotypic plasticity of *C. albicans* is not due to random gene mutation (Soll 2014; Noble, Gianetti, and Witchley 2016). Rather, *C. albicans* plasticity is cued by a wide range of environmental signals sensed by cell surface compounds, which trigger particular transcriptional pathways and discussed further in chapter 3.

The focus of much recent *C. albicans* research has been on understanding and mapping these pathways because they regulate virulence factors such as adherence, biofilm development, and immune evasion (Homann et al. 2009). Some transcriptional factors have broad effects, whereas others are specific in terms of the regulation of colony and biofilm development and environmental signalling. MAPK and cAMP–PKA are the two major signalling pathways involved in phenotypic transitions and activate the transcription factors Efg1 and Wor1 (Hogan and Muhlschlegel 2011; Noble, Gianetti, and Witchley 2016). These pathways are under negative and positive transcriptional control, i.e., they are activated in the presence or absence of the transcription factors (Homann et al. 2009).

Although Homann et al. (2009) found that the pathways can be regulated independently of each other, Noble, Gianetti, and Witchley (2016) note that the transcription factors themselves are interdependent (Figure 46): Efg1 promotes yeast-hypha-yeast transitions, the production of chlamydospores and the opaque-white, grey-white and GUT-white transitions. Wor1 promotes the white-opaque and grey-opaque transitions and blocks the opaque-yeast and GUT-white transitions, suggesting that expression of Efg1 and Wor1 are mutually inhibited. In addition, the Wor1 white-opaque switch regulates filamentation (Si et al. 2013). Filamentation is also regulated by farnesol (Höfs, Mogavero, and Hube 2016), which inhibits the cAMP morphogenesis regulatory pathway at high cell densities, promoting yeast cell growth. Soll (2014) argues that the regulatory circuits of *C. albicans* are extremely complex and sensitive since the plasticity of *C. albicans* is predominantly due to only three transcriptional factors. Scaduto and Bennett (2015) suggest that such complex epigenetic regulation enables rapid adaptation to novel environments and is particularly common in host-pathogen symbioses.

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140 Transcription pathways are the metabolic cascades that result in transcription factors, the proteins that bind to specific DNA sequences in order to regulate the expression of a particular gene.
In each example in the figure, arrows indicate activation and bars represent inhibition. Reprinted by permission from Macmillan Publishers Ltd: *Nat Rev Micro* (Noble, Gianetti, and Witchley 2016, fig. 4), copyright (2016).

### 2.2.3 Niche construction

*C. albicans* doesn’t just respond to environmental conditions through complex regulatory pathways, it also improves its chances of survival by chemically and physically altering its environment. Metabolites secreted by *C. albicans* can change the pH of its environment, influence and evade host immune cells and induce biofilm formation (Nobile and Johnson 2015; Höfs, Mogavero, and Hube 2016; Palková and Váchová 2016; Jones and Elliot 2017). Such environmental modification can improve survival under stressful conditions. For example, when energy sources are scarce, *C. albicans* catabolises amino acids, which releases extracellular ammonia, causing a localised alkalisation and inducing hyphal transition (Palková and Váchová 2016; Jones and Elliot 2017). Jones and Elliot (2017) speculate that such pH-induced hyphal growth
maximises propagation, surface exploration and colonisation enabling movement to improved conditions. The ammonia also signals a shift in colony development and metabolic reprogramming. Furthermore, yeast cells produce ammonia in response to being phagocytosed (engulfed by host macrophages) (Trevijano-Contador, Rueda, and Zaragoza 2016). The subsequent pH neutralisation of the phagosome\textsuperscript{141} induces the engulfed yeast cell to transition to the hyphal form, which can then escape from the macrophage (Figure 47). Hyphae penetrate the macrophage cell wall, but Jacobsen and Hube (2017) note that the pH modification also inhibits host macrophage maturation. This is just one of several adaptations that enable \textit{C. albicans} to evade the host immune system.

Figure 47 Escaping the host immune system: morphogenesis of \textit{C. albicans} (red) within macrophages disrupts the immune cell and allows \textit{C. albicans} to escape. Reproduced by permission from Jiménez-López and Lorenz (2013, fig. 1) under the terms of a Creative Commons Attribution License.

\textit{C. albicans} has an active and complex immune evasion system that is dependent on its ability to transition between phenotypes. In addition to their ability to escape macrophages, hyphal cells express defence proteins against anti-oxidants produced by host phagocytes and other microbes (Noble, Gianetti, and Witchley 2016). Both yeast and hyphal cells are able to inhibit the formation and maturation of phagocytes and produce a chemoattractant that activates transcription factors for innate immune cells (Höfs, Mogavero, and Hube 2016). The signal fades rapidly, enabling low concentrations of both yeast and hyphal commensal populations. Transition between yeast and hyphae in response to environmental cues, combined with an increase in “hyphal burden” past a certain threshold level, initiates a strong immune response (Figure 48) (Höfs, Mogavero, and Hube 2016). Opaque cells do not produce the chemoattractant,

\textsuperscript{141} A phagosome is a vesicle within a macrophage or other host innate immune cell type that forms around a microorganism or particle in order to protect the host.
making them invisible to phagocytosis (Soll 2014; Noble, Gianetti, and Witchley 2016). In addition, C. albicans modulates the composition of its cell wall to shield against recognition by host cells (Whiteway and Oberholzer 2004; Höfs, Mogavero, and Hube 2016). However, biofilm construction is the most effective defence against host attack.

Figure 48 C. albicans responses to host immune activation. Reproduced by permission from Peters et al. (2014, fig. 1) under the terms of a Creative Commons Attribution License.

C. albicans constructs three-dimensional extracellular structures called biofilms that enable it to evade the host immune system and protect from antagonistic environmental conditions (Nobile and Johnson 2015). Biofilms consist of a dense network of multiple cell forms distributed throughout a complex extracellular matrix (ECM) produced by the C. albicans cells (Figure 49). Biofilm formation, maturation and extent are dependent on a multitude of biotic and abiotic environmental cues, including available nutrients, pH, and temperature, thigmotropism, quorum sensing compounds like farnesol or their mimics, fluid flow, other microbial products, peptide hormones, e.g. insulin, steroid hormones including progesterone, estrogen, dehydroepiandrosterone (DHEA), monoamines, e.g. catecholamine and essential vitamins, including vitamin K, extracellular DNA (eDNA) and surface roughness and hydrophobicity (Kumamoto 2008; Sapaar et al. 2014; Chandra and Mukherjee 2015; Feraco et al. 2016). These cues cause yeast cells to aggregate and adhere to a surface and secrete the ECM (Scaduto and Bennett 2015).

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142 Discussed further in chapter 3.
143 Aggregation and adherence are discussed further in chapter 3.
Figure 49 *Candida* biofilms contain multiple morphologies contained within an extracellular matrix (ECM). Scanning electron micrographs of a *C. albicans* biofilm on the inside lumen of a vascular catheter from a rat central venous catheter model. (a) Cross section of a biofilm. Yeast and filamentous cells are seen encased in matrix material. The depth of the biofilm in this image is greater than 200 µm. Magnified 1000 times. (b) Image of section of venous catheter. Majority of catheter lumen is coated with biofilm. Magnified 50 times. Reproduced from Nett and Andes (2006, fig. 1), with permission from Elsevier.

Figure 50 Stages of *C. albicans* biofilm formation. 1. Adherence of yeast-form cells to a surface. 2. Initiation of cell proliferation, forming a basal layer of anchoring cells. 3. Maturation, including growth of hyphae concomitant with the production of extracellular matrix material. 4. Dispersal of yeast-form cells from the biofilm to seed new sites. Reprinted by permission from Nobile and Johnson (2015).

Typically, a mature biofilm consists of several basal layers of yeast cells that anchor the biofilm to the biotic or abiotic support and an upper layer of vertically oriented hyphae that deposit an ECM in this area of the biofilm (Figure 50) (Nobile and Johnson 2015). The ECM is a complex architecture of proteins and glycoproteins, carbohydrates (polysaccharides), lipids and nucleic acids. These materials are secreted by *C. albicans* hyphae, although the ECM also contains host-derived biomolecules such as fibrinogen, dead cells and extracellular DNA (eDNA) (Sapaar et al. 2014; Chandra and Mukherjee 2015). Sapaar et al. (2014)
propose that eDNA induces the transition from yeast to hyphae during biofilm development. Cells are bound together by connective fibres, which strengthen the structure (Palková and Váchová 2016). Yeast cells disperse from the mature biofilm into the environment, possibly to colonise other host niches (Höfs, Mogavero, and Hube 2016).

The biofilm is not an inert environment, subject to construction and reconstruction by its occupants. It is a highly complex, intra-active structure within which C. albicans lives (Figure 51). The ECM is differentially permeable to molecules, impenetrable by host immune cells and resistant to drugs (Palková and Váchová 2016). This resistance is not just due to physical impenetrability: the matrix upregulates drug efflux pumps to sequester some antifungal drugs, dispersing their effective concentration (Berman 2012; Palková and Váchová 2016); some of its 500 proteins are hydrolysing enzymes that actively break down biopolymers (Nobile and Johnson 2015); and the eDNA within the matrix contributes to the biofilm structural integrity and tolerance to antifungal drugs (Martins et al. 2010; Martins et al. 2011; Höfs, Mogavero, and Hube 2016).

Survival is demonstrably improved by life in a biofilm, although individual cell growth rate is inhibited (Höfs, Mogavero, and Hube 2016). Cells within the biofilm have increased resistance to antifungal compounds compared to planktonic (free-living) cells and dispersed yeast cells can be more virulent (Uppuluri et al. 2010). Individual cells are protected by other cells and the ECM from antagonistic immune cells, antifungal drugs and other microbes. In addition, stationary-phase or “persister” cells dwell in the depths of biofilms (Figure 51). Formed early during biofilm development, these cells are metabolically dormant and cannot be recognised by antifungal drugs or immune cells. Persister cells comprise approximately one percent of the biofilm and form a reservoir for repopulation if the biofilm is destroyed (Höfs, Mogavero, and Hube 2016; Palková and Váchová 2016). Little is known about this cell form “despite their importance to the drug resistance of C. albicans biofilms” (Nobile and Johnson 2015, 80). The mixture of multiple cell forms in biofilms already adapted for a range of conditions enables rapid adaptation to environmental changes. Palková and Váchová (2006, 813) observe that “the actual reaction of a mixed population can be much quicker than the reaction of a homogeneous one that must extensively change its gene expression during the switch.” Biofilms facilitate rapid responses via cell density, the concentration of chemical gradients that enhance cell-cell signalling or quorum sensing and the presence of forms already suited to the altered conditions.
Figure 51 *C. albicans* biofilm complexity and agency. The growth in form of biofilms, multicellular communities with a complex three-dimensional ultrastructure, is associated with a high intrinsic tolerance to several stressful conditions, e.g., antifungal treatment, immune defence mechanisms, physical and chemical stresses. Some important resistance mechanisms are represented in this figure. ECM, extracellular matrix; PBMCs, peripheral blood mononuclear cells. Reproduced by permission from Polke et al. (2015, fig. 3).

Nobile and Johnson (2015, 78) note that “biofilm formation by *C. albicans* can occur over a broad range of conditions and the genetic requirements likely vary from one condition to the next.” Key differences in architecture between biofilms formed on different biomedical materials have been observed (Chandra and Mukherjee 2015). Hawser and Douglas (1994) observed pathogenicity differences between biofilms formed by different isolates of *C. albicans* and Kuhn et al. (2002) and Li, Yan, and Xu (2003) found variation in biofilm formation between *C. albicans* strains. However, further studies are needed to determine the evolutionary relationships involved in biofilm formation. Although it is now thought that biofilms are the

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144 In one experiment, denture biofilms were 20–30 µm thick, comprised mostly yeast cells in confluent layers, and had irregular topography. In contrast, the biofilms that formed on catheters were much thicker (up to 450 µm), with a 10–12µm thick basal layer of yeast cells overlaid with a hypha-rich layer and uniform thickness.

145 A strain is a genetic variant or subtype of a microbial species (Dijkshoorn, Ursing, and Ursing 2000).
default lifestyle for *C. albicans* in the host (Arzmi et al. 2015),\(^{146}\) “little is known about the variation and evolution of biofilm formation within populations” (Li, Yan, and Xu 2003, 353).

2.2.4 Evolutionary implications

The unusual phenotypic plasticity of *C. albicans* is an evolutionary adaptation to myriad complex in vivo microenvironments that provides fitness advantages for each form in each niche (Pande, Chen, and Noble 2013; Scaduto and Bennett 2015; Ene et al. 2016; Noble, Gianetti, and Witchley 2016). The host has myriad distinct niches about which little is known (Figure 52) but which are subject to constant movement and nutritional and temperature fluctuation. For example, the skin, vagina, mouth and intestines have distinct thermal and nutritional conditions and complex microenvironments. The temperature, moisture and light conditions under the armpit differ from that of the nipple. The intestine is dark, anoxic and acidic, whereas the mouth is aerobic and filled with saliva. *C. albicans* occupies all these environments and each cell form exhibits optimal fitness under distinct conditions (Noble, Gianetti, and Witchley 2016), which suggests that environment and organism are engaged in an active, mutual feedback loop:

\[^{a/α}\] hyphae and pseudohyphae exhibit superior virulence in localized oral infection models, whereas white\(^{a/α}\) yeasts, hyphae and pseudohyphae are all required for virulence in disseminated infections. MTL heterozygous opaque\(^{a/α}\) and MTL homozygous opaque\(^{α}\) or α) cells have both been reported to have superior fitness during skin colonization, whereas grey\(^{a/α}\) cells are the fastest proliferating cell type in an ex vivo tongue infection model. Finally, \[^{a/α}\] gastrointestinally induced transition (GUT) cells outcompete other cell types in the mammalian gastrointestinal tract, with a relative fitness of GUT over white\(^{a/α}\) over opaque\(^{α}\) or α). Noble, Gianetti, and Witchley (2016, 7)

![Image](image.png)  

**Figure 52** *C. albicans* morphotypes exhibit enhanced fitness in specific host niches. Reprinted by permission from Macmillan Publishers Ltd: *Nat Rev Micro* (Noble, Gianetti, and Witchley 2016, fig. 3), copyright (2016).

\(^{146}\) Biofilms are now thought to be the default lifestyle for the majority of microbes (Clarke 2016).
Soll (2014) suggests that phenotypic plasticity itself, i.e., the ability to transition between phenotypes, provides the most significant fitness advantages and is selected for by host-pathogen interactions. The high level of commensal microvariation that is generated by phenotypic plasticity improves fitness within biofilms, as discussed, but also increases mating efficiency, induction of biofilm formation, immune and toxin evasion and promotes commensalism (Pande, Chen, and Noble 2013; Wartenberg et al. 2014; Zhang et al. 2015). Jacobsen et al. (2008), for example, have observed that closely related but diverse strains of *C. albicans* are common, particularly under antifungal selection pressures. The white-opaque transition maintains the diversity of natural *C. albicans* populations by genetic recombination and chromosomal ploidy shifts (Odds et al. 2006). Scaduto and Bennett (2015, 106) argue that “the result of this synergy is that the ‘whole is greater than the sum of its parts’ when it comes to evaluating phenotypic diversity.”

In fact, Soll (2014) concludes that the regulatory system for *C. albicans* phenotypic plasticity (Figure 53) is so complex that it could not have evolved from a single gene change but from the complex and continuing recruitment of hundreds of genes to differentiate into new cell forms in response to distinct environmental conditions and to manipulate those conditions. The pleiotropism of each cell form demonstrates this complexity: opaque cells are famous for being mating-competent but also undergo the differential expression of more than 1000 genes, upregulating pathways involved in oxidative respiration rather than the fermentation pathways of white cells (Noble, Gianetti, and Witchley 2016). These cell forms, therefore, metabolise carbohydrates differently, are able to survive in distinct nutritional conditions and manipulate their niches differently. *C. albicans* is also able to rapidly remodel its transcriptional networks under selection pressures. Wartenberg et al. (2014), for example, found that when exposed to the constant selection pressure of the macrophage phagosome, yeast cells could direct gene mutation to initiate hyphae transition to escape phagocytosis, bypassing the usual Efg1/Cph1 pathway. This environment-induced directed adaptation provides evidence for plasticity-first evolution, discussed below. Further investigation of *C. albicans* phenotypic plasticity can, therefore, provide new insights into the mechanisms by which cell specialization and evolution occur (Scaduto and Bennett 2015).
2.3 Trans•forming Natural Selection

2.3.1 Introduction

Natural selection is considered to be the primary driver of adaptation and evolution (Subramaniam 2014). Individuals subject to natural selection compete for scarce resources and small trait variations may arise through random gene mutation that improve survival, i.e., an individual is “more fit” or “better adapted” and therefore more likely survive to reproduce (West-Eberhard 2009). Variations that enhance survival are reproduced and amplified within a population. Irreversible variations, i.e., traits whose genes become fixed in the genome and improve “fitness,” are adaptive and evolutionary. Natural selection, therefore, results in small changes in the variance of trait distributions within a population, which can confer a large advantage (Lewens 2010). However, as Subramaniam (2014, 49) argues, the mechanisms and applications of the three features of natural selection proposed by Darwin—“phenotypic variation, differential fitness, and heredity”—are highly contested and entangled. For example, although the metric of selection, “fitness,” is assessed by number or viability of offspring in eukaryotes, for microbes it is assessed by genomic or allelic changes that improve the survival of individuals (Xu 2004). Fitness describes the

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147 Kull (2014) argues that adaptation is evolutionary ONLY if irreversible and Vane-Wright (2014) discusses how variations are made irreversible.
probability of an individual’s reproductive success and the average contribution of the trait to the population gene pool.

As discussed, gene-centrism and biological determinism dominated theories of natural selection during the late twentieth century. Emerging from the Modern Synthesis and its reliance on Mendelian inheritance and population genetics, the combination of the discovery of genetic regulation and assimilation in the 1950s and the universal acceptance of Crick’s central dogma of molecular biology crystallised genes as the drivers of natural selection (Lewens 2010; Subramaniam 2014). Walsh (2014b) has demonstrated the importance of genes for the modern synthesis, tracing the privileging of germline cells as the vehicles of genetic inheritance. He argues that the combination of central dogma and germline inheritance strengthened an already existing disdain for phenotypic inheritance mechanisms, which were dismissed as Lamarckian.148

As discussed, the co-evolution of host and pathogens is typically explained via the Red Queen hypothesis,149 which conjoins Van Valen’s (1973) model of “hostile interspecies coevolution,” Bell’s (1982) explanation of sexual evolution and Hamilton’s cyclical host-parasite system. The CandidaHomo ecology is therefore positioned as the site of an “evolutionary arms race” where C. albicans and H. sapiens are engaged in antagonistic feedback loops of gene-driven adaptation. However, the selective pressures in the CandidaHomo ecology are poorly characterised and vary depending on niche conditions. note that “the fitness of a symbiont depends on environmental features that can change, such as the coexisting microbiota, the diet of the host, and which species and even particular individual is the host. Thus, the adaptive landscape is dynamic.” From my research with C. albicans, I would add niche-specific conditions, intraspecies interactions, pharmaceuticals such as antibiotics and hormones, technological devices and phenotypic plasticity to this landscape.150

2.3.2 Plasticity-first evolution

The plasticity-first adaptation demonstrated by C. albicans phenotypic plasticity supports the long-standing insistence during the nineteenth and twentieth centuries that evolution is the result of adaptive interactions between organism, environment, behaviour and genes (Baldwin 1896; Osborn 1897; Margulis 1970; Lewontin 1978; Gould 1981; Vane-Wright 2014). Evolutionary developmental biology (“evo-devo”) has provided the most evidence to date (West-Eberhard 2002; Gilbert 2003), although “eco-evo-devo” (ecological evolutionary developmental biology) is increasingly being integrated into a proposed Extended Evolutionary Synthesis (Pigliucci 2007; Blute 2017). However, the need for an extended synthesis is hotly

148 Lamarckian inheritance asserts that an organism can pass on characteristics that it has acquired during its lifetime to its progeny (also known as heritability of acquired characteristics or soft inheritance) (Ghiselin 1994). An accusation of Lamarckism has been one of the most significant insults in evolutionary theory (West-Eberhard 2007).

149 Commonly used to explain why C. albicans might have retained the mechanisms for sexual reproduction, although these papers attribute the hypothesis to Van Valen. Refer to the Introduction and chapter 1.

150 This is not a complete list.
debated (Laland et al. 2014; Pigliucci and Finkelman 2014; Futuyma 2017), despite evidence supporting non-genetic adaptation and evolution. The peer commentaries received by Jablonka and Lamb (2007) to their 2005 proposal that evolution occurs in four dimensions: epigenetics, behaviour, culture and symbolism, indicate the depth of feeling involved.

Jablonka and Lamb (2005) (J&L) argued that random mutation is not the single or even most common cause of genetic variation and that genes are not the only units of heredity. They were soundly criticised and accused of being neo-Lamarckian by Brace (cited in J&L 2007, 366–367) and Bridgeman (367–368), especially in reference to their claims of epigenetic and behavioural inheritance. Dickins and Dickins (368) held to neo-Darwinism and gene-level selection, arguing that “evolutionary theory is about design” and Faulkes and Baines (369–370) asserted that there is limited evidence for epigenetic evolution. Gabora (371) argued that J&L’s argument was non-Darwinian since natural selection is a theory of population-level not individual change and Lappan and Choe (373–374) were unconvinced by J&L’s claims of directed/non-random variation, arguing that this is so rare as to be irrelevant and failures to evolve useful traits and excessive diversity of responses to the same problem are much more common. Despite these criticisms, the phenotypic plasticity of C. albicans supports at least some of Jablonka and Lamb’s claims that epigenetics and behaviour are involved in adaptation and that directed variation is not necessarily rare.

In the 13 years since the first edition of Evolution in Four Dimensions appeared, evolutionary theorists have largely accepted that genotype and phenotype evolve together, even if they continue to argue about the mechanisms. Vane-Wright (2014) explains that

> Behavioural processes, together with development, learning, and social and environmental interactions, play a key role in mediating this pluralist vision of inheritance, with the mixture of top-down as well as bottom-up causation seen, for example, in robust gene regulatory networks...In effect, organisms are ‘negotiated’ by all these multi-way connections, ‘not computed, or decoded’ as has often deemed to be the case. (230–231)

As demonstrated by C. albicans experiments, phenotypic plasticity can produce variants that exhibit increased fitness under stress (Levis and Pfennig 2016). Variation due to plasticity can lead to adaptation (through genetic assimilation\(^{151}\)) or be non-adaptive (through genetic compensation\(^{152}\)) (Ghalambor et al. 2015). These mechanisms are related but separate and the intensity of selection depends on the fitness cost of plasticity:

151 Genetic assimilation occurs when “a trait that was originally triggered by the environment loses this environmental sensitivity (i.e. plasticity) and ultimately becomes ‘fixed’ or expressed constitutively in a population” (Ehrenreich and Pfennig 2016).

152 Genetic compensation occurs when a phenotype is expressed by alternative genes, RNA or transcriptional pathways (Grether 2014; El-Brolosy and Stainier 2017).
through phenotypic plasticity, the plastic traits of individuals are modified without modifying the genetic diversity of the population. But phenotypic plasticity can influence the fitness of individuals and be the target of selection. The intensity of selection for plasticity depends on the balance between a positive effect and a negative one, the cost of plasticity on fitness. (Grenier, Barre, and Litrico 2016, 1)

Grenier, Barre, and Litrico (2016) further argue that natural selection acts on phenotypic variations in three ways: it can be directional (favouring variations “above or below” the population “optimum” for an environment), stabilising (favouring variations closest to the norm, by killing off the most divergent variations) and disruptive (favouring extreme variations).

Despite this enthusiasm for phenotype-driven adaptation, even its proponents fall back to genes as the primary drivers of natural selection. Kull (2014) argues that natural selection and phenotypic plasticity are inseparable, and then asserts that natural selection is the differential, non-random reproduction of genotypes. Grenier, Barre, and Litrico (2016, 1) stress that “phenotypic plasticity can influence the fitness of individuals and be the target of selection” but note that “genetic diversity is essential in the long term since it increases the ability of populations or communities to adapt to new environmental conditions.” “The Baldwin effect” asserts that phenotypic plasticity increases the persistence of individuals in an environment, which allows more time for selection pressures to act on genes (Kull 2014; Ghalambor et al. 2015). Even Jablonka and Lamb (2014) suggest that “natural selection will favour the most well-adjusted phenotypes and the genes underlying them—the genes whose effects lead to a more reliable, faster, developmental adjustment, or the ones with fewer undesirable side-effects” (362). This is not to say that genes have nothing to do with adaptation or natural selection but they are not necessarily the primary driver or unit on which natural selection acts. What is evident is that the relationship between phenotype and genotype is often complex and difficult to determine.

The debate over sexual dimorphism and sex roles provides an excellent example of the contentions around phenotypic plasticity. As discussed in chapter 1, an animal-centric heteronormative model of sexual selection emerged from the Darwin-Bateman anisogamy paradigm and has become a persistent cultural belief (Gowaty 2003; Ah-King 2011; Gowaty, Kim, and Anderson 2012; Hoquet 2013). This androcentric model asserts that males compete with each other for female mates or females choose between males who will give her the best value offspring or be the best provider. A heteronormative parental theory was introduced in the 1970s to describe observed differential investments in offspring, which argued that females were more likely than males to be invested in parenting (Gowaty 2003). Sexually dimorphic mate conflict and parental investment have become dominant features of sexual selection (Leonard, 2005 #8954), where males are almost universally described as active and indiscriminate (Ah-King and Ahnesjö 2013), competing with each other for the chance to pass on their genetic material, uncooperative and uninterested in caring for their offspring. Females, on the other hand, are described as
passive, choosy and cooperative. She waits for the strongest male to plant his seed and devotes all her resources to ensure the survival of her offspring. Despite knowing of that sexes and sexual behaviours exhibit extraordinary diversity and variety, biologists continue to “parse continuous variation into only two categories” (Ah-King and Ahnesjö 2013, 461). Gowaty (2003) argues that, in fact, selection favours flexible responses to sex and Ah-King and Gowaty (2015) demonstrate that many species, including fish, insects, amphibians, birds, lizards and snakes, show “phenotypic plasticity in reproductive decision-making in response to environmental, social, demographic and internal factors” (221).

The “sex role” concept is arguably one of the fundamental disputes in evolutionary biology. A range of discrete, complex behaviours, morphologies and physiologies are usually collapsed under the idea of “sex role,” including mate choice, mating competition, courtship, parental care, mating pattern, territory defence and selection intensity (Ah-King and Ahnesjö 2013). Bailey and Zuk (2009, 441) further observe that “sexual behavior, sexual preference and sexual orientation are distinct but often conflated concepts.” Ah-King and Nylin (2010) propose that each behaviour and phenotype be considered as a distinct trait on which selection can act. They argue that these traits are “reaction norms,” responsive to environment, behaviour, culture, desire and genetic mutation. Importantly here, sex roles are not fixed for individuals or populations and individuals (male and female) can be “both competitive and choosy at the same time” (Ah-King and Gowaty 2015, 223) or at different times, under different environmental and social conditions, in order to improve chances for survival (Gowaty and Hubbell 2009).

As can also be seen in the reversible and heritable transitions and rapid microevolutions of C. albicans, non-genetic modes of inheritance can lead to evolution since natural selection pressures cause persistent and widespread changes in the phenotypes of descendants and populations. Walsh (2014b) rejects the gene-centric model entirely and argues for the entanglement of genomes, behaviour, environment and phenotype as evolutionary units, using the evidence of regulatory networks. In fact, Grether (2014) suggests that plasticity under natural selection may enable more rapid adaptation than gene-centric theories. Similarly, Levis and Pfennig (2016) argue that plasticity-first evolution has much greater evolutionary potential as it: (1) affects more individuals at once, leading to greater selection action and genetic accommodation; (2) traits are always associated with the environment that triggers them, which suggests that they experience “consistent selection and directional modification” (565); and (3) plasticity results in both the “storage and release of cryptic genetic variation” and genetic accommodation. West-Eberhard (2009) asserts that environmental adaptation has the potential to affect a population more than random mutation in individuals, leading to accelerated evolution. Finally, the microbiome is heritable and

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153 For example, Parker and Pizzari (2015) are dismissive of what they call the “gender role controversy” (152), and describe intersexual competition as “primordial” (153). For example, Parker and Pizzari (2015) are dismissive of what they call the “gender role controversy” (152), and describe intersexual competition as “primordial” (153).
traits acquired by members of the microbiome can be passed without altering the DNA of the host body (Gilbert & Epel 2009; Bateson 2012).

However, as Levis and Pfennig (2016) and Grenier, Barre, and Litrico (2016) acknowledge, more work is needed for field assessments of plasticity-first evolution.\footnote{Levis and Pfennig (2016) provide criteria for field studies, including: (1) exhibition of ancestral plasticity; (2) cryptic genetic variation; (3) change in regulation, form or both; and (4) adaptive refinement. They also provide an evaluation framework for all four criteria and show that most systems satisfy (1) and (3), but few satisfy (2) and (4). They argue that (4) is essential to rule out alternative explanations.}

Despite the systematic coexistence of plasticity and selection in natural populations which encounter different environments (spatial and/or temporal changes), there is a lack of experimental information on their combined influence on the evolution of the genetic diversity of populations. (Grenier, Barre, and Litrico 2016, 1)

\textit{C. albicans} seems an ideal model for field assessments of phenotypic plasticity. As Palková and Váchová (2006, 814) observe, “phenotypic switching can play an important role during the natural coexistence of a yeast with its host organism. On the yeast side, this includes adaptation to different host-body environments, leading to better survival of the microorganism; on the host side, to the development of protective mechanisms preventing efficient expansion of the microorganism within the body.”

\subsection*{2.3.3 Niche construction}

Although plasticity-first evolution acknowledges the role of environment as a driver of evolution, almost all models of natural selection reduce the environment to a pre-existing, external force that poses a problem which an organism has to solve (Lewontin 1978; Bateson 2014). Kull (2014, 288), for example, calls “a change adaptive if it solves some problem a living being faces, i.e. if it turns certain incompatibility into a compatibility.” West-Eberhard (2014, 503) notes that “under natural selection the contest is with a relatively unchanging environment, or one that usually does not change in response to progress achieved, a notable exception being co-evolutionary races between species-specific parasites or pathogens and their hosts.” Similarly, Benton (2009) observes that very few models account for the effects of abiotic factors in shaping an ecology.

The “Court Jester” hypothesis,\footnote{Benton (2009) suggests that the Court Jester model is appropriate for large-scale evolutionary events such as meteors or climate change.} which was developed in response to the Red Queen, proposes that abiotic factors are the drivers of evolution rather than the interspecies arms race (Barnosky 2001; Benton 2009). Rabajante et al. (2016) argue that both the Red Queen and the Court Jester are at work in host-parasite/host-pathogen systems like the Candida\textit{Homo} ecology. Nevertheless, although the Court Jester model attends to abiotic influences and acknowledges their agency, neither it or the Red Queen consider abiotic manipulation by organisms. Although Jablonka and Lamb (2014) briefly mention niche construction,
they also focus on organismal variation caused by environmental change. However, neither environment nor genotype are constant. Rather, organisms and environments are entangled in reciprocal and responsibility relationships of construction. They are Baradian apparatuses of intra-active performativity and mutual affordance.

Walsh (2014a) argues that evolution is positioned within dominant gene-centric theories of natural selection as an adaptive landscape, where phenotypic traits are representational axes on a multi-dimensional surface. The traits/axes of an organism “traverse a fitness surface” (215) and are subject to an autonomous topography of fitness optima and adaptive peaks, where “form evolves in response to the landscape, but not vice versa” (216). Walsh draws on Lewontin’s (2000, 63) conclusion that “so long as we persist in thinking of evolution as adaptation, we are trapped into an insistence on the autonomous existence of environments independent of living creatures.” In order for organisms to solve a problem posed by an environment, that environment must pre-exist the organisms. Like any landscape painting, an adaptive landscape depicts a pre-existing niche constrained by the size and quality of the canvas and unaffected by content—a space where form and context are uncoupled. Walsh describes this figuration as “among the most vivid, pervasive and enduring spatial metaphors in biology…a device employed to depict evolutionary change in a population or lineage undergoing natural selection” (214).

However, proponents of niche construction theories argue that “the complementary fit between organism and environment is not simply the consequence of adaptation by natural selection, but instead of reciprocal bouts of natural selection and niche construction (‘reciprocal causation’)” (Scott-Phillips et al. 2014, 1234). Rather, organisms bring about changes in their local environments through niche construction (Day, Laland, and Odling-Smee 2003). Niche construction theory expands gene-centric inheritance to include modified niches that are bequeathed to progeny and describes the selective process by which organisms actively discriminate between resources and alter an environment to their benefit (Odling-Smee, Feldman, and Laland 2003; Laland, Matthews, and Feldman 2016). Focused on the co-evolution of organism and environment, advocates argue that it is as important as natural selection for evolutionary change (Scott-Phillips et al. 2014). However, the evolutionary significance of niche construction is as disputed as phenotypic plasticity, since sceptics assert that adaptive change produced by niche construction can be accommodated within gene-centric evolutionary theories (Laland et al. 2014; Scott-Phillips et al. 2014).

Walsh (2014a) proposes that an affordance landscape, as a reciprocal, co-constitutive adaptation of organism and environment, provides an alternative to the dominant model of an adaptive landscape that uncouples organism and environment. For Walsh, an affordance landscape

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156 Ehrenreich and Pfennig (2016, 769) observe that although phenotypic plasticity is commonplace, “the evolutionary significance of such developmental flexibility remains controversial.”
is not inert or ‘detached’ from the properties of form, nor does it have ‘its own intrinsic dynamics.’ It is constantly shifting with changes in organismal form. Nor is there a relation of asymmetrical dependence of form on the affordance landscape. Form and the affordance landscape affect one another reciprocally; they co-evolve. (223)

Walsh’s affordance landscape is an evolutionary intra-active apparatus or companion species. This is niche construction and phenotypic and genotypic plasticity and naturecultural performativity. It requires a more inclusive metric of fitness than reproductive success or population growth, encompassing traits that may reduce reproductive efficiency, yet still improve survival, such as the alternate carbohydrate metabolism of the opaque cell or the formation of persister cells deep within biofilms. It incorporates facultative and condition-dependent sex, the resource-intensive construction of biofilms and the sacrificial secretion of immune cell chemoattractants in the unpredictable environment of the human body. Reconfiguring the CandidaHomo ecology as an affordance landscape embraces the agency of both C. albicans and H. sapiens and the possibilities of this always already transformative performativity.

2.4 TRANS*FORMING

Trans* theory examines the complexity and variability of gender and sexuality and is particularly focused on the intersections of technology, embodiment, identity and biopolitics (Stryker and Currah 2014; Halberstam 2016). Jack Halberstam (2016) argues that

Seeing trans* bodies differently—not simply as trans bodies that provide an image of the non-normative against which normative bodies can be discerned—but as bodies that are fragmentary and internally contradictory, bodies that remap gender and its relations to race, place, class and sexuality, bodies that are in pain or that represent a play of surfaces, bodies that sound different from the way they look, bodies that represent palimpsestic relations to identity, means finding different visual, aural and haptic codes and systems through which to figure the experience of being in a body. (371)

Trans* theory resists notions of a “natural” body and examines the naturecultural ambivalences that surround transformation and unsettles notions of “the biological as fixed, locatable, and originary” (Wilson 1998). Trans* bodies flow through sex and genders, unsettling categories. Hayward and Weinstein (2015, 198) propose that trans* “foregrounds specificity while emphasizing the processes of its materialization.” Therefore, trans* theory provides a map to navigate the ambivalences of queer theory towards biology and bodies. This ambivalence is a legacy of social constructionism, which leaves “the biological body invisible. Change is often assumed to take place in the gender part of the sex-gender dichotomy, since the physiological body is supposed to be invariable” Ah-King (2009, 213).

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157 Parts of this discussion are adapted from “We have never been Homo sapiens: CandidaHomo nature cultures” (Bates 2015c).
A “natural” body referent assuages anxieties about indeterminate sexed and gendered bodies. Some sexual difference feminists have argued, for example, that trans women are not women—not being born female, they have not experienced patriarchal oppression; or worse, may have perpetrated it. Hird (2006a) notes that trans women are declared to be confused, inauthentic and artificial, revealing complex assumptions about what a woman is. “Authenticity” implies that femininity can be defined, identified, delineated and universalised, demonstrating the slippages between sex as biological and gender as cultural: female is conflated with woman, i.e., genitalia and DNA—those crucial double Xs—maketh the woman; gene-centrism and environment trump behaviour, choice and performativity; apparently, women are born, not made.

Hird (2006a) critiques the common argument that the technological manipulation of trans bodies makes those bodies artificial and therefore inauthentic. She observes that this argument is morally inconsistent since the technological manipulation of bodies is accepted and welcomed in other cultural spaces. The hormonal manipulation of ovulation is the most striking example of this—the birth control pill made women’s liberation possible (May 2010). Consequently, arguing that a body should be rejected because it is technologically manipulated is patently illogical. The rejection of (some) “artificial” biotechno bodies draws on the notion of a “natural” body as “purely” biological. Certainly, dominant theories of natural selection assign “transbiological” bodies (Franklin 2006) to “artificial” or “unnatural” selection: technology is, therefore, neither body or environment but an artefact of human culture.

Many bodies that express phenotypes outside the “norm” tend to be pathologised and biomedicalised, with inconsistent regard for the health of the individual (Fausto-Sterling 2000), which suggests that cultural concerns are at play. As Crocetti (2013) observes,

> chromosomes and hormones...contain many variants. Some of these variants are considered pathological...because they are not common and they disrupt an image of pure maleness and femaleness. However, the symptoms of these variations are related to assumptions surrounding the gendered body, not actual functional problems. (31)

Conscious physiological manipulations of phenotypes through hormonal birth control, diet or cosmetic manipulations are tolerated, even encouraged, as long as they contain the bodies within “natural,” heteronormative phenotypes. Similar manipulations of diseased or disabled bodies are justified and encouraged for “health” reasons. While these interventions may improve lives, Fausto-Sterling (1987; 2000) demonstrates that many “abnormal” bodies are surgically and hormonally manipulated to bring them back into a heteronormative framework. Recent “crip” theory similarly argues that “disabled” bodies are drawn

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158 Germaine Greer is the most recent and (in)famous example of this position (Wahlquist 2016).
into a biopolitical regime that sees “able” bodies as normal bodies. This understanding of “norm-able” draws on an evolutionary understanding of a “fit” body. Likewise, the hormonal and physical manipulations of trans and intersexed bodies are justified for health reasons, both mental and physical. Pathologised as mental illness, “gender dysphoria” can be “cured” within a biomedical system. However, I have been unable to find any studies that examine the incidence of C. albicans infections in nonbinary, or intersex, trans people. Since C. albicans is highly sensitive to human hormones, it is surely possible that trans, nonbinary or intersex people undergoing hormone treatment are experiencing thrush or other infections that have nothing to do with sexual transmission.

The ambivalence about gender and biology is not limited to cisgender feminists, however. Distinctions within trans discussions between gender assignment, gender identity and gender expression elide biology and suggest that some trans people themselves struggle with the tensions between cultural constructions and biological essentialism (Bettcher 2014; Drabinski 2014). Casid (2012) observes that the term cis-gender, which refers to people whose gender identity correlates with the gender assigned to them at birth, conflates gender and biology:

Making a term to signal identification with and conformity to the sex to which one is assigned at birth conflates gender presentation with sex in binary biological terms. The term cis-gender performs yet one more twist on that other dueling dualism, nature vs culture, in which cis takes the place of nature (on the side of biology) and trans that of culture (on the side of an array of technologies of the self). (142)

The term trans-gender, when used as the opposite of cis, also conflates gender and biology, causing both to be seen as “fixed, locatable, and originary” (Wilson 1998, 95). Casid (2012, 143) complicates this impasse, arguing that although the use of cis as “not-trans” seems dialectical, its Latin origin as “on this side of” allows it to “enfold and unfurl its own transformations from within its side.”

If we understand bodies as naturecultural, as affordance landscapes, then neither trans or cis are inherently cultural or biological. Surely the extraordinary plasticity of bodies made possible by oestrogen and testosterone demonstrates that the performativity of gender is as cultural and biological as the performativity of genitals and DNA. Hayward (2008) describes being of her body, not in her body, and argues that all bodies experience this ambivalence. She draws on McRuer’s (2006) refiguration of disability as a kind of queer embodiment, a becoming that is not a cure, not whole but still coherent. This figuration of trans bodies as continual regeneration, as “re/iterative enactment of not only growing new boundaries (rebodying), but also of imperilling static boundaries.” (Hayward 2008, 76), recognises gender and biology as naturecultural, material-discursive performativity.

Crip theory draws on the critique of norms provided by queer theory to attend to the dialectical figuration of “dis-ability” (McRuer 2006; Löfgren-Mårtenson 2013).
The Unsettling Eros of Contact Zones

Considering bodies through trans* theory recognises that all bodies craft themselves, continually negotiating their fit with inhospitable environments, physically and behaviourally, biologically and culturally (Hayward 2008; Vaccaro 2015). Such crafting is performative in that iterative action consciously and unconsciously makes a body “more fit” for an existing social environment or actively disrupt it. Davis (2009) observes that individuals, whether transgendered or not, attempt to present themselves in a manner that facilitates social recognition and encourages suitable interactions... gender presentations and identities are negotiated with particular people in particular settings and are contingent on the form and function of particular interactions. Gender identification is neither unconstrained nor homogeneously structured; the level and form of structural regulation is situational. (100)

Similarly, Hammers (2015, 841–842) argues that “our flesh is the primary guide to the world, shaping as it does affective boundaries and bodily orientations...while the body is not “fixed,” neither is it a scene of continual fragmentation and flux (maybe more than we wish to acknowledge).”

Trans* theory shifts to encompass the plasticity of all bodies, not just human. The moral panic emerging over recent discoveries that xenoestrogen pollution is changing the sexes of fish and amphibians demonstrates the heteronormative anxieties around body plasticity and complex more–than–human implications of naturecultures. Ah-King and Hayward (2014) argue that heteronormativity underlies discussions of estrogen-induced feminisation of fishes and explore the material-discursive possibilities of endocrine disruptive pollution for re-imagining/embodying sex and sexuality. They draw on Ah-King’s (2010) previous proposal with Nylin that sex is a reaction norm, a dynamic evolutionary responsiveness to environment. Such discussions introduce a de-essentialised biology into both sex and gender by showing that hormones create a spectrum of bodies which are “parsed” into sexual dimorphism.

Intersections of trans* with more–than–human sexuality and variability are figured variously as “animal transex” (Hird 2006a), “tranimalities” (Kelley 2014; Hayward and Weinstein 2015) and “tranimacities” (Steinbock, Szczygelska, and Wagner 2017b). Hird (2006a) argues that transex is common among many species of nonhuman animals, plants and fungi and provides examples of behavioural and physical “transvestism” and morphological trans sex. Leonard (2005) discusses the importance of polymorphism for hermaphroditic species and Nieuwenhuis and Aanen (2012) describe the hundreds, if not thousands, of mating types of some fungal species, which for species can change in the presence of other mating types. Beekman et al. (2016) provide an overview of numerous strategies that challenge sexual dimorphism, including sequential and simultaneous hermaphroditism and sexual polymorphism such as in honey bees and other social insects. They note a “putative lack of clear sexual dimorphism” in plants (5). Darwin himself was fascinated by the intersexuality of barnacles (Wilson 2002).
However, care is advised for queer or trans* scholars looking to biology for either evidence or critique. Hird (2006a) cautions against claiming the abundance of nonhuman transex as evidence that human trans* is, therefore, natural. Instead, she describes trans* as “movement across, through and beyond normal classifications” (37). In addition, the metonymy of gender and sex in biology, can result in misguided critique. For example, Stefan Helmreich (2014) criticised Dorian Sagan for conflation of gender and sex in his description of Wolbachia bacteria as “gender-bending” because they “transform a population of insects of two genders into one that is all females” (Sagan, quoted in Helmreich 2014, 57). “I am not so certain [writes Helmreich] that ‘gender’ is the right optic to describe the dynamic in motion here. Rather than saying that Wolbachia are ‘gender-bending,’ we might rather say that they are sex-bending” (Helmreich 2014, 58). Helmreich’s critique may to be due to misinterpretation of discipline specific terminology. Ah-King (2009) notes that

> gender is not commonly used in evolutionary biology except as a synonym for sex, but could be seen as sex differences in behaviour, or as suggested by Roughgarden (2004), “the appearance, behaviour and life history of a sexed body”. There is no dichotomy between sex and gender (appearance and behaviour) in evolutionary biology; both are viewed as functions of how ecological variables influence organisms. (216)

Through a trans* lens, Wolbachia may be both gender- and sex-bending.

This is also the phenotypic plasticity of candida; performativity cued by hormones, temperature, pH, environment, other bodies. When Monica Bakke (2014, 155) claims that knowledge of our microbiome does not threaten our identity, although “an awareness of it definitely alters the way we think of our bodies, as they no longer can be perceived as sealed vessels,” she ignores a long lineage of scholarship that shows that the perception of the body as “sealed vessel”—a “unified self”— has always been a fantasy (Shildrick 2001). This is certainly not the lived experience of trans* bodies. The “unified self” has always been threatened by our microbiome and this threat is not merely cognitive, as Bakke suggests. Anyone who has had candidiasis understands immediately that cognition is embodied, that organisms transform their environments.

### 2.5 Performing Trans* Ecologies

Having explored the affordance landscapes of C. albicans and trans* and the controversies in natural selection theories, I discuss two artworks as material-semiotic resolutions. Control of Cell Morphology in vivo (2015) examines the technological and imaging apparatuses with which we comprehend the bodies of others. Ereignis, Gelassenheit und Lichtung: A love story (2015) brings the human body into the candida world and explores the intra-active performativity of niches. Generated during the research process, these

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160 As well as crip and aged bodies.
artworks express the microbiopolitics of affordance landscapes and transform understandings of bodies and environments as entangled and performative. They are figurations of scientia sexualis and ars erotica, reminding us that bodies and environments are plastic and pleasurable and in constant co-construction.

2.5.1 Control of Cell Morphology in vivo

*Control of Cell Morphology in vivo* (2015) is a zoetrope rotated using a hand-crank (Figure 54). The zoetrope drum contains a sequence of digital micrographs depicting the phenotypic plasticity and reproduction of *C. albicans* (Figure 55). The viewer looks through the drum slits and the still images are animated. The frame rate and verisimilitude of growth and movement depend on the speed at which the viewer rotates the drum. The viewer observes the contained images from a distance, completely in control. The simplicity of the analogue apparatus materialises the scales of spacetimematter and reveals a wonder in the technology used to see the motion of the organism.

![Control of Cell Morphology in vivo](image)

*Figure 54 Control of Cell Morphology in vivo, 2015, installation detail, Didactic Tools exhibition, Fremantle Arts Centre, Perth. Photo by author.*
Zoetropes were one of several “philosophical toys,” which included the thaumatrope and praxinoscope, developed during the nineteenth century that played with the biophysical phenomenon of the persistence of vision (Wade 2004). These toys were hand-operated mechanical instruments that entertained and educated the public about emerging scientific understandings of perception and vision (Gunning 2012). A zoetrope creates an illusion of motion by animating still images when the viewer looks through the slits in the wall of the spinning drum. Unlike the thaumatrope or phenakistoscope, which could only be used by one person, the zoetrope was designed for group viewing (Wade 2004).

The zoetrope, or “wheel of life,” lent an illusion of life to early microphotographs. For example, Etienne-Jules Marey used the zoetrope in experiments with micro-chronophotography in order to make the unseen optical and temporal movements of microbes visible (Gaycken 2011). Mileaf (2002, 38) argues that “the ability to capture an imperceptible moment moved photography beyond a record of reality into a medium that produced new knowledge” and Gaycken (2011) notes that microbiology was one of the first adopters of this new technology. For Marey and other microbiologists, “the ability to recreate movements was useful for what it could contribute to the expansion of visual knowledge, both as a storage medium and as a source of accurate reference” (365). As Marey wrote, “there are an infinity of the most curious movements in the field of the microscope” (quoted in Gaycken 2011, 367).

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161 The zoetrope was invented in 1834 by William Horner and patented in 1867 by M. Bradley and William Lincoln.
162 Eadweard Muybridge’s early scientific animations are erroneously associated with the zoetrope. He famously demonstrated the movements of a running horse using a zoopraxinoscope, a similar philosophical toy that used mirrors (Muybridge 1883; anon. 1889; Mileaf 2002; Lawrence 2003; Clarke and Doel 2005).
163 The microscope is again described in terms of the sublime by Marey.
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Marey embraced the zoetrope for chronophotography because it enabled the animation of temporality while still allowing for the analytic, objectivity of the still image (Mannoni cited in Gaycken 2011).

Animation enriched perception by giving “the eye the true sensation of movement”:

> When chronophotography translates successive positions of a moving object, it shows them to us completely differently from how our eyes see them. In each of these positions, the object appears immobile, and the actions that are produced in successive moments are brought together in a series of images as if they were simultaneous. These images therefore appeal more to the mind (‘à l’esprit) than to the senses (aux sens). They prepare us, it is true, to observe nature better and to seek out, for example, in an animal in movement, positions that we have not yet perceived. But this education of our eye can be made even more complete if, in presenting the images to it in a certain manner, one renders to it the impression of movement in the conditions to which it is accustomed to capturing them. (Marey quoted in Gaycken 2011, 365–366)

Contemporaneously, Watkins combined kinetography and photomicrography in the “micromotoscope” to record and reproduce the movements of living blood samples, largely for diagnostic purposes. A journalist lauded his efforts, proclaiming that “this power of studying the motion of the corpuscles is expected to prove of infinite value in the diagnosis of certain diseases. From this it will be seen that kinetography, which commenced in a scientific industry, has made distinct steps in scientific progress, in addition to captivating public taste” (quoted in Gaycken 2011, 372). Consequently, the zoetrope was instrumental in the emergence of microbiopolitics.

Gunning (2012, 506) argues, however, that in demonstrating the persistence of vision, the uncertainty of vision is revealed. These philosophical toys do not “primarily produce an image of movement, but rather an image involving an optical transformation—an ancestor of the moving image.” He further suggests that this is “more than a representation of motion. For this is an image whose nature is unfixed, liberated from material inscription and dependent on both a mechanical operation (manipulation and movement) and a perceptual transformation (a literal change in the way something is seen or appears)” (506). This “unfixity” results from the illusion inherent in our perception of motion, i.e.,

> the illusion derives from the lingering, persistent after-image, by which we see something after it has vanished from our visual field...This image is the product of a collusion between the device and our eye. Alternatively, the tricky device has taken advantage of the weakness of our eye in order to make us believe we see something that does not exist...We see this image not simply as a representation of something, but as an event, a process, an almost theatrical turn in which the image behaves in an unexpected manner, calling attention to its own production, making its appearance into a performance of image-ness, of becoming visual, of appearing. As a trick, this image surprises me not only because I know it isn't "really there" but also because I participate in its appearance. (Gunning 2012, 308)

The viewer is reassured by this participation (Mary Ann Doane cited in Gunning 2012) and this ability to produce movement at will—the ability to manipulate and transform static, analytical images.
However, the viewer cannot escape the “really there”–ness of the zoetrope or the double awareness of the not “really there” image and the tangible device. Gunning (2012) argues that this awareness is a feature of all technological images. Yet, zoetropes reveal more than just the entanglement of device and image—they reveal the tangible immateriality of all perception and knowledge; the complicity of material/discursive apparatuses in seeing, exploring, experimenting and comprehending. Zoetropes are rough and disruptive: hand cranking causes inconsistent exposure and projection rates, the gaps between images are visible and the device stops if the viewer does not act. This is not the smooth suspension of disbelief offered by high definition cinema. The persistence of vision is unsettled by zoetropes. Although the images may frame, represent and “comprehend” the thing, the thing still exists in excess of the image, an agential being—in—the—world. Consequently, the experience is simultaneously illusion and reality. Hence, zoetropes are intra-active apparatuses that transform and regenerate bodies.

The artwork *Control of Cell Morphology in vivo* employs the playful performativity of the zoetrope to transform bodies and knowledge. Viewers crank the handle to animate micro-chronographs of *C. albicans* transitions between yeast and hyphae. Unlike Horner’s *Dæduleum* (Figure 56), the viewer must use their entire body to activate the images. The slits are positioned at the viewing height of my then eight-year-old daughter, forcing taller viewers to bend to see the illusion, activating and manipulating their own bodies. Dulac and Gaudreault (2004) suggest that

> we are not invited to follow, narratively speaking, the vicissitudes of this or that zoetropic figure from one time, space, or situation to another. Rather, we are invited to take delight in the transformation–substitution relationship the images are subjected to and which they illustrate. This is a *recurring metamorphosis* of the figure, not a *reiterated following* of the action. (para. 20)

This is a device that reveals, comprehends, constrains and affords, generating bodies through intra-active, re/iterative performativity.

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164 Gunning (2012, 308)

165 The *Dæduleum* was named after the mythical Greek craftsman, Daedalus, who is said to have carved statues that looked as if alive, capable of self-motion.
Control of Cell Morphology in vivo is firmly located within scientia sexualis and entangled with the scientific legacy of microphotography. Bodies of C. albicans were isolated from H. sapiens bodies, bred in a laboratory, manipulated with serum extracted from my body to induce the yeast cells to form germ tubes, contained within a small plastic vitrine and subjected to the technoscientific gaze of state-of-the-art live-imaging technology to open a world that all might comprehend. As discussed in chapter 1, the formation of germ tubes by yeast cells is unique to C. albicans and was a common diagnostic technique for identifying C. albicans as the causative agent of an infection (Taschdjian, Burchall, and Kozinn 1960). This ambiguous body is drawn into the microbiopolitics of human research and disease, differentiated from other species of Candida and classified as virulent, pathogenic and eradicable. More than 95% of C. albicans cells form germ tubes in response to two distinct inductive chemicals present in mammalian serum (Mackenzie 1962; Hudson et al. 2004). Although horse or sheep sera are most often used for the “Germ Tube Test” (GTT), the test was originally developed using human serum. All three are still used in many parts of the world, however, the use of human serum is restricted due to concerns about possible transmission of infectious agents in contaminated blood used to make the test media.

For this artwork, C. albicans cells were induced to form germ tubes by culturing them in serum prepared from blood drawn from my own body (Figure 57).\textsuperscript{166} I used my own blood to entangle myself in the material-semiotics of C. albicans lives and the artwork and acknowledge my response-ability to my involuntary collaborators. The serum was inoculated with yeast cells (Figure 58) and incubated at 37°C in a

\textsuperscript{166} The serum was prepared using serum tubes provided by PathWest (www.pathwest.com.au) and the protocol provided by ThermoFisher Scientific (2007).
Tokai Hit Stage Top incubator for 24 hours (Figure 59). Timelapse images of filamentation were taken by a Nikon Digital Sight DS-2Mv attached to an Olympus IX81 microscope. After 24 hours, the *C. albicans* cells were removed and killed by exposure to 4% bleach for 10 minutes.

Figure 57 Preparing serum from my own blood to induce germ tube formation in *C. albicans*. Photo on left reproduced by permission from Tiffane Bates.167 All other photos by author.

Figure 58 *C. albicans* in serum prepared from my blood, ready for live-imaging of filamentation induction. Photo by author.

Figure 59 Live-imaging microscope setup for imaging germ tube induction of *C. albicans*. Photos by author.

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167 Many thanks to Philippa Cecil, UWA Medical Centre, for being so kind, generous and supportive of this project and my phobia.
The Unsettling Eros of Contact Zones

The temporality of the candida plasticity is collapsed by the zoetrope. For the artwork, I selected twelve images that spanned the 24-hour incubation, which I manipulated using Adobe Photoshop CS6 to ensure high and consistent contrast and tone and compiled into a chronological sequence. I spent many hours learning and practising the complicated technical skills of sample preparation and microscopy necessary to obtain focused images suitable for aesthetic comprehension, just as the early microscopists admired by Koch had done. The aesthetic qualities of digitised images are just as subject to “the photographic eye.” As Lawrence (2003) argues,

> when the materiality of the image changes, so does its capacity for conveying time...what the graphics comment on is the hidden, disguised ways that photography also constructs time...indexicality is no proof of time. How much time passed during the production of a photograph? What was the shutter speed? Was there a shutter? (21)

The sequence of twelve images was mirrored to produce a sequence of 24 images (Figure 60) and placed in the zoetrope drum ready for animation (Figure 61).

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168 Many thanks to Paul Rigby and Alysia Buckley in particular, CMCA, UWA, for their enthusiasm and seemingly endless patience.
According to Dulac and Gaudreault (2004, 233), "this ‘interactive’ aspect is central to the attractional quality of optical toys. The pleasure they provided had as much to do with manipulating the toy as it did with the illusion of movement." This “interactive aspect” also liberates candida from the solitary “objective” gaze of the live-imaging microscope: “image-making optical instruments...remained in the hands of a few savants who controlled their operation and reception, maintaining an atmosphere of the mysterious around them. The full experience of the technological image became widely available and commercialized in the nineteenth century with the philosophical toy” (Gunning 2012, 509). Certainly, van Leeuwenhoek was (in)famous for not sharing (Lane 2015).

Candida is “brought to life” by Control of Cell Morphology in vivo and the crank handle is the contact zone by which the life is controlled. The handle visually and functionally references the Daedaleum (Figure 56) and early motion picture cameras. The viewer must grasp it firmly to animate the drum and in doing so translocates microbiomes of past and present viewers. The metallic handle warms from the clasp of previous viewers creating an unsettling affect, a reminder of the liveness of bodies, including those examined. The animation frame rate is dependent on the speed at which the viewer rotates the handle, affecting the resolution of the images and the clarity of the animation. When the handle is released, the drum comes to a halt and the illusion is broken—life is differentiated into separate images and the artifice...
of motion is disrupted. Yet the mechanism that allows the handle to turn the drum resets after release, which causes the drum to turn independently of the human viewer and allows both device and candida to have a disquieting agency.

2.5.2 Ereignis, Gelassenheit und Lichtung: A love story

_Ereignis, Gelassenheit und Lichtung: A love story (EGL)_ is an immersive multi-channel video installation that projects a time-lapse video of candida morphing and reproducing into an architectural space (Figure 63). The video is projected onto the walls and floor and the bodies of viewers (Figure 64). Proliferating candida coats the internal surfaces of the building, as it does the internal surfaces of humans. Viewers are immersed (visually at least) in a yeasty environment: “once within the room viewers have no choice, they are ‘infected’, yet it is as soft and gentle as air caressing a surface” (Wilson 2015, viii). Like _Control of Cell Morphology in vivo_, _EGL_ uses the images of candida germ tube formation produced by the live-imaging microscope. In this work, however, every still image taken over the 24 hours of growth is digitally compiled into a high definition, digital timelapse video. Sophisticated contemporary imaging technology contrasts with the analogue machinery of the zoetrope and these paired works explore the transformational affordances of microbiopolitical apparatuses, spacetimematter and performativity.

Figure 63 _Ereignis, Gelassenheit und Lichtung: A love story_, 2015, installation still. Photo reproduced by permission from Karl Ockelford.
Ereignis, Gelassenheit und Lichtung: A love story explores the materialisation of the scientific gaze and spectatorship. A time-lapse video taken through a microscope is an example of the intra-active performativity of a material-discursive apparatus. The operator–microscope–camera–candida–editor–computer–projector is the apparatus—bodies are framed by the microscope and images of those bodies are captured by a still camera. Microscope, computer and projector allow us to view the film. A series of still images are taken, edited and then replayed at 24 frames per second. Each still image is a phenomenon, as is the compiled film. Each image “cuts out” a part of the world, including and excluding, “cutting together–apart.” The operator chooses how often the world gets captured and the editor which parts of the world get cut and which get shown. The film played by the projector shows us a particular selection of the world, which would be different if other cuts/images were included. The speed at which the film is replayed depicts a particular event-time: any faster or slower and we see the world differently. We are unable to see the film without the camera and the technology of the camera determines what we see. Change the technology/apparatus and the film/phenomenon changes.

Timelapse microfilms are always already illusion and reality, just as a zoetrope is. Hannah Landecker (2012, 395) argues that “one of the greatest demarcations between 1910 and 2010 is that representation in the contemporary period is seen as a means of remaking the thing through its image, not reproducing it.” While representation is now seen as a way that a thing can be remade, I disagree that this is a recent phenomenon. The early contestations about the objectivity of microphotography and chronophotography and the role of the microscopist in their construction indicate that scientists have always been aware that the thing is remade, not reproduced. Landecker herself notes that the capacity to edit enabled Julius Ries to

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169 This paragraph is adapted from “Cutting together–apart the mould” (Bates 2015a).
make one of the first time-lapse micrographic films in 1907. Ries imaged and condensed the 14-hour process of fertilization and development of a sea urchin into two minutes—“an intentional derangement of the time of observation” (Landecker 2012, 382). This is *scientia sexualis*, demonstrating the entanglement of microscopy, imaging and microbiopolitics. However, the “not really there”—ness of the sea urchin would have been evident to Ries and viewers of the film, partly because of the quality and materiality of the editing and viewing process but also because of the broader conceptual contestations about the status of this nascent technology. This reproductive ambivalence is potentially less apparent in 2017 than it was in 1907, due to the extraordinary resolution of microscopic images and the seamlessness of frame stitching enabled by digital technology.

*For Ereignis, Gelassenheit und Lichtung: A love story*, hundreds of micrographs of *C. albicans* transitions were taken using the high-resolution digital camera described above, controlled by time-lapse imaging software. These images were reconstructed into stack files using *Fiji*, an opensource biological-image analysis software and digitally manipulated using Adobe Photoshop CS6 for consistent tone and high-contrast. The image sequence was rendered into a time-lapse video using Adobe Premiere. The resulting video was projected using four BenQ SH915 Full HD 3D short throw projectors. This process of image collection and data transfer is largely digital. Light reflected from the *Candida* bodies is captured and transposed into digital information, which is transcribed through a series of software and hardware. This binary information is manipulated, transformed back into light and transposed onto biotic and abiotic surfaces. The projected *Candida* bodies are magnified to several million times life-size and their proliferation is 3,600 times faster than actual. Where is the body of *Candida*, the “truth” of this organism in this technoscientific transference?

The title of this work combines terms used by the philosopher Martin Heidegger, whose work redefined understandings of “being—in—the—world.” *Ereignis* [trans. an event] describes the coming into being of “things” which is only possible through their relationships with each other. *Gelassenheit* [trans. letting—be] expresses the acceptance of the mystery of being—in—the—world and *Lichtung* [trans. a clearing; illumination] refers to the necessity to clear a space in order to understand how it is to be—in—the—world. *Ereignis, Gelassenheit und Lichtung: A love story* suggests that all three are intertwined and performative, even in our own bodies.

**Ereignis— intra-action**

The timelapse film projected on the walls of the gallery comes into being because of the relationships between candida, human artist/scientist as serum donor, serum, microscope technician and film editor,

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170 Many thanks to Peter Todd, UWA, for his video editing assistance.
171 This work would not have been possible without the generosity of Hire Intelligence, Sohan Ariel Hayes and Ruedi Hauri.
live-imaging microscope technology, image manipulation software, projection hardware, gallery architecture, install crew and viewers (human and non). Candida yeast, germ tube, pseudohyphae and hyphae come into being because of the relationships between candida bodies and my serum. The experience of the human viewer comes into being because of their relationships with galleries, this gallery, art, this artist, video projection, representations of microbes, magnification, microbiology, scientific representation and, of course, with *C. albicans*, thrush, candidiasis and yeast infection. Landecker (2012) argues that

livecell imaging hangs the [cell] in a living but empty (unstained) background, and the image is of the cell as a skein of movement—a network not of molecules that stand in place as nodes or strings connecting nodes, but a network of very specific possible relations with actual entities moving in and out of various states or conformations of being...Where classic cell theory posited that all cells come from other cells, and all organisms are composed of nothing but cells, 21st-century cell theory thought through live-cell imaging might look something like this passage from a contemporary textbook: ‘No cell lives in isolation. Cellular communication is a fundamental property of all cells and shapes the function and abilities of every living organism’ (Lodish and Berk, 2008). Life as molecular network is a theory with origins, causes and practices that reach well beyond live-cell imaging, but at the same time, the role of imaging in giving life to theory should not be underestimated. As Julius Ries observed, a film can be understood to move in various ways, including moving the viewer to a position of belief. (393)

This means that *Ereignis, Gelassenheit und Lichtung: A love story* entangles the human viewer within a conceptual framework as much as a physical one, drawing on the legacy of scientific theories of representation and embodiment. The projected movement of cells “moves the viewer to a position of belief” that cells are fundamentally relational. However, *EGL* makes this belief tangible by projecting the network of living cells onto the viewer’s own body and so they recognise *Ereignis* not just of the cells “out there,” but also of cells “in here.”

**Gelassenheit—acceptance of unknowable/partiality**

*Ereignis, Gelassenheit und Lichtung: A love story* transforms through intra-active performativity. This is not to ignore the microbiopolitical legacy of these theories and technologies. However, although “magnification is not an innocent practice...the magnified image is invasive and surveilling, but it is also incomplete...magnification is always partial” (Hayward 2005, 35). It is fragmented, abstracted and sublime. These aspects are not in and of themselves wrong—they also draw attention to the material and conceptual construction of both images and bodies and the potentials for both naturalisation and transformation. Hayward (2005) asserts that

extreme close-ups as well as macro- and microscopic magnifications produce a discourse on space and experience: defamiliarization and then re-meeting on other terms...both inside and outside, within and nearby. This indeterminacy articulates the ongoing nature of enfolding...Proximity unlinks the spectator from an easy position of domination through separation and abstraction. The closeness folds the spectator into the production of the image, and part of that production is...specificity. (35)
The Unsettling Eros of Contact Zones

This specificity is the intra-active phenomena, the situated knowledge, the “not really there”-ness, the excess of being-in-the-world. The artwork is an apparatus that affords partial agency to all players and accepts that this is all we get.

Lichtung—clearing a space

Ereignis, Gelassenheit und Lichtung: A love story is illumination, it is light. It is a projection of a past that is present within. The light cast by the projection fills the space with illusion and reality, clearing a perceptual space that is illuminated yet ambiguous. The grey tones of the micrographs darken, flicker and fade, gather and recede:

things do not have fully determinate boundaries or properties. Things happen in and by encounter—refraction is one critical mode of encounter. What is seen is no longer simply a “true” reflection of the observed object…Through refraction, the object is altered by scale and encounter. The extension of the object (produced by changes in focal length in the apparatus) distorts, boundaries are rendered indeterminate and exist only to the extent that they are continually enacted. (Hayward 2005, 37)

The “objective” microphotographic gaze is confounded by extreme magnification, imaging distortion and spatial deformations (Figure 65). This is not being-in-the-world. This is transmogrifying-the-world.

A love story

The traces of ars erotica that loiter on the surfaces of Control of Cell Morphology in vivo erupt in a seething frenzy in EGL. The viewer is unable to control or discipline the candida or prevent it from swarming over their body, “yet it is as soft and gentle as air caressing a surface” (Wilson 2015) The viewer cannot linger on a specific point, attention drawn away by the flickering, teasing, shifting, drawn away and out to other bodies, other surfaces, other spaces. The light crawls across body, walls, floor, door, plinth, footpath, road, bus, out into the world... (Figure 66)
2.6 CONCLUSION

2.6.1 Summary

This chapter formed the cat’s cradle shown in Figure 67, untangling the threads of bodies, environment, plasticity, agency, natural selection, trans* theory, technology and perception of the CandidaHomo ecology. The review of current research into *C. albicans* phenotypic plasticity demonstrated the extraordinary ability of *C. albicans* to transition between forms in response to environmental cues without genetic modification. Several recently identified transitions demonstrate the importance of *in vivo* experimentation for understanding the evolutionary pressures within the CandidaHomo ecology. *C. albicans* also actively manipulates its environment through physical and chemical niche construction, including biofilm construction, pH manipulation and immune evasion. Bodies and environment are responsive and performative. As with *C. albicans* sex research, relatively little is known about the natural selection pressures acting on *C. albicans* and its environment. *C. albicans* is an ideal model for understanding co-evolution within the human body and for reconfiguring gene-centric evolutionary theories to include phenotypic plasticity and niche construction.
The Unsettling Eros of Contact Zones

Figure 67 Cat’s cradle for chapter 2 Queer affordances.

Theories of gene-centric evolution and biological determinism have dominated natural selection theories throughout the nineteenth and twentieth centuries. The linear and irreversible equation of the central dogma secured genes as the drivers of natural selection and has been extraordinarily persistent. Alternatively, plasticity-first theories allow phenotypes to influence adaptation, other modes of inheritance and environment-organism co-evolution. Neither organism or environment are passive, subject to the whims of random gene mutation. Rather they are affordance landscapes, engaged in intra-active performative transformation. The plasticity and niche construction of *C. albicans* provide a model for this reworking of the gene-centric and heteronormative theories of natural selection. Slippages between gender and sex, culture and biology reveal anxieties about ambiguous bodies and technological interventions. Trans* theory articulates a more–than–human understanding of the performative affordances of bodies, technologies and environments and reconsiders response-abilities. Being–in–the–world *is* response-able, intra-active performativity at all scales.

2.6.2 Takeaways

1. *C. albicans* has extraordinary phenotypic plasticity that enables it to survive and adapt to a wide range of environmental conditions, providing evidence for plasticity-first evolutionary theories.
2. *C. albicans* manipulates its environment by constructing biofilms, manipulating pH, and evading immune cells.
3. Plasticity-first evolutionary theories that challenge the gene-centrism of the twentieth century have gained traction in the ecological turn of the last forty years. Supported by epigenetics, life-history, developmental biology, niche construction, behavioural ecology and cultural theory, these theories assert that adaptation and evolution are driven by the entanglements of phenotype, genotype and environment.
4. Affordance landscapes understand evolution as a performative entanglement of bodies and environments rather than the adaptation of organisms to pre-existing environments.
5. Trans* theory prompts reconsideration of the performative, intra-active agency of body, culture and environment and positions humans in a more–than–human world but has yet to consider the microbiopolitics of the *CandidaHomo* ecology.

6. Artistic resolutions of candida affordance landscapes entangle perception and encounter, transforming bodies, environment and technologies.

### 2.6.3 Re-stringing the cradle

And so, the cat’s cradle untangled in this chapter transitions to the next figuration, for queer ecologies are communal. Evolving with others, they are about communication and sensation. The *CandidaHomo* ecology is a complex tactile, sensual entanglement of hundreds, if not thousands, of species. *C. albicans* forms communities with these species, building and dwelling in mixed-species biofilms. Competitive, individualistic, gene-centric evolutionary theories struggle to reconcile this multispecies sociality. Queer families of choice are discussed in relation to heteronormative and gene-centric theories of kin selection and eros is offered as a way to navigate the intimacies and response-abilities of more–than–human kind. Hence, the next chapter, *Queer Kind: Caressing kin selection in the CandidaHomo ecology*, weaves the phenotypic plasticity and niche construction of *C. albicans* into multispecies sociality, natural selection into kin selection and trans* theory into haptic intimacies and commensalism.

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Figure 68 Re-stringing the cradle for chapter 3, *Queer Kind: Caressing kin selection in the CandidaHomo ecology*. Illustrations by Furness Jayne (1906, figs. 747 & 748).
Figure 69 C. *albicans* communities. Photo by author.
3 QUEER KIND: CARESSING KIN SELECTION IN THE CANDIDA/HOMO ECOLOGY

3.1 INTRODUCTION

This chapter weaves together Candida albicans social interactions,\textsuperscript{172} evolutionary theories of community and queer understandings of family, kinship and intimacy (Figure 70). Chapter 2, Queer Affordances, explored the trans*performativity of C. albicans bodies and their environments and the possibilities this offers for transforming our understandings of bodies, environments and natural selection. However, C. albicans is not alone in its environment, which is a complex ecology of biotic and abiotic surfaces, other microbial species and host immune cells. This milieu and the mechanisms used by C. albicans to navigate its interactions are the focus of this chapter. This is an environment where contact zones are physical; vision is irrelevant, touch is all. Bodies slide against each other and their surrounds and communications are visceral; chemical signals excreted and received by cell surface moieties.\textsuperscript{173} Communities form and dissolve as communication is ingested, digested and excreted. This microbial sociality cannot be explained by biogenetic theories of kin selection and has been reconfigured by symbiotic co-evolution and microbial social evolution theories (West et al. 2006). These evolutionary theories are woven through queer intimacies and families of choice, and the palpable, multispecies sociality of Candida/Homo ecologies is discussed as eros, a sensual differentiation of kind that reimagines how to eat well together.

\textsuperscript{172} West et al. (2007, 598) describes a behaviour as social “if it has consequences for both the actor and the recipient. Social behaviours can be categorized according to the fitness consequences they entail for the actor and recipient.” The emergent field of microbial social evolution (also referred to as sociomicrobiology) discusses the role of such behaviours between microbes and their evolutionary implications. Discussed further in section 3.3 and refer to West et al. (2006); Xavier (2016) for historical reviews.

\textsuperscript{173} A moiety is both a functional part of a molecule (chemistry) and kinship groups into which a society is organised (IUPAC 1997; Australians Together n.d.).
3.1.1 Context

Although laboratory living tends to be a solo affair for microbes like *C. albicans*, the host environment is a crowded place (Figure 71). Encounters with other members of the microbiota, host cells and abiotic materials, including nutrients, toxins and biomedical devices are inevitable. These encounters are extremely complex and are the most common and significant contacts and communications that *C. albicans* has in the CandidaHomo ecology. In addition to its engagement with host cells, *C. albicans* competes with other microorganisms for niches, adhesion sites and nutrients and must deal with toxins secreted by its neighbours (Polke et al. 2015). It also cooperates and coaggregates with other species, shares host niches and nutrients, forms protective biofilms and exchanges metabolic by-products with its neighbours (Mallick and Bennett 2013; Polke et al. 2015). Interkingdom interactions are affected by conditions in the host niche, species composition and the presence of antibiotics. These complex interactions and encounters are mediated by chemical signalling and surface sensitivity.

![Image of a C. albicans biofilm on rat dentures](https://example.com/image.png)

Figure 71 Scanning electron microscopy (SEM) images of a *C. albicans* biofilm on rat dentures. 2,000x magnification. Reproduced by permission from Nett et al. (2010, fig. 3).

Despite their fundamental importance for *C. albicans* dwelling, few of these social interactions have been examined from an evolutionary perspective. A handful of studies, reviewed by Jacobsen and Hube (2017), investigate the evolution of *C. albicans* inside and between hosts. However, interactions between *C. albicans* individuals, populations, strains and isolates have been neglected. The selection mechanisms of social interactions between *C. albicans* and the other microbial species with which it cohabits are also rarely discussed, despite increasing evidence that interkingdom biofilms are its predominant lifestyle.
Further, although the evolutionary dynamics between host and *C. albicans* cannot be separated from multi-species communal interactions, they are rarely considered. Although studies tend to focus on the comorbidity of infections, investigation of the selection pressures on *C. albicans* as a commensal in these communities would provide crucial evidence for microbial social selection theories.

The field of social evolution theory is almost as dynamic as the *CandidaHomo* ecology and mechanisms of selection and population dynamics are highly contested (West et al. 2006). Cooperation and symbiosis, although clearly necessary for communities to form and flourish, have been significant challenges for dominant evolutionary theories based on competition and individualism (West et al. 2006). Until recently, mutualistic relationships, where both parties benefit, have primarily been described through competitive, individualistic and heteronormative natural or sexual selection theories and the dynamics of interspecies mutualisms have been considered anomalous. Attempts to explain altruistic and mutualistic behaviours have included the Red Queen hypothesis, kin selection (Hamilton 1964a) and group selection (Wynne-Edwards 1963; Wilson 1975), all of which are based on gene-centric theories of scarcity and biogenetic relatedness. West-Eberhard (1983) has proposed social selection as a mechanism that acts on social traits. Her definition of social selection as “interactive intraspecific competition for resources” (West-Eberhard 2014, 502), restricts the theory to competitive traits within a single species and does not allow for inter or multi-species community interactions. The importance of cooperation and sociality in evolutionary theory, in particular, microbial evolutionary theory (Xavier 2016) have been reconfigured by increasing evidence that host-microbe symbioses are fundamental to life, the widespread acceptance of symbiosis as an evolutionary mechanism and the discovery that multispecies microbial biofilms are the norm rather than the exception.

Dominant understandings of kinship are founded on biogenetic relatedness, implied by Darwin’s “descent” through reproductive lineage and distilled over the twentieth-century into genetic replication. This system considers any other marker of relatedness as non-biological and therefore unnatural. However, Haraway (1997a, 53) argues that kinship is “a technology for producing the material and semiotic effect of natural relationship, of shared *kind*” [emphasis added]. Existing and potential systems that recognise non-biogenetic relatedness struggle for legitimacy in the face of this monolithic heteronormative and gene-centric “technology of kind.” Haraway (2015, 162) writes that “I was moved in college by Shakespeare’s

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174 West-Eberhard (1983) argues that social selection encompasses sexual selection, where mates and fertilisation success are resources subject to competition. West-Eberhard’s social selection differs from Roughgarden’s (2009) proposal of social selection as an alternative to sexual selection, in that West-Eberhard considers social behaviours other than those involved in reproduction to be subject to social selection and sexual selection as a subset of social selection.

175 Symbiogenesis (speciation due to symbiosis) arose from the understanding that the eukaryotic cell likely evolved through endosymbiosis, i.e., the engulfment of one prokaryotic cell by another, which led to a fitness benefit for both (Margulis 1970; 1981).

176 Derived from or relating to biological, physiological or genetic characteristics (Bestard 2004).
punning between kin and kind—the kindest were not necessarily kin as family; *making kin and making kind* (as category, care, relatives without ties by birth, lateral relatives, lots of other echoes) stretch the imagination and can change the story” [emphasis added]. *C. albicans* sociality and queer families of choice, which tend to be nonbiogenetic and include nonhumans, make kinder and more diverse stories of “shared kind” and open up alternatives for “staying with the trouble” (Haraway 2016).

### 3.1.2 Chapter Overview

In this chapter, I review contemporary scientific understandings of *C. albicans* sociality. This sociality is highly tactile and sensual; bodies are in constant touch with chemicals, cells, surfaces, tissues, prosthetics. I describe the tangibility of communication between bodies to understand the intra- and interspecies contact zones of this haptic ecology. The corporeal communications of *C. albicans* with other members of its community are discussed, focusing on *C. albicans* as commensal rather than pathogen and teasing out its ecological experiences. The formation and maintenance of multispecies communal biofilms and the challenges for understanding the selection mechanisms that influence the social evolution of *C. albicans* are considered. I then discuss the highly contested field of social evolution, including heteronormative, biogenetic kin and group selection theories. The development of kin selection as an attempt to understand homosexuality and altruism and its biases about reproduction, intimacy and care are also examined. I explore the developing technologies of shared kind (qua Haraway (2015)) that consider the *sine qua non* of the microbial sociality and multispecies co-evolution and draw on Haraway’s notion of *companion species* and more–than–human naturecultural kinships as drivers of co-evolution.

*CandidaHomo* ecologies are then woven through queer kinship that is biological but not genetic, embodied but not essentialist. Queer families of choice founded on more–than–biological inclusivity challenge dominant gene-centric kinship theories (Weston 1997; Xhonneux 2016). These structures are intimate, performative and more–than–human (Weaver 2015), emerging from necessity and constantly co-created. They are discussed here as a potential technology for living-with our microbial companion species and mess mates. In addition to families of choice, I consider Luce Irigaray’s figuration of eros as a visceral and tactile “technology” for re-orienting relatedness and care towards more–than–human kind, always already formed through impersonal intimacies and caresses. Finally, two artworks, *Surface Dynamics of Adhesion* (2015) and *The Unsettling Eros of Contact Zones* (2015) are discussed as material–semiotic resolutions of shared kind, presenting the *CandidaHomo* ecology as a palpable, sensual and troubling multispecies community.
3.1.3 Key terms and definitions

**Chosen family** Non-biological kinship bonds, deliberately chosen networks of support in LGBT communities, consisting of friends, partners and ex-partners, biological and non-biological children, and others who provide kinship support. Chosen families may live together in a single household, or they may be spread through a larger community (Weston 1997; Gates 2016).

**Community** An assemblage or association of populations of two or more different species occupying the same geographical area and in a particular time (Christian, Whitaker, and Clay 2015).

**Contact sensing** Directional growth response to mechanical cues (Perera et al. 1997). See **thigmotropism**.

**Cooperation** The process where groups of organisms work or act together for common or mutual benefits. Also, any adaptation that has evolved, at least in part, to increase the reproductive success of the actor’s social partners (Gardner, Griffin, and West 2001).

**Eros** A “sexual or carnal ethics,” based on touch and a constitutive force for generating difference (Cohoon 2011, 481). Developed by Luce Irigaray (Irigaray 1992; 1993) from Lévinasian alterity.

**Group selection** Natural selection that works to the advantage of a population (the group) rather than individuals (Wilson 1975).

**Kin** A group of persons descended from a common ancestor and so connected by blood-relationship; a group of persons related biologically or by marriage (Dykstra 2009).

**Kind** A class or category of things distinguished by common characteristics and attributes possessed by its members; a group of people united by shared beliefs, interests, or character.¹⁷⁷

**Kin selection** “A process by which traits are favoured because of their beneficial effects on the fitness of relatives” (West et al. 2006, 599).

**Kinship** The recognized ties of relationship, by descent, marriage or ritual that form the basis of social organization (Dykstra 2009); also “a technology for producing the material and semiotic effect of natural relationship, of shared kind” (Haraway 1997a, 53).

**Social behaviour** A behaviour that “has consequences for both the actor and the recipient. Social behaviours can be categorized according to the fitness consequences they entail for the actor and recipient” (West et al. 2007, 598); the emergent field of microbial social evolution discusses the role of such behaviours between microbes and their evolutionary implications.

**Social evolution** The evolution of social behaviours and traits (Alexander 1974; West et al. 2006). Although originally only intraspecific, the role of interspecies symbioses is increasingly considered part of social evolution theory.

**Social selection** A process of “interactive intraspecific competition for resources” (West-Eberhard 2014, 502) and a broad mechanism of natural selection that encompasses sexual selection (West-Eberhard 1983), where mates and fertilisation success are resources subject to competition.

**Thigmotropism** “The ability of cells to orientate growth with respect to features of the physical environment” (Kumamoto 2008, 669).

3.1.4 Contribution to Knowledge

The discussion in this chapter makes several contributions to understandings of CandidaHomo communities:

1. This is the first study discussing *C. albicans* sociality outside microbiology or immunology. The poetics of the microbiome have infiltrated popular culture, philosophy and contemporary art, however, the social interactions between species and evolutionary implications outside the human realm are rarely considered. Several recent environmental humanities scholars have examined multispecies microbiopolitics, including those involving malaria, lichen and avian flu and the intersections of HIV with human sexuality are well examined in queer theory. However, apart from Alissa Overend’s discussion of leaky gut discourse, *C. albicans* has been largely ignored. Here, I explore the sensuality of *C. albicans* biological and cultural experiences with other microbes and extend it into queer and environmental humanities discourses.

2. This is one of the first considerations of the experiences of *C. albicans* as a commensal within the human body, as the majority of scientific papers position it as a virulent invader. In public health discourse and marketing, it is exclusively perceived as a voracious antagonist. I draw attention to the importance of multispecies biofilms for *C. albicans* survival and note the gaps in *C. albicans* research.

3. This research examines the heteronormative and biogenetic biases in dominant theories of social evolution and argues that their focus on genetic relatedness and monospecies populations is gene-centric and individualistic and should be reconfigured in light of the ubiquity of host-microbiome co-evolution.

4. This research articulates a lineage between evolution and queer families of choice and examines the possibilities that non-biogenetic markers of relatedness offer for reconfiguring more–than–human kinships. I contaminate anthropocentric discussions of kinship with candida, arguing that candida has “been in the garden from the get go,” as Haraway (2003, 5) would say.

5. I adapt Luce Irigaray’s understanding of eros as a tactile and sensuous generative space of difference to a more–than–human model of kinship founded on touch. The CandidaHomo ecology is eros and we are at the same table. How can we eat well together?

6. Finally, this is the first research to explore the sociality of *C. albicans* through contemporary art-making. Previous representations of *C. albicans* sociality have been materialised exclusively through scientific experimentation or music. Several artworks have engaged with the microbiopolitics of consumption, using vaginal secretions and yeast isolated from human beards to ferment bread and beer, which would include Candida spp. However, they have been conceptually anthropocentric, exploiting the organisms to provoke discussions about human
sexuality and consumption. The implications of being a multispecies community are secondary. The two artworks examined in this chapter explore the social behaviours of a single member of the human microbiome and the microbiopolitics of production and consumption.

3.2 The Science of *C. albicans* Sociality

3.2.1 Introduction

*C. albicans* dwells primarily in multispecies, interkingdom communities on the surfaces of human cells and abiotic materials and interacts socially with hundreds of other fungal, bacterial and archaeal species. These interactions are almost exclusively described in terms of their implications for human health and so research has focused on mechanisms by which *C. albicans* planktonic cells colonise and invade human tissue and are recognised by and evade immune cells and the interspecies interactions that enhance or reduce virulence. However, as Neville, d’Enfert, and Bougnoux (2015) observe, what we consider to be invasive and virulent behaviours are defensive responses to attack by the host immune system from the perspective of *C. albicans*. Therefore, I explore how *C. albicans* negotiates and experiences its social interactions and describe them from the perspective of *C. albicans* rather than from the *H. sapiens* experience. Further, I focus on the social dynamics in multispecies biofilms because these biofilms are the predominant lifestyle for *C. albicans* in the human body.

*C. albicans* social interactions differ in each niche and over time due to the complex variety of abiotic and biotic factors in each niche (Figure 72). It is important to note that little is known about the conditions that occur in most of the myriad, diverse niches within the human body. However, abiotic factors typically include nutrient and energy availability; hormones; chemical toxins; pH and temperature; shear forces and fluid dynamics; and the presence of biomedical and cosmetic devices such as dentures, catheters, piercings or antibiotics (Kumamoto and Vinces 2005; Chandra and Mukherjee 2015; Feraco et al. 2016; Höfs, Mogavero, and Hube 2016). Biotic factors include whether the *C. albicans* is surface-associated or planktonic; different surface topographies of human cells and tissue (for example, vaginal and gut mucosa, skin, teeth, tongue); peristalsis; microbiome species composition and diversity; signalling and metabolic chemicals produced by other microorganisms; diverse human immune cells; and biofilms.
The Unsettling Eros of Contact Zones

Figure 72 An overview of the complexity of chemical and physical interactions between *C. albicans*, *H. sapiens* epithelial cells and Gram-positive bacteria in two of the many ecological niches; (A) oral cavity, (B) female reproductive tract. Reproduced by permission from Morales and Hogan (2010, fig. 1), under the terms of the Creative Commons Attribution License.

3.2.2 Haptic sociality

As an organism without eyes, in a lightless, crowded environment, *C. albicans* navigates and communicates with its body. It literally grasps the biotic and abiotic elements of its environment (Chaffin 2008), including other *C. albicans* individuals, human cells, other microbial species and abiotic materials. These encounters occur through three mechanisms: chemical signalling between cells, including quorum sensing, mechanical contact with biotic and abiotic surfaces, and aggregation and adhesion to cells and surfaces. The complex and plastic cell wall is the point of contact for these mechanisms. As Chaffin (2008) observes,

> the surface is the contact point between the microbe and host surfaces including phagocytic cells. It may also be the target of antibody response. In addition, commensal microbes found in biofilms on mucosal surfaces or microbes in biofilms formed on medical devices and prostheses have surface interactions. For *Candida albicans*, the cell wall has been a consistent focus of attention over the last several decades. (496)

As can be seen in Figure 73, the cell surfaces are not smooth but contain cell wall proteins (CWP) and microfibres that extend into the environment and mediate cellular interactions (Gow and Hube 2012). The cell wall proteins secrete enzymes, sense chemicals, surfaces and temperatures, transport materials inside the cell, attach to proteins on the surfaces of other cells and adhere to the surfaces of abiotic materials. External signals are recognised by *C. albicans* cells if their cell wall has a corresponding receptor (León-Sicairos et al. 2015), in which case the chemical or physical signal binds with the receptor like a lock and key (Figure 74). This physical joining activates internal metabolic cascades and the subsequent phenotypic responses may be chemical or physical, for example, the expression of farnesol, transition between cell forms, adhesin production, iron acquisition or production of biofilm ECM. Cottier and

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178 The wall of white yeast cells is composed of the polysaccharides chitin (poly-β-(1,4)-N-acetylglucosamine) (5%), β-glucan (60%) and mannann (mannoproteins) (35%) (Gow and Hube 2012; Cabral et al. 2014; Poulain 2015).
Mühlischlegel (2009) note that the *C. albicans* cell wall is extraordinarily complex, containing more than 500 distinct proteins and that “even if a number of sensors have been identified, their method of interaction with the ligand and the structural modifications required to transduce the signal are largely unknown” (6).

Figure 73 Transverse sections of the association of *C. albicans* cells and epithelial cells. The arrows indicate the interconnections between the fibrillar structure of the yeast cell wall and the epithelial cell surface interdigitations. CA, *C. albicans*; E, epithelium; CW, cell wall. Bar, 0.3 µm. Reproduced from Tokunaga et al. (1990, fig. 2), with permission of Springer.

Figure 74 Diagram indicating the receptors and other ligands in the *C. albicans* cell wall for acquiring different forms of environmental iron. Reproduced by permission from León-Sicairos et al. (2015, fig. 3), under the terms of a Creative Commons Attribution License.
The cell walls of the yeast and hyphal forms have distinctly different cell wall proteins, as shown in Figure 75. Opaque forms also have distinct CWPs that increase their permeability to mating pheromones and cause them to be invisible to host immune cells (Berman 2012). In fact, the composition and distribution of CWPs in the cell wall differ significantly according to the cell form and the environmental niche, suggesting a possible mechanism of cellular differentiation (Soll 2014). However, little is known about the diverse compositions and specific roles of the cell wall in these niches. Hyphal cell walls are enriched with adhesins, proteins that promote adhesion and aggregation. This enrichment is thought to be the result of adaptation to the stresses of the host-pathogen relationship since these genes are not enriched in non-pathogenic Candida species (Gow and Hube 2012; McManus and Coleman 2014; Neville, d’Enfert, and Bougnoux 2015).

Figure 75 C. albicans cell forms morphotypes and cell wall composition. Reproduced by permission from Rizzetto, Weil, and Cavalieri (2015, fig. 1), under the terms of a Creative Commons Attribution license.

Chemical signalling

Quorum sensing (QS) is one of the most common C. albicans intercellular signalling processes (Palková and Váchová 2006). QS describes the secretion and accumulation of a signalling molecule caused by an increase in the density of a microbial population, which leads to a coordinated response by the whole population. Farnesol is the most well-characterised quorum sensing molecule (QSM) produced by C. albicans, although a second (tyrosol) has been described but not well studied (Palková and Váchová 2006; Mallick and Bennett 2013). Farnesol induces and regulates multiple phenotypic transitions and coordinates a range of population-level behaviours, including mating competency, filamentation, biofilm formation, host immune evasion, and colony development (Mallick and Bennett 2013; Hargarten et al. 2015; Jacobsen and Hube 2017). It also mediates several interspecies behaviours, including inducing hydrogen peroxide production, which inhibits bacterial growth and inhibiting filamentation to prevent Pseudomonas aeruginosa attack of hyphae (Peleg, Hogan, and Mylonakis 2010). White cells also secrete E,E-farnesol to

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179 Quorum sensing is the term used to describe this phenomenon in bacteria species. von Bodman, Willey, and Diggle (2008) argue that the behaviour in yeasts should more correctly be called “cell-cell signalling.” However, “quorum sensing” is more commonly used in the majority of research papers.
attract macrophages, within which they are able to survive and eventually escape (Hargarten et al. 2015). Opaque cells do not secrete this chemoattractant and so are able to evade recognition by immune cells.

Synergistic associations that enhance virulence occur via interspecies crosstalk (Figure 76), i.e., each species has receptors that recognise signalling molecules secreted by the other species. For example, such crosstalk can enhance virulence in *P. aeruginosa–C. albicans* hospital-acquired infections, particularly those “linked with colonization of medical devices such as catheters, patients with cystic fibrosis, and burn victims” (Mallick and Bennett 2013, 3). Other associations mutually enhance virulence. For example, *C. albicans* virulence increases in response to an endotoxin (LPS) secreted by *Escherichia coli* and cohabitation increases the virulence of *Enterococcus faecalis, Staphylococcus aureus, and Serratia marcescens* (Mallick and Bennett 2013). The mechanism of synergism in these interactions is unknown but is thought to occur via chemical signalling. Metabolic by-products of *S. gordonii* can be used by *C. albicans* and *C. albicans* produce metabolic by-products and reduce oxygen tension, which enhances survival of *S. gordonii* (Morales and Hogan 2010). A niche specific association occurs in the cystic fibrosis lung between *Staphylococcus aureus* and *C. albicans*, where *S. aureus* signals promote *C. albicans* hyphae formation and then hitchhike on the hyphae into the lung cell wall (Figure 76b) (Jacobsen and Hube 2017).

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180 Synergistic interactions have been of particular interest to human-centric biomedical research (Höfs, Mogavero, and Hube 2016).
Antagonistic relationships also form. *P. aeruginosa* produces phenazines, which chemically suppress the yeast-hyphae transition, adherence and biofilm development and other bacterial species such as *E. faecalis*, *Burkholderia cenocepacia* and *Xanthomonas campestris* secrete substances that inhibit hyphal growth (Mallick and Bennett 2013; Morales et al. 2013). The “normal microbiota” produce signalling molecules that inhibit *C. albicans* filamentation and biofilm formation, produce hydrogen peroxide or organic acids that
are toxic to \textit{C. albicans} or alter the host immune response and compete for adhesion sites (Mallick and Bennett 2013) (Figure 77A). In the vaginal tract, for example, \textit{Lactobacillus} spp. prevent \textit{C. albicans} colonisation by producing inhibitory chemicals, including biosurfactants to which \textit{C. albicans} cannot bind, metabolic by-products such as hydrogen peroxide or lactic acid that lower environmental pH and inhibit reproduction and hyphal formation, or bacteriocin-like substances that suppress \textit{C. albicans} growth (Morales and Hogan 2010; Höfs, Mogavero, and Hube 2016). In fact, Jacobsen and Hube (2017, 327) conclude that the predominance of the commensal yeast form in the gut may be the result of the suppression of hyphal formation by “probiotic and facultative pathogenic bacteria” rather than environmental cues as previously believed. Höfs, Mogavero, and Hube (2016) have similarly concluded that the virulence of commensal \textit{C. albicans} following the use of broad-spectrum antibiotics is largely due to the absence of microbes that produce chemicals that suppress the hyphal transition rather than the absence of resource competition (Figure 77B).

Figure 77 Influence of host microbiota on \textit{Candida} colonization and infection. (A) Commensal bacteria prevent an overgrowth of \textit{C. albicans} on epithelial surfaces through competition for adhesion sites and secretion of the small inhibitory molecule as well as short chain fatty acids (SCFAs), which induce the production of β-defensins and LL-37, respectively. These molecules exhibit protective properties against fungal infections. Furthermore, yeast-to-hypha transition is inhibited by the secretion of quorum sensing molecules (QSM) and by low environmental pH, resulting from the secretion of bacterial metabolic products. (B) In the absence of commensal bacteria, e.g. after antibiotic treatment, \textit{C. albicans} is able to colonize epithelial surfaces and form hyphae. Reproduced from Höfs, Mogavero, and Hube (2016, fig. 1), with permission of Springer.

Adhesion

Conditions at internal human mucosa vary depending on the niche but are generally like a river bed, i.e., a rough surface over which fluid passes (Thompson, Carlisle, and Kadosh 2011). These sites are subject to fluidic shear and peristalsis. Consequently, adhesion to each other, host cells, abiotic surfaces or other microorganisms is crucial for \textit{C. albicans} colonisation and survival in these dynamic and stressful conditions (Nather and Munro 2008; Wartenberg et al. 2014; Höfs, Mogavero, and Hube 2016; Jabra-Rizk et al. 2016).

\footnote{Refer to chapter 2 for a discussion of the GUT cell form.}
Contact is initially mediated by passive van der Waals forces, which move cells into proximity with each other and cells are attracted and repelled by hydrophobic and electrostatic forces (Chaffin 2008; Moyes, Richardson, and Naglik 2015). Adhesion is an active process of connection via adhesins:

*C. albicans* can adhere to itself by flocculation, to other microbes by coaggregation, and to host proteins and cells, e.g., fibronectin. These interactive properties are associated with surface adhesins. The interactions may be between proteins and proteins or between proteins and sugars. The interacting partners may both be cell associated, or the interaction may be between *C. albicans* and a soluble or immobilized host ligand. (Chaffin 2008, 519)

*C. albicans* cells also adhere to dental prosthetics, polystyrenes and resin and the nature of the adherence is dependent on surface structure properties, composition of biomaterials, hydrophobicity and roughness, *C. albicans* CWPs and the surface free energy of the materials (Figure 78). Adhesion differs between strains, although it is unclear why (Noumi et al. 2010).

![Figure 78 Main fungal components or properties and putative host ligands involved in adherence of *C. albicans*. *C. albicans* yeasts (arrowheads) and germ tubes (arrows) adhere to an intestinal villus. Reproduced from Tronchin et al. (2008, fig 6), by permission of Oxford University Press.](image)

Yeast cells adhere to surfaces and the contact induces the transition to hyphae, which are able to explore through a contact sensing process called thigmotropism (Höfs, Mogavero, and Hube 2016). Surface obstructions (0.79μm ± 40nm) stimulate mechanosensitive receptors in the hyphal cell wall to undergo

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182 “Atoms at a free surface experience a different local environment than do atoms in the bulk of a material. As a result, the energy associated with these atoms will, in general, be different from that of the atoms in the bulk. The excess energy associated with surface atoms is called surface free energy...[Negligible for macroparticles], the surface to volume ratio becomes significant [for nano-size particles], and so does the effect of surface free energy.” (Dingreville, Qu, and Mohammed 2005, 1827)

183 Exposure to an electrical field (galvanotropism) has a similar effect on hyphae, but however, this phenomenon is poorly characterised (Cottier and MühlSchlegel 2009).
conformational changes, causing the cell membrane to stretch and re-orient (Kumamoto 2008; Cottier and Mühlschlegel 2009; Jacobsen and Hube 2017). Thigmotropism allows hyphae to discriminate between types of surfaces and respond to its environment (Figure 79). The hyphal tip also senses the hydrophobicity of the surface, which may contribute to this discrimination (Cottier and Mühlschlegel 2009). On semi-solid surfaces, hyphae traverse ridges and valleys and enter small grooves and crevices such as those between epithelial cells (Figure 80), whereas contact with a solid surface induces biofilm formation (Kumamoto 2008). Jacobsen and Hube (2017) note that the mechanisms of thigmotropism are still poorly defined, despite their importance in physical interactions, virulence and biofilm formation.

Figure 79 Thigmotropic responses of *C. albicans*. Reproduced by permission from Brand and Gow (2009, fig. 2), under the terms of a CC BY 3.0 license.

Figure 80 Scanning electron micrographs of *H. sapiens* intestinal cells (enterocytes) after 3 hrs of incubation with *C. albicans*. B, *C. albicans* filament projecting between adjacent enterocytes. C, higher magnification of boxed area in B, more clearly showing the intimate association between the enterocyte microvilli and the distal end of the *C. albicans* filament. Scale bars: A, 5 µm; B, 2 µm; C, 1 µm. Reproduced by permission from Wiesner et al. (2002, fig 3).
Autoaggregation

Palková and Váchová (2006) observe that microorganisms, including C. albicans, rarely behave as individuals. C. albicans cells adhere to each other and “autoaggregate,” forming colonies. Cells generate progeny that co-locate and accumulate in colonies, which tend to be genetically similar, due to high proportions of clonal reproduction and population viscosity. Quorum sensing can coordinate and synchronise behaviours within colonies. It has long been assumed that the most significant social interactions within a C. albicans population are cooperative because they are predominantly clonal (Odds et al. 2006). Bougnoux et al. (2008, 2) observe that “in the majority of studies on the population structure of C. albicans, the samples complexities were largely neglected. C. albicans was treated as a homogeneous population.” Consequently, selection pressures within colonies and populations are poorly characterised and populations could be competitive and/or antagonistic.

In vivo survival depends on being a diverse community of specialised cell forms and types. Consequently, colonies are a diverse mix of yeast, pseudohyphae, hyphae and opaque cell forms, which are distributed throughout a colony. This diversity provides advantages to the whole population, including protection from environmental harm, immune attack, antifungals and microbial antagonists, adhesion to surfaces, improved ability to colonise new locations, nutrient and resource provision and storage, resistant subpopulations and functional specialisation (Odds et al. 2006; Palková and Váchová 2006; Jacobsen et al. 2008; Wartenberg et al. 2014). For example, regulated yeast cell death (YCD) is essential for the long-term survival of the colony population, with new cells using compounds released from dying cells (Palková and Váchová 2006).

The smooth, white, “butyric” colonies grown on agar consist predominantly of yeast forms and are typically considered to be the normal or “wild-type” colony form (Figure 81). Other colony morphologies are typically described as “abnormal” or “deviant” (Homann et al. 2009). However, if diversity of cell forms is essential for in vivo survival, then these homogenous, “wild-type” colonies are abnormal and the diverse, “deviant” colonies are the norm. Consequently, growth and observation conditions are crucial and in vitro studies that prevent colony or surface-associated multicellular development foreclose typical in vivo behaviours and generate distorted understandings of C. albicans. Palková and Váchová (2006) suggest that studies that treat colony populations as undifferentiated will modify population-level behaviours or miss the differentiated behaviours of subpopulations. This is a classic example of Barad’s intra-active apparatus.
The diversity of forms in *C. albicans* colonies enables rapid adaptation to environmental conditions (Palková and Váchová 2006). Microvariation\(^\text{184}\) and microevolution\(^\text{185}\) can follow, principally through the loss of heterozygosity.\(^\text{186}\) Consequently, different strains occur occasionally within the same host and unique strains tend to persist in each host (Odds et al. 2006), implying co-adaptation between *C. albicans* and *H. sapiens* individuals (Odds et al. 2006; Jacobsen et al. 2008). However, research predominantly describes variation of strains and isolates between human hosts or host niches rather than between strains within the same host (Odds et al. 2006; Odds 2010). Such microvariation and microevolution are largely explained through natural selection mechanisms, specifically Red Queen host-pathogen interactions. Although studies have observed behavioural differences between strains (Brand et al. 2008; Brand and Gow 2009) and 13 “clades” have been identified globally (McManus and Coleman 2014), few studies have explored intra-species population dynamics or selection pressures between strains in the *CandidaHomo* ecology or considered how social evolution might work within and between *C. albicans* colonies and populations. This research would contribute to knowledge of virulence and commensalism dynamics as well as host-pathogen and microbiont dynamics more broadly.

**Coaggregation**

Although interkingdom coaggregation between *C. albicans* and bacteria is common, little is known about the mechanisms or dynamics (Arzmi et al. 2015). However, coaggregation tends to be dependent on cell type. For example, Nobbs and Jenkinson (2015, fig. 1) note that *S. gordonii* will adhere to *C. albicans* hyphal cells but not to the yeast form. The bacteria “form micro-societies in some areas and are able to cross-link the *C. albicans* hyphae...suggesting a process of adherence followed by aggregation and accumulation” (489). Similar behaviour, where the bacteria attach to the hyphae but not the yeast, has been noted by

\(^{184}\) Microvariation refers to small but detectable changes in DNA sequences among isolates (Odds et al. 2006).

\(^{185}\) Microevolution refers to population-level evolution rather than speciation (Allaby 2015c).

\(^{186}\) Loss of heterozygosity may result from chromosome deletion or loss, recombination and/or gene conversion events (Odds et al. 2006)
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Shirtliff, Peters, and Jabra-Rizk (2009) within *C. albicans* and *S. aureus* biofilms and by Metwalli et al. (2013) within *C. albicans* and *S. mutans* biofilms (Figure 82). Arzmi et al. (2015) note that aggregation contributes to the integration of new microbial species into biofilms, facilitating the exchange of genes and metabolic products that in turn supports survival of microorganisms against variable environmental conditions. Furthermore, coaggregation has been shown to improve the colonization of oral epithelial cells by *C. albicans*...*Escherichia coli* or *Klebsiella pneumoniae* increases the adherence and subsequent attachment of *C. albicans*. Preadherence of *Streptococcus sanguinis* and *S. gordonii* to the hard surfaces of the oral cavity provides adhesion sites for *C. albicans*, which supports the importance of interkingdom interactions in the oral cavity. (3)

Consequently, researchers of multispecies biofilms assert that interkingdom coaggregations promote biofilm formation (Shirtliff, Peters, and Jabra-Rizk 2009; Morales and Hogan 2010; Morales et al. 2013).

![Figure 82 SEM of mature mixed biofilms formed on hydroxyapatite (a major component and essential ingredient of normal teeth), demonstrating *S. mutans* aggregation with *C. albicans* hyphae. Bacterial cells attach in chains as they adhere to and wrap around the hyphae. Bars 10 µm. Reproduced by permission from Metwalli et al. (2013, fig. 2), under the terms of a CC BY 3.0 license.]

3.2.3 Multispecies biofilms

Although Arzmi et al. (2015) and Elias and Banin (2012) note that microbial interactions are necessarily associated with multispecies biofilms, the majority of *C. albicans* biofilm research has been undertaken on monospecies biofilms. The dynamics within multispecies biofilms, including communication and resource use, reflect those of a community rather than a single species population, providing mutualistic and synergistic benefits for the occupants (Elias and Banin 2012; Mallick and Bennett 2013). For example, Mallick and Bennett (2013) have observed that in the oral cavity, commensal *Streptococcus* species adhere to *C. albicans* cell wall proteins and adhesins, thereby enhancing biofilm formation. *Streptococcus* species can also absorb protein components from saliva resulting in increased adherence and hyphal development in *C. albicans*, strengthening the biofilm and providing additional places for *Streptococcus* cells to bind. Extracellular matrix

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187 With the notable exception of oral biofilms, where *C. albicans* is commonly associated with oral bacteria, including *Streptococcus* spp. and *Actinomyces oris* (Zijnge et al. 2010; Mallick and Bennett 2013).
production by *S. epidermidis* can inhibit penetration of antifungal drugs such as fluconazole in mixed-species biofilms. (3)

In addition, the ECM secures bacterial cells and provides water channels through which liquid flows distributing nutrients and signalling molecules that facilitate communication between the cells (Figure 83) (Metwalli et al. 2013).

![Figure 83 Scanning electron micrographs of mature mixed biofilms of *C. albicans* and *S. mutans* grown on extracted human teeth, demonstrating the tight coadherence between *C. albicans* hyphae (red arrows) and *S. mutans* cells (blue arrows). Microbial cells can be seen embedded in a matrix of extracellular polymeric substance with water channels (white arrows) through which liquid flows distributing nutrients and signaling molecules that facilitate communication between the cells. Bars 10 µm. Reproduced by permission from Metwalli et al. (2013, fig. 1), under the terms of a CC-BY 3.0 license.](image)

The dynamics in multispecies biofilms depend on the species involved. For example, Cavalcanti et al. (2016) observed differences in the spatial and temporal distribution of species within dual- and tri-species biofilms that included *Streptococcus oralis*, *Actinomyces oris* and *C. albicans* (Figure 84). *S. oralis* cells were spatially integrated throughout the dual-species biofilm, whereas *A. oris* cells were mainly associated with the upper layers. Cell numbers were augmented 15 to 20-fold in both dual- and tri-species biofilms, however, *A. oris* cell numbers were lower in the tri-species biofilm. Biofilm volume was augmented more by the *S. oralis–C. albicans* association than the *A. oris–C. albicans* association or the tri-species association, which led Cavalcanti et al. (2016) to conclude that *S. oralis* was able to outcompete *A. oris* in a tri-species biofilm with *C. albicans*. Although the authors note that cell numbers are “not a meaningful indicator of biomass because multi-cellular hyphal filaments were the major morphological components of *C. albicans* 24 h biofilms” (Cavalcanti et al. 2016, 4), they formed their conclusion based on this metric, which is the
standard measure of fitness. Furthermore, although they observed cooperative coaggregations for all species, they relied on competitive natural selection.

Figure 84 Dual-species or triadic biofilms formed on salivary pellicle-coated denture acrylic resin after 1.5 or 24 h incubation. Microbial cells were labelled by FISH probes for S. oralis (red), A. oris (green) or C. albicans (blue). Reproduced from , by permission of Oxford University Press.

Elias and Banin (2012) argue that consideration of the social dynamics within multispecies biofilms is neglected yet crucial since they have synergistic effects on the phenotype of the entire community. Not only do the social interactions within multispecies biofilms make them more resistant to antibiotics, toxins and the host immune system, individual cells within the biofilm exhibit distinct phenotypes from planktonic cells, including increased adherence, biofilm formation ability and enhanced virulence (Berman 2012; Nobile and Johnson 2015; Scaduto and Bennett 2015). In addition, the structure of C. albicans biofilms promotes aerobic conditions and enhances respiratory metabolism, even in anoxic conditions (Morales et al. 2013). Elias and Banin (2012) observe that interactions among species within a biofilm can be antagonistic, such as competition over nutrients and growth inhibition, or synergistic. The latter can result in the development of several beneficial phenotypes. These include the promotion of biofilm formation by co-aggregation, metabolic cooperation where one species utilizes a metabolite produced by a neighboring species, and increased resistance to antibiotics or host immune responses compared to the mono-species biofilms. These beneficial interactions in mixed biofilms have important environmental, industrial, and clinical implications. (990)

Although multispecies biofilms generate population-level phenotypic plasticity and genetic microevolution has been reported, the selection mechanisms within the CandidaHomo ecology are largely unexamined (Elias and Banin 2012).
3.3 Queering Kin Selection

3.3.1 Introduction
Social behaviours such as cooperation (aka reciprocity) and altruism have been described as the greatest problem for dominant evolutionary theories (West et al. 2006). These theories suggest that an organism will only behave in ways that maximize its individual fitness, i.e., provide the best chance for survival and reproduction of its genes, and, therefore, individuals will always try to gain a fitness advantage by exploiting common goods and services. As Hamilton (1964b, 19) describes, “the social behaviour of a species evolves in such a way that in each distinct behaviour-evoking situation the individual will seem to value his neighbours’ fitness against his own.” According to Hamilton, cooperative behaviours are evolutionarily unstable since the production of goods or services is costly and reduces the fitness of the individual producing them. “Cheaters” gain the benefits of production but do not incur the costs and are therefore more fit and likely to survive to reproduce than the individuals producing the public good (von Bodman, Willey, and Diggle 2008). Cheaters will come to dominate the population and social goods will no longer be produced. The community breaks down under the pressure of social conflict and populations collapse (von Bodman, Willey, and Diggle 2008). This is known as the “tragedy of the commons”—the “situation when individuals would do better to cooperate, but cooperation is unstable because each individual gains by selfishly pursuing their own short-term interests” (West et al. 2006, 598).

Clearly, however, social behaviours are ubiquitous since all species have microbial consortia. In fact, social behaviours and symbiotic relationships are fundamental to evolution (Margulis 1995; 1999). However, microorganisms have been largely ignored by evolutionary theory (Xavier 2016) and the co-evolutionary dynamics of mutualists and commensals have only started to be explored (von Bodman, Willey, and Diggle 2008). The dynamics of microbial consortia such as biofilms, where hundreds of species cohabit, cannot be explained by current theories of kin selection. Even holobiontism argues that host-microbiome communities must be considered as co-evolved multicellular individuals and, therefore, ultimately falls back into the dominant model of individualism. Clarke (2016) has suggested that selection acts at multiple levels in microbial consortia and proposes that they be explored through a combination of “neighbour-structured, contextual, and social evolution models which allow us to understand the fitness of microbial cells as constitutively social or context dependent” (209).

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188 Reciprocity describes the production of goods or services by both individuals that provide mutual benefits. Altruism describes behaviours by an individual that result in other individuals receiving fitness benefits (West et al. 2006).
189 Mutualists are individuals of different species that both exhibit improved fitness through association, whereas commensals are individuals that benefit from an individual of another species without affecting the fitness of that individual (Shirtliff, Peters, and Jabra-Rizk 2009).
190 von Bodman, Willey, and Diggle (2008) provide a comprehensive survey of the brief history of the study of cell-cell signalling and coordinated behaviour in microbes.
3.3.2 Microbial sociality

Emerging literature on microbial communities has demonstrated that microbes are intensely social, communicating and cooperating to perform a wide range of multicellular activities, such as dispersal, nutrient acquisition, protection, biofilm formation and developmental quorum sensing (Palková and Váchová 2006; West et al. 2006; Smukalla et al. 2008; von Bodman, Willey, and Diggle 2008; Elias and Banin 2012; Nobbs and Jenkinson 2015; Rendueles and Ghigo 2015; Barker and Bronstein 2016; Xavier 2016). These social behaviours (also called microsociobiology (Xavier 2016)) are regulated by intercellular chemical and physical signalling and are the rule, not the exception. The production of these so-called “common goods and services” is therefore fundamental to microbial survival (von Bodman, Willey, and Diggle 2008; Barker and Bronstein 2016). Such behaviours are considered to be costly for the “producer” because they are resource intensive and open to “exploitation” (von Bodman, Willey, and Diggle 2008). Given the legacy of competitive individualism throughout the twentieth century, evolutionary theory has struggled to understand how such behaviours between individuals of the same species, or even community, evolve and are sustained, let alone between species (Barker and Bronstein 2016).

West et al. (2007, 598) describes a behaviour as social “if it has consequences for both the actor and the recipient.” They include intra- and interspecies communication, cooperation and competition, resource use and habitat construction. For microbes, these population-level behaviours are coordinated primarily by the exchange of chemicals, like farnesol, between cells (von Bodman, Willey, and Diggle 2008; Czárán and Hoekstra 2009; Popat et al. 2012). Originally identified as the mechanism of homeostatic population control, this chemical exchange or “quorum sensing” coordinates other social behaviours, including morphogenesis, biofilm formation and interspecies communication (Czárán and Hoekstra 2009). As the numbers of organisms secreting the QS molecules increase, the concentration of the molecule in the environment and the strength of the signal increases, cueing more cells to engage in whatever behaviours are induced by the molecule, including mating, hyphal formation or inhibition or biofilm formation. QS molecules are considered to be “public goods” and “have both direct and indirect fitness benefits” (West et al. 2007, 598).

3.3.3 Kin selection theory

According to kin selection theories, an individual will only engage in cooperative or altruistic behaviours in order to improve the fitness of genetically related individuals or kin because one’s own genes can be indirectly reproduced by improving the survival and reproductive chances of a relative who shares those

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Further, the nascent field of “microsociobiology” explicitly draws on gene-centric sociobiology (Greenberg 2001; Parsek and Greenberg 2005; Nadell, Xavier, and Foster 2009; Connell, Whiteley, and Shear 2011; Xavier 2016), implying that microbial social behaviours are gene driven rather than the complex negotiation of gene, behaviour and environment.
genes (West and Gardner 2010). This is described as “inclusive fitness,” where your kin’s fitness is included in your own. “Hamilton’s Rule” posits that an individual is likely to perform a costly action if

\[ C < rB \]

where \( C \) is the cost in fitness to the actor, \( r \) is the genetic relatedness between the actor and the recipient, and \( B \) is the fitness benefit to the recipient (West et al. 2006). According to this rule, a gene that expresses a behaviour is under selection if it provides a fitness benefit to the population, measured by population growth. Kin selection discourse conflates behaviour with genes—relatedness is genetic and fitness is defined by fecundity—thereby consolidating the gene-centric individualism of early twentieth century evolutionary theories and naturalising biogenetic kinship. However, West et al. (2007, 598) notes that “classifying specific behaviours can be complicated because of the difficulties in measuring the long-term consequences for fitness, and because behaviours can have multiple consequences.”

So, if an individual is willing to share but only with genetic relatives, how does that individual recognise another individual as having the same genetics? Hamilton (1964a; 1964b) argued that “close genetic kin” can be recognised either by “active” kin discrimination or the ability to recognise “close genetic kin and non-kin” and/or via the “passive” mechanism of limited dispersal, also known as viscous population:

If he [sic] [an individual] could learn to recognise those of his [sic] neighbours who really were close relatives and could devote his [sic] beneficial actions to them alone an advantage to inclusive fitness would at once appear. Thus a mutation causing such discriminatory behaviour itself benefits inclusive fitness and would be selected. In fact, the individual may not need to perform any discrimination so sophisticated as we suggest here; a difference in the generosity of his [sic] behaviour according to whether the situations evoking it were encountered near to, or far from, his [sic] own home might occasion an advantage of a similar kind. (Hamilton 1964b, 21–22)

Both mechanisms apply in monospecies microbial communities since clonal reproduction ensures that genetic relatives will always be in close proximity. Wall (2016) argues that

kin recognition involves specific biochemical interactions between a receptor(s) and an identification molecule(s). Recognition specificity, ensuring that nonkin are excluded and kin are included, is critical and depends on the number of loci and polymorphisms involved. After recognition and biochemical perception, the common ensuing cooperative behaviors include biofilm formation, quorum responses, development, and swarming motility. Although kin recognition is a fundamental mechanism through which cells might interact, microbiologists are only beginning to explore the topic. (143)

Classic kin selection therefore does not explain the co-evolution of genetically unrelated multispecies communities, like those within the CandidaHomo ecology. However, von Bodman, Willey, and Diggle (2008) argue that relatedness (\( r \)) is only relevant for the genetic loci of the social trait, not the whole genome. An
individual therefore would recognise expression of the social trait (phenotype) as a marker of kinship, rather than the gene per se—the green beard hypothesis, which has been proposed as an explanation for social behaviours, such as aggregation and biofilm formation that occur between individuals with low or no genetic relatedness (West and Gardner 2010). A single gene (or tightly linked genes) that expresses a cooperative behaviour and has a distinctive phenotypic marker can be recognised by other individuals with the same marker (such as a “green beard”). Such a behaviour can provide an evolutionary advantage even if the individuals are not genetically related (Smukalla et al. 2008). Individuals are less likely to cheat/exploit the common good or service because the trait signals kinship. However, green beard genes are thought to be extremely rare and have largely been considered insignificant as evolutionary mechanisms (West and Gardner 2010).

Green beard genes may, in fact, be common in microbes and may help explain the ubiquity of social behaviours and the evolution of commensal and mutualistic multispecies communities. For example, Smukalla et al. (2008) recently demonstrated that the gene responsible for autoaggregation (flocculation) in *S. cerevisiae* is a green beard gene. Yeast flocculation is a social behaviour that is exploited by humans for beer and wine production and wastewater treatment. The genes that express the adhesins in *C. albicans* cell walls, which promote auto- and coaggregation and biofilm formation, are homologs of the *S. cerevisiae* green beard gene (Li and Palecek 2003) and, therefore, could also be green beards. Such research has yet to be conducted in *C. albicans* but might explain the coaggregation of *C. albicans* with other microbes and the evolution of biofilm formation. However, “although kin recognition is a fundamental mechanism through which cells might interact,”192 it is cannot explain the complexity of social behaviours within multispecies biofilms.

Concurrent with Hamilton, Wynne-Edwards (1963, 623) proposed that selection acts “simultaneously at the two levels of the group and individual.” Drawing from his observations that animals sacrifice individual fitness to maintain population density, he argued that group survival is dependent on social behaviours, especially altruism. He concluded that intergroup selection could override selection for individual advantage and although the mechanism was unclear, “relatively simple genetic mechanisms can be evolved whereby the door is shut to one form of selection and open to the other” (626). Although Wynne-Edwards’ theory lost traction because the genetic mechanism was unclear, it has re-emerged as part of the Extended Evolutionary Synthesis, supported by E.O. Wilson’s theory of the superorganism and embraced by holobiontism (Clarke 2016). However, West, El Mouden, and Gardner (2011, 240) argue that group selection only leads to group adaptations in special circumstances and the results of extant group selection models can be explained by kin selection. Jablonka and Lamb (2014, 37) also assert that “today, models of

192 (Wall 2016, 143).
group selection are as gene centric as any other models of natural selection.” Consequently, neither kin or group selection explain the complexity of social behaviours within multispecies biofilms.

### 3.3.4 Biofilms

Rendueles and Ghigo (2012) and Elias and Banin (2012) discuss the social dynamics that occur within multispecies biofilms (Figure 85). They argue that the few studies on multispecies biofilms have shown that multispecies cohabitation is usually advantageous to the whole community. Myriad cooperative behaviours occur within mixed-species biofilms, including colonization and aggregation, metabolic commensalism, altruistic niche construction and interspecies induction of physiological changes to confer resistance to toxins and antimicrobial (Elias and Banin 2012). Different species coaggregate to form or join the biofilm and the proximity within biofilms promotes metabolic commensalism, i.e., the consumption of metabolic by-products generated by different species, although Holcombe, O’Gara, and Morrissey (2011, 799) note that it may be difficult to determine if metabolic commensalism is “accidental eavesdropping” or “evolved interactions.” Members of biofilms can provide niche conditions that promote the survival of other species via the physical structures of the biofilms themselves or by altering pH or oxygen. For example, anaerobic microbes survive deep within biofilms because surface oxygen is consumed by the aerobes (Elias and Banin 2012). In addition, extracellular enzymes secreted by different species in the biofilm can induce transient changes in the morphology or physiology of neighbouring species, including enhanced resistance to antibiotics or host immune cells.

![Figure 85](image)

**Figure 85** Individual and social processes occurring within biofilm communities. Microorganisms within a mixed biofilm interact physically, via quorum sensing and/or metabolically. Interactions can be synergistic or antagonistic and result in phenotypic changes, such as increased resistance to antimicrobial agents or to host defence systems, spatial distribution or emergence of variants (SCVs). Nutritional interaction can be either competitive or cooperative.” Reproduced from West et al. (2006); Elias and Banin (2012, fig. 4), by permission of Oxford University Press.
West et al. (2006) argue that the common assumption that biofilms promote cooperative behaviours because they provide population or species level benefits may be incorrect. They maintain that competition is important in biofilms and assert that “the population is at risk from invasion by selfish individuals (cheaters or free-loaders), who do not cooperate but can obtain the benefit of cooperation from others” (597). Elias and Banin (2012) concur that competition over nutrients and antagonistic signal manipulations play a central role in defining the structure and activities of multispecies communities, but the mechanisms are not well understood given the focus on monospecies systems. They draw on the “survival of the fittest”/scarce resources argument, suggesting that “when bacterial species are crowded together and resources are limited, members of a biofilm community are more prone to competition. Often, one species will invade a specialized nutritional niche already occupied by another species with similar nutritional requirements.” (996). Griffin, West, and Angus (2004) agree and note that scale is important to consider in multispecies biofilms:

> a significant interaction between relatedness and the scale of competition, with relatedness having less effect when the scale of competition is more local. More generally, the scale of competition is likely to be of particular importance for the evolution of cooperation in microorganisms, and also the virulence of pathogenic microorganisms, because cooperative traits...have an important role in determining virulence. (1024)

However, social behaviours in multispecies communities are both spatially and temporally contingent. A behaviour may be cooperative or exploitative depending on its context, as indicated in Figure 86, and Barker and Bronstein (2016) argue that its costs and benefits cannot be assumed or prescribed.

Figure 86 A cooperation-conflict space is useful to visualize and evaluate social interactions. Organisms will move through this space under changing ecological contexts, such as development, resource availability, population size, and species interactions. “The shading around the points is meant to convey the possibility of small changes in cooperation-conflict in any context.” Reproduced by permission from Díaz-Muñoz et al. (2016, fig. 2), under the terms of a CC BY 4.0 license.
Several researchers have proposed that multispecies biofilms are multicellular individuals since they demonstrate spatial specialisation and coordinated behaviour (Elias and Banin 2012; Clarke 2016). However, Clarke (2016) argues that cooperation and competition in biofilms are subject to selection at multiple levels and it is more appropriate to consider biofilms as ecologies comprised of diverse niches in which selection acts at multiple levels (Figure 87). She suggests that a combination of mechanisms be considered when discussing social evolution in multispecies biofilms, including kin selection, neighbour-modulated fitness, biological marketing theory and contextual analysis.

Figure 87 Ecological and evolutionary parameters operating within biofilm communities. Group effects: increase bacterial fitness compared to solitary life. Cooperation: biofilm bacteria can actively cooperate to increase their individual fitness. Kin competition: under high stress and low nutrient conditions, kin can become a source of competition and enhance spatial segregation. Genetic expression profiles: planktonic bacteria express different genes than those expressed by biofilm. Genotypic and phenotypic diversification: Due to competition, different variants can spontaneously appear within biofilm communities. Reproduced by permission from Rendueles and Ghigo (2015, fig. 1)

3.3.5 Heteronormative kinship

Classic kin selection theories define “kinship” as genetic relatedness, reinscribing the gene as the unit of heredity. They draw from the heteronormative biases of sexual and natural selection and assert that genetic replication drives evolution. Fitness is measured by population growth, firmly placing reproductivity and fecundity as the central poles of kin selection. Wilson (1971) reinforced these heteronormative biases in his development of kin selection in social insects, drawing on the reproductive hierarchy of the modern synthesis and Hamilton’s rule, where all are subordinate to the reproductive couple. Wilson’s explanation

193 The challenges of discussing microbial social behaviours and potential for anthropomorphisation are evident in the use of human hands to indicate cooperation and kin competition in Figure 87.
of the “altruistic” behaviours of asexual workers in honeybees and other social insects focused on behaviours that support the sexual triad of queen, drone and larvae. Workers that contribute to the reproduction of the hive through niche construction, food collection, grooming and hygiene are designated female because they have the same genes as the individual who produces the larger gametes, has sexual intercourse with the male (smaller gametes) and lays eggs.\textsuperscript{194} Social behaviours such as niche construction, food collection and care are described as “altruistic” (aka “sacrificial”), reinforcing gender biases of females as unselfish and altruistic.\textsuperscript{195}

Heteronormative evolutionary theories argue that social behaviours not directly involved in gene replication evolved to help raise the progeny of the “replicating” couple, improving their chances of survival. However, this argument reduces reproduction to gametes, presumes that progeny can only be produced sexually and designates highly complex and responsive social behaviours necessary for survival as nonreproductive. It also neglects pleasure and intimacy.\textsuperscript{196} Joan Roughgarden (2012) discusses pleasure as an alternative to punishment in social interactions and notes that Darwin frequently mentioned how pleasure is expressed. He writes, ‘With the lower animals we see the same principle of pleasure derived from contact in association with love. Dogs and cats manifestly take pleasure in rubbing against their masters and mistresses, and in being rubbed or patted by them. Many kinds of monkeys...delight in fondling and being fondled by each other, and by persons to whom they are attached.’ (2297)

Contemporary theories of kin and group selection allow for reciprocity and altruism but tend to be competition focused. The legacy of scarcity economics is glaringly apparent in the language of kin selection, which describes social behaviours as “common goods and services” open to “cheating” or trading according to a “biological marketing theory” (Barker and Bronstein 2016). Capitalist economic theories of competition for goods and services and scarce commodity exchange inscribe social interactions as “tolerated theft,” “diminishing returns” and “exploitation” (for example, in Figure 88). Cooperative dynamics are punitive, “sanctioning” community members who don’t comply. Population growth measures of “fitness” reflect and reinforce social and economic progress as GDP. Such models do not allow for alternative economics of custodianship, communal tenure, crofting, not-for-profit lending, gifting, pleasure or play.

\textsuperscript{194} The workers do not produce gametes at all, so can they be “female,” if female is defined by gamete size?
\textsuperscript{195} Refer to chapter 1 for a discussion of gender bias in sexual selection theories.
\textsuperscript{196} Elizabeth Grosz (2008) discusses the evolutionary possibilities of sensation and pleasure and Jeffrey Cohen (2012) argues that evolution is productive excess.
Figure 88 Capitalist economies of individualism and competition are the material-semiotics of contemporary theories of kin selection. The exploiter provides no reward or service in exchange for the commodity it takes from the shared partner and competes with the mutualist to obtain this commodity. Reproduced by permission from Barker and Bronstein (2016, fig. 1), under the terms of a CC BY 4.0 license.

Developed during the cold war and reinforced during the war on terror, they reinscribe “natural” kinship as biologically, genetically, evolutionarily “self” and “non-self.” However, if kin recognition is phenotypic—how we look, smell, behave—and spatial—those closest to you—the CandidaHomo ecology is kin all the way down. Considering nonreproductive traits as acts of kindness that enhance the survival of species other than our own reconfigures theories of kin selection. These theories, driven by individualism and discrimination between kin and not-kin, seem unable to comprehend the productive possibilities of difference. A theory of kin selection based on more-than-genetic, multispecies community driven by commensalism rather than altruism, kind-ness rather than cooperation, companion species rather than spite and response-ability rather than green beards, would, of necessity, be extraordinarily complex. In fact, such a theory is of necessity.

3.4 SELECTING KIND

3.4.1 Introduction
Queer kinship is, for the most part, non-biogenetic (Weaver 2015). Often rejected by their biological families, queers form families of choice, i.e., families based on intimacy and community (Weston 1997). These families may include biogenetic kin but are usually “intensifications of community ties” and “modes of enduring relationship” (Butler 2002, 37), uncoupled from genetic relatedness and sexual reproduction. Not rooted in biogenetics, queer kind create their own recognition systems—intra-active, non-genetic green beards. Such systems offer opportunities to rethink biogenetic kin and kin selection, re-orienting to

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197 It is worth noting that Barker and Bronstein (2016, 2) “focus on cases where the mutualist and exploiter are different individuals exhibiting pure behavioral strategies, rather than a single individual that switches roles (a mixed strategy).” Do individuals ever exhibit “pure” behavioural strategies? Don’t we all “switch roles”?
the performativity of social behaviour and choice, temporal and spatial contingency, intimacy and kindness. Queer kinships are more–than–human, generous configurations that include other species, reproductive technologies and cultural institutions—companion species, as Haraway would say. Such kinships have ambiguous markers. This section explores the performative sensations of queer kinships, the material-semiotics of living-with, and the naturecultural intimacies through which more–than–human queer kind emerge. Human language, scale and vision are de-centred to traverse the generative tangibility of the CandidaHomo ecology.

The dominant figuration of kinship as “blood ties,” i.e., heteronormative, biogenetic relatedness contiguous across time and space, is founded on biological assumptions about self and not-self, sex, sexuality, race and nation (Levine 2008; Cohler 2014; Wilson 2016). It has been reinforced during the nineteenth and twentieth century by notions of reproductivity, individuality and competition inherent in sexual and natural selection theories and re-inscribed by gene-centric kin selection theories and eugenics (Cohler 2014).

“Natural” kinship is understood to be heterosexual reproduction, biological lineage, “survival of the fittest” and “it’s us or them.” Kinship becomes a “structure of exclusion” and, therefore, inclusion (Hird 2004, 219). As Maddee Clark (2015) argues, there is an ongoing materialdiscursive relationship between sexuality and nation, which is used to justify war rape, eugenics programs, “stolen generations,”

198 exclusionist national policies, facial recognition surveillance and biometric security, the war on terror and “illegal aliens,” socio-economic inequality and environmental extinction. “Us or them” is couched as a biological imperative, where “keeping it in the family” ensures survival in a hostile world.

3.4.2 “Natural” kinship

In The Elementary Structures of Kinship, Claude Lévi-Strauss (1969) articulated a “natural” kinship that hinged on the relationship between biology, sexuality and “clan.” Couched in a framework of primitivism, biological determinism, post-WWII eugenics and cold war nationalism, Lévi-Strauss’ “natural” kinship reinforced heteronormative and gene-centric understandings of family and nation and was widely acclaimed (Butler 2002). David Schneider has argued that “American kinship” [conflates] the order of nature, which invokes the ‘shared substance’ of blood, and the order of law, based upon a customary ‘code for conduct”’ (quoted in Weston 1997, 3). This “natural” kinship re-inscribed the central dogma and the intense reconfigurations of post-war Europe, Japan and the US and the cold war. Subsequent wars and global migrations aligned and re-aligned nations politically, ethnically, racially, colonially, economically, technologically, religiously.

198 This term refers specifically to an Australian government policy of forced removal of indigenous children from their families during the twentieth century, and more broadly to government sanctioned eugenics programs during the nineteenth (Read 2006). This policy continues, framed as “child protection.”
The anthropological study of kinship emerged during the 1960s and 1970s, contemporaneous with this global instability, and gender, sexual and racial emancipation and the environmental and peace movements (Wilson 2016). Robert Wilson (2016) claims that a distinction between “physical” and “social” kinship was important for British social anthropology during the 1960s, although he does not discuss why. Surely anthropology and evolutionary biology, scholarly disciplines interested in cultural and biological reproduction, would have been deeply affected by the naturecultural instabilities and reconfigurations of the period. Gene-centric kin selection theory would undoubtedly have calmed social and anthropological anxieties about the apparent disintegration of family and environment, the migration of postcolonial subjects and war refugees and fears of environmental collapse (qua Rachel Carson) and nuclear holocaust.

Tensions between “natural” and “cultural” kinship continue post-911, reflecting contemporary anxieties about migration, race, sexuality, gender, reproduction and biotechnological chimerism (Butler 2002; Franklin and McKinnon 2002; Haraway 2016). Australia is currently experiencing a resurgence of the xenophobia and heteronormative nationalism that underpins our culture as articulated by Clark (2015). Nash (2004, 1) argues that the “geneticized genealogy” provided by companies such as 23andme, “produces new versions of genetic kinship.” Do they really, or do they just reiterate and reassure? Kath Weston (1997) for example, queries which body fluids/substance count when considering kinship and how long they have to be in the body and Haraway (2003) laps up the more–than–human exchange of fluids and DNA between herself and her dog. Hird’s (2004) and Casid’s (2011) discussions of hybridity, mosaicism and chimerism destabilise anthropocentrism and microbiomes undo us all.

3.4.3 Queer kinship
Lévi-Strauss’ account of “natural” kinship has subsequently been rejected, including by Lévi-Strauss himself (Butler 2002; Wilson 2016). Kinship that relies on biogenetic categories excludes other existing and potential systems for recognising relatedness (Butler 2002; Hird 2004; Pidduck 2009) that disrupt bioessentialist “categories of law and nature” (Weston 1997, 3). Of course, a vast diversity and specificity of kinship structures have existed for millennia, using a multiplicity of naturecultural markers (Wilson 2016). Carol Stack (1974) for example, describes the “personal kindred” relationships formed by African Americans during and since slavery to cope with the murder of their biological families and subsequent 400 years of systemic and institutional racism. Many Indigenous Australian societies recognise kin as a complex of “moiety,” “totems” and “skin,” which include biological, cultural, environmental and spiritual markers (Palmer 2016). Of particular relevance to this discussion, are the non-biological communities of care formed by gays and lesbians during the AIDS crisis of the 1980s. Rejected as deviant and diseased by their biological kin, gays and lesbians could not rely on “blood ties” and actively sought connections to help them stay alive or grieve their loved ones (Weston 1997). These communities and many, many others, including

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199 Refer to Australians Together (n.d.)
transnational migrations, first nations legacies, war zones, adoption and fostering, are kinships that operate at the limits of biogenetics, where “nature” breaks down and “culture” takes over.

Kinship is “no longer conceptualized as grounded in a singular and fixed idea of ‘natural’ relation, but is seen to be self-consciously assembled from a multiplicity of possible bits and pieces” (Franklin and McKinnon 2000, 14). Sarah Franklin and Susan McKinnon (2002) discuss the tenuous hold on kinship and relatedness in the face of contemporary biotechnologies, including assisted reproductive technologies (ARTs) and genetic and tissue engineering, which biologically hybridise individuals and species. Butler (2004) argues that queer kinships constitute a “break-down” of traditional kinship that not only displaces the central place of biological and sexual relations from its definition but gives sexuality a domain separate from that of kinship, which allows for the durable tie to be thought outside of the conjugal frame and thus opens kinship to a set of community ties that are irreducible to family. (127)

Queer kinships are biologised though ARTs, where explicit negotiations of sperm, ova, uterus, sex intersect with economics, technology, race, gender, naming and passing (Levine 2008; Mamo and Alston-Stepnitz 2015). Of course, queers have always unsettled biogenetics: lesbians often brought children from previous relationships into their chosen families, gay men donated sperm to lesbian women, gay couples cohabited with lesbian couples to raise offspring. Kinship has always been performative: ongoing, daily practices of relation, a doing rather than a being (Schneider 1984; Butler 2002; Xhonneux 2016). As Lies Xhonneux (2016) suggests, we constantly create kin and can never automatically know who counts as kin. Queer domesticity includes other species as kin (Weaver 2015) and Haraway (2008) argues that domestication makes kin of us all.

Doing kinship does not disrupt the notion of “natural” kinship in and of itself, however. Not only has altruistic kin selection been repeatedly used to explain the evolution of human homosexuality (Zietsch et al. 2008) but families of choice can reinscribe heteronormative structures (Jones 2009). Duggan (2002, 179) argues that the neo-liberalisation of the queer community reasserts a middle-class white suburban sensibility, a “homonormative” sexual politics that “does not contest dominant heteronormative assumptions and institutions but upholds and sustains them while promising the possibility of a demobilized gay constituency and a privatized, depoliticized gay culture anchored in domesticity and consumption.” Such notions enfold temporary and public acts of queer sex and intimacy within a heteronormative monogamy, supported by legislation that restricts acts of sodomy and polyamory to domestic and private spaces (Eng 2010). Further, Butler (2002) cautions against the homonormativity that lurks in calls to legalise same-sex marriage, arguing that such calls legitimise discriminatory heteronormative kinship structures, force the illegitimacy onto someone else, and foreclose other possibilities for relatedness. Butler acknowledges her own ambivalence about her caution but urges a
political criticality that examines not just the boundary, but the need to draw boundaries. David Eng (2010, 36) notes the “racialization of intimacy” that has “shaped the geographies of family and home” (Weaver 2015, 349) and Deborah Cohler (2014, 126) asserts “the dependence of an anti-identitarian, anti-utopian queer theory on unarticulated whiteness.”

In addition, despite the potential for queer ART to disrupt naturecultural bioessentialism, the increasing use of assisted reproductive technologies by queers to have “own” children also reinscribes heteronormative biogenetic kinship (Butler 2002; Mamo and Alston-Stepnitz 2015). Chateauneuf and Ouellette (2017) observe that biogenetics and adoption are deeply entangled. It is understandably easier for a couple (who can afford it) to use ARTs for a child or for queer single women to “pass” in those places where only heterosexual single women can access them. However, multiparental, polyamorous and international formations that have long enabled queers to have children require complex cultural, social and emotional negotiations that continue to be unrecognised and unsupported (Eng 2010; Wesling 2011).

Many definitions of kinship, including calls for marriage equality, assume a temporal or spatial permanency, a constant proximity (Dykstra 2009). As Butler (2002, 37) describes, “whatever relations qualify for kinship enter into a norm or a convention that has some durability, and that norm acquires its durability through being reinstated time and again.” Schneider (1984) values the “enduring solidarity” of kinship. Similarly, Michael Morris (2015) describes the commitment declarations at “ecosexual” marriage ceremonies to be vital for challenging anthropocentrism and creating more–than–human kin. If kinship is doing, an intra-active performativity, neither temporal or spatial endurance are essential and a radical reframing of the spatiotemporality of kinship in light of the contemporary scale of environmental devastation is necessary (Rose 2008; Ensor 2012; Haraway 2016). If we disentangle genealogy and intimacy to allow for contingent and momentary alliances, we “locate the seeds of a different queer politics that makes even fleeting, faceless contacts also count as practices of relating, ones that disrupt recognition” (Weaver 2015, 357).

Elizabeth Povinelli (2002) argues that physical intimacy and love have been reduced to heterosexual and anthropocentric family formations, despite the more–than–humans with whom we have co-evolved and cohabit. Consequently, re-orienting to these companion species may be a strategy for “recuperating intimacy as a productive category” (Weaver 2015, 352). Such more–than–human kinships exceed human language and sensation. If we take re-orienting to companion species seriously, haptic and nonvisual intimacies that exceed their roles as pet within human households, like the butt sniffing between dogs, must also be taken seriously (Weaver 2015). Such politics are a tactic for responding to the enormity of

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200 This “unarticulated whiteness” in queer theory and activism, despite its claims of intersectionality, and the entanglement of race and sexuality has been noted and challenged by multiple scholars. Refer to Eng, Halberstam, and Muñoz (2005); King (2009); Muñoz (2009); Eng (2010); (Wesling 2011); Cohler (2014); Muñoz (2015) among others.

201 Of course, this depends on the types of kinship claims made.
climate change and mass extinction and opens us to the impersonal intimacies and response-able haptics of more–than–human kind (Ensor 2017).

Heather Davis (2015) draws on Klein’s 2014 figuration of “kinship with the infertile” as “the beginning of a queering of social reproduction...that is less focused on individual reproductive capacity,...toward a love and care that extends outward, beyond one’s immediate biological family” (239). Such a kinship obliges us to acknowledge our fantasy of an apocalyptic future, a radical singularity of mass extinction and environmental collapse. We are compelled instead to recognise the anti-reproductivity of global extinctions in the herenow, the deep spacetime of environmental toxicity and the “slow suffering that has already begun” (243), that human reproductivity and overconsumption have caused. Such human-induced devastation is justified by recourse to human exceptionalism that recognises only genes and proximity as markers of kinship, where altruism and reciprocity are treated as exceptions to individualism and competition and naturalised by neo-Darwinian “survival of the fittest.” Can’t we be more kind than this? Can’t we be more generous in who counts as kin and who gets to eat at the table?

3.4.4 Eros

In the desire for a queer kinship, we must not lose touch with the bodies through which we connect. Kinship is done by bodies. Luce Irigaray’s conceptualisation of eros as an ethical encounter firmly grounds Lévinas’ ethics of difference in embodied intimacy, in the caress. In *The Fecundity of the Caress*, Irigaray (1993) configures eros as rebirth of self and other. She rejects Lévinas’ eros as an anti-social encounter between two that leaves the other as other and procreates a third individual. She argues that “we are at least three,” and the caress of “at least three” generates difference, not individuality (quoted in Cohoon 2011, 482). The caress opens Lévinas’ radical alterity from the visuality of the face–face relation to the faceless and the sensual. Surfaces become thresholds that enable “fluid exchanges,” reciprocities that trouble self. Irigaray’s caress is “inherently reciprocal,...a call to coexist” (Cohoon 2011, 485).

In caressing, touch renews the openness to each other, a re-circulation of sensation that generates a commensal pleasure, a “feeling otherwise” (486). Eros is a fecundity that proliferates radical difference, not a variant of the same, not procreation (Irigaray 1993; Chanter 1995; Cohoon 2011). It is highly specific, converging on the loci of the caress and so cannot totalise the other. The caress is spatially and temporally ephemeral, quanta of difference that cannot represent the world, cannot be universalised (Parker 2015). The caress of eros is ephemeral, fleeting, exciting and invigorating. It is the stroke, the tickle that stimulates

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202 I do not argue here for a biopolitical human population control.

203 Parts of this section are adapted from “HumanThrush entanglements: *Homo sapiens* as a multispecies ecology” (Bates 2013).

204 I have relied on translations of Irigaray’s French texts.
laughter only if performed by an other, quickly, gently, unpredictably. It is the sensual, affective desire for interconnection and intra-action that exists simultaneously and paradoxically alongside perception of difference and desire for autonomy (Cohoon 2011).

Bodies subject to Irigarayan eros exist as potential energy, in states of immanent becoming–with (Cohoon 2011). Matter is a generative opportunity, where membranes are “zones and processes of differentiation” (Neimanis 2016, 13) and differentiation spawns difference. Although Irigaray’s eros is founded in an irreducible sexuate difference, she avoids essentialising sexual difference since the other she describes is *sexed*, not *the other sex* (Cohoon 2011). She, therefore, does not foreclose queer eros. However, Irigaray herself remains firmly heteronormative and humanist: “cultivating our sexuate belonging inclines us to respect and cultivate transcendence, first, towards a differently sexuate human and, then, towards any sort of otherness, especially that of living beings” (quoted in Parker 2015, 116). It is also important to note that Irigaray categorically rejects the possibility that asexuality is generative: “sexuate belonging implies a transcendental dimension that does not exist in a *mere* asexual body” (Irigaray quoted in Parker 2015, 116, emphasis added). However, if the caress is localised and specific, surely it is always already queer—sexuate and asexual, as the haptic encounters of candida demonstrate.

Tim Morton (2015) extends Irigaray’s eros to all beings and ecologies, arguing that ecologies and their components can never be categorically measured as they are in constant formation and generation. Eros offers a queer, ecological ethics, as creative, fluid “work” that re/generates subjects. This work is not comforting or comfortable. It is friction that activates, irritating and unsettling, attracting and repulsing. As Barad (2012b) describes:

> All we really ever feel is the electromagnetic force, not the other whose touch we seek. ...electrons, which lie at the farthest reaches of an atom, hinting at its perimeter, cannot bear direct contact. Electromagnetic repulsion: negatively charged particles communicating at a distance push each other away. That is the tale physics usually tells about touching. Repulsion at the core of attraction. (209)

The caress of eros is electromagnetic repulsion, a sensual, interstitial “etc,” an already always becoming–with. It is impatient and restless, in constant flux, “the most extreme experience of sensation” (Irigaray 1992, 19). Irigaray (2011, 137) argues that

> if touch remains always invisible as such, some parts of our body, that are particularly concerned by eros, are also invisible. It is especially the case for women whose mucous membranes are the most sensitive parts affected by an erotic awakening and touching.

So, by definition, eros extends to the more–than–human, despite Irigaray’s humanism, extends to candida, who dwells in those sensitive mucous membranes, invisibly caressing and whose entire membrane is a sensor “affected by erotic awakenings and touchings.”
3.5 **Caressing Kind**

Exploring the relationship between the contact zones and eros of the *CandidaHomo* ecology led to the production of two artworks, *Surface Dynamics of Adhesion* (2015) and *The Unsettling Eros of Contact Zones* (2015). These artworks weave and reweave the complex material-semiotics of candida social encounters, haptic performativity, multispecies contact zones, companion species co-evolution and the ephemeral, unsettling and sensual intimacies of *CandidaHomo* cohabitation. *Surface Dynamics of Adhesion* (*SDA*) explores the eros of surfaces and technologies of containment and *The Unsettling Eros of Contact Zones* (*TUEoCZ*) invites viewers to ingest and digest the microbiopolitics of *CandidaHomo* commensalism.

3.5.1 **Surface Dynamics of Adhesion**

Encased in a series of acrylic boxes, living candida grows in a pattern (Figure 89) adapted from the first drawing of the organism by Charles Philippe Robin in 1853 and reminiscent of patterns popular on the wallpaper of parlours and art galleries in Europe at the time (Bates 2015b). The candida grows on blood agar, a growth medium that contains the blood of the human artist. The work is hung on the gallery wall as a dado rail, a horizontal border approximately one metre from the floor (Figure 90). The acrylic containment frames the artwork as an un-still-life and minimises the risk of contamination or infection.

![Figure 89: Surface Dynamics of Adhesion, 2015. Installation detail. Living *C. albicans* on artist’s blood agar. Photo by author.](image)

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205 Parts of this discussion are adapted from “We Have Never Been Homo Sapiens: *CandidaHomo* Naturecultures” (Bates 2015c).

206 A dado rail is a decorative frame that separates protective panelling on the lower part of the wall (the dado or wainscot) from the upper part of a wall, which was often covered with expensive wallpaper or artwork (Dado 2006).
Surface Dynamics of Adhesion is an intra-active apparatus that performs and reconfigures the eros of the CandidaHomo ecology. Although initially constrained by a patterned stencil (Figure 91), candida is free to roam across and penetrate the surface of the agar. Growth on artist’s blood agar enables an interspecies eros, caresses between “at least three”\textsuperscript{207}—human blood cells, agar (polysaccharides extracted from algae) and candida bodies proliferate into a flourishing communion. This fecund performativity is consumed by the human viewer and by the candida, which rapidly disrupts the pattern (Figure 92). This work grasps the spaces and surfaces which contain us—domestic rooms coated with decorative paper and photographs, the framed treasures of art galleries and museums and the beige standardisation of public buildings.

\textsuperscript{207} Irigaray quoted in Cohoon (2011, 482).
Figure 91 *Surface Dynamics of Adhesion*, 2015. Artwork preparation showing patterned stencil. An emulsion of living candida cells is applied to the surface of acrylic stencils laid on artist’s blood agar plates and incubated overnight at 30°C. Photo by author.

Figure 92 Living candida resisting constraint, *Surface Dynamics of Adhesion*, 2015, install detail. Photo by author.
Surface Dynamics of Adhesion is a material-semiotic eros of fecund fluidity that both incites and upsets the urge to sterilise. Antagonism towards disease-causing microbes intensified in the second half of the nineteenth century after John Snow identified environmental transmission of cholera as the cause of epidemics in London 1854/55 and Louis Pasteur and Robert Koch formalised studies of pathogen transmission and virulence (Sangodeyi 2014). Diseased bodies were integral to the emerging clinical science of medicine, which measured, classified and contained these bodies (Foucault 2003). The subsequent biopolitical figuration of the diseased body as physically, intellectually and morally corrupt marks a historical shift in the organisation of knowledge (Foucault 2003; Smith 2007). Bruno Latour (1988) argues that human and pathogen were co-constituted by this biopolitics.

A mechanised “Pasteurian ethics” emerged, founded on a microbiopolitical regime that “configured microbes as elements to be eliminated so that human polities might be cultivated” (Paxson 2008, 16). Europe, particularly Victorian England, became obsessed with hygiene; understandable, given the devastation of repeated plagues and appalling sanitation caused by urban intensification (Shail 2007; Smith 2007). “Appropriate human behaviours vis-à-vis microorganisms” were prescribed, including transmission, vaccination and consumption (Paxson 2008, 17). Once under control, “pure” social relations could proceed—“relations that would not be derailed by microbial interruption, that could be predicted and thus rationally ordered” (17).

The assumption that a diseased body is also morally unclean is deeply culturally embedded and well-articulated by Smith (2007) in Clean: A History of Personal Hygiene and Purity. In addition, Shildrick’s (2001, 72) observation that “the outward appearance of an ailing body may be taken as the sign of an inner deficiency of will, or prior moral dereliction,” intersects with Grosz’s (1994b, 203) claim that “women’s corporeality is inscribed as a mode of seepage.” Thrush has long been considered to be a sign of moral weakness: “there is also a popular opinion, that vaginal discharges have their origin in constitutional or local debility; hence a complaint of this kind is denominated a ‘Weakness’” (Jewel 1830, 2). In his 1830 treatise on leucorrhœa (aka fluor albus, the white flow, “whites”), Jewel laments this phrasing as “an error in practice” (2), meaning that the physiology of the condition, which he describes as “general and local excitement” (38), is unrelated to “constitutional or local debility,” and therefore the denomination “Weakness” is moral, not physical. We now know that candida is the most common cause of leucorrhœa (Bankar et al. 2012), but at the time, it was attributed to

a highly nutritious diet, and the free use of wines, spirituous or fermented liquors; violent exertions of the body, such as dancing; pyrexia, or fever, and exposure to cold. In short, such complaints may arise from any unnatural activity in the vascular or nervous systems. (Jewel 1830, 38; my emphasis)
According to Jewel then, vaginal discharge may not be a moral weakness, but it is caused by “unnatural activity.” The activities that Jewel describes as “unnatural” reflect religious puritanism and assumptions about gender and class.

The production of *Surface Dynamics of Adhesion* is scientia sexualis: surveillance and manipulation of candida reproduction and social interactions. Emerging from scientific protocols within a laboratory, the work depends on the fecundity of candida and its affinity for surfaces, aggregation and biofilm formation. Optimum growth conditions are provided to maximise cell numbers, which are isolated, extracted, concentrated, cleaned and emulsified (Figure 93). The purified cells are then applied to a nutrient-rich growth medium that includes human blood extracted from the artist. Cell proliferation is simultaneously encouraged (by nutrient availability) and discouraged (by human blood). Blood is extracted from the artist (Figure 94) to colour the agar and inhibit excessive overgrowth. Artist’s blood agar plates are prepared in custom–designed containers (Figure 95) and the candida applied to the agar using a resist printing technique commonly used in the mass production of wallpapers: a stencil is laid on the agar surface and emulsified living candida is rolled evenly over the surface (Figure 96). The plates are incubated overnight at 30°C, during which time the stencil resists candida growth and a living pattern emerges.

![Figure 93 Clean and purified emulsion of candida cells prepared for artwork and applied to artist’s blood agar plate. Cells were grown in SDA broth, concentrated by centrifugation and washed in DDI. Photos by author.](image)

208 Antigens in human blood induce germ tube formation but inhibit adhesion, as does human serum (Ding et al. 2014; Everest-Dass et al. 2017).
Figure 94 Blood is extracted for artist’s blood agar plates. Photo on left reproduced by permission from Benjamin Warner; photo on right reproduced by permission from Tiffane Bates.

Figure 95 Preparation of artist’s blood agar plates for *Surface Dynamics of Adhesion*. Photos reproduced by permission from Benjamin Warner.

Figure 96 Resist printing process for *Surface Dynamics of Adhesion*. The plastic stencil disciplines the candida into the desired pattern and the roller is used to apply the candida emulsion evenly across the surface. Overnight incubation at 30°C encourages growth. Photos reproduced by permission from Megan Schlipalius.
The Unsettling Eros of Contact Zones

Surface Dynamics of Adhesion ensures that human social relations are not “derailed” by candida’s social relations. Instead, it disturbs “pure” social relations, wrestling with continuing legacies of hygiene, aesthetics, sexuality and gender. The work was inspired by the homonymy of “floccing” and “flocking,” where the first is the social behaviour of aggregation performed by microorganisms, including candida, and the second is the process of depositing many small fibre particles (flock) onto a surface (qua “flocked wallpaper”). Hence, the human viewer is caught in a circular act of voyeuristic pleasure, attracted by the beauty of the pattern and disturbed by the realisation that it is alive and candida and beautiful and alive and candida... The work collapses interiority and exteriority, an insinuating oscillation between the living organisms coating the surfaces of our domiciles and those dwelling on the surfaces of our bodies, external and internal—the microecologies of intimacy—seething all the way down. It is the dado rail that we both grasp, the mould on the ceiling and in the grout, the fungus creeping up the wall and the bacteria under the toilet seat. It is the herpes on our lips and the acne on our face, the plaque on our teeth and the thrush on our cervixes (Figure 97). Soft, blood-red agar echoes the invisible mucous membranes and the microbial profligation caresses our “most sensitive parts [into] an erotic awakening and touching” (Irigaray 2011, 137). The voyeur’s gaze is turned back on itself, drawn inwards in a dissolute, synaesthetic caress.

The candida is indifferent. Engaged in its own jouissance, it takes advantage of nutrients and warmth, opportunistically reproducing and replicating. In this doing of kinship, it eats and excretes, inhales and exhales and coats the interior of its container with condensation (Figure 98), diffracting transparency and frustrating clarity. The human must get close, bend and twist, shuffle and squint (Figure 99) but can never completely comprehend. Tempted to wipe the condensation away, the viewer is unable to access the interior surface from the exterior and is simultaneously tantalised and thwarted. The candida ars erotica draws a veil and the human scientia sexualis comes away unsatisfied.
3.5.2 The Unsettling Eros of Contact Zones

In eating we are most inside the differential relationalities that make us who and what we are... there is no way to eat and not to kill, no way to eat and not to become with other mortal beings to whom we are accountable, no way to pretend innocence and transcendence or a final peace. Because eating and killing cannot be hygienically separated does not mean that just any way of eating and killing is fine, merely a matter of taste and culture. Multispecies human and nonhuman ways of living and dying are at stake in practices of eating. (Haraway 2008, 295)

Many of the foods we consume are produced with or contain a variety of microorganisms, including the basics: cheese, bread, milk and beer (Bates 2015b, 4). The artwork The Unsettling Eros of Contact Zones (Figure 100) offers bread leavened with candida and baker’s yeast to share (Figure 101), inviting consideration of the microbiopolitics of consumption, our bodies and the food we consume. The bread is
served with commercial brie or camembert, soft cheeses matured by the fungi *Penicillium candidum* and *Penicillium camemberti*. These living organisms coat the cheeses served with the bread.

![Image of bread and cheese](image1.png)

*Figure 100 The Unsettling Eros of Contact Zones, 2015. Installation detail. Organic artisanal white bread leavened with candida and baker’s yeast, brie and hummus, dimensions variable. Photo by author.*

![Image of people and food](image2.png)

*Figure 101 The Unsettling Eros of Contact Zones, 2015. Service still. Photo reproduced by permission from Megan Schlipalis.*
The Unsettling Eros of Contact Zones declares its *ars erotica* upfront: it is experience—consumption will be pleasurable but also disturb. Potential human consumers are advised, verbally and through labels and signage (Figure 102), how the bread was produced—that it was leavened with *C. albicans* and baked at 230°C for 30 minutes to ensure the organism was killed. An informed choice to consume or not to consume must be made. The artwork attends to the ambiguous microbiopolitics of consumption—the decision to consume, awareness (or lack) of what is being consumed, sensations of ingestion and digestion, the futurity of excretion. The consumer is entangled in cognitive dissonance—disconcertingly mindful of the consumed, simultaneously attracted and repulsed (Bates 2015c). Consumption becomes an act of parasitic antagonism (Figure 103).

![Figure 102 Label informing potential consumers of details of ingredients and production method for The Unsettling Eros of Contact Zones, 2015. Photo by author.](image)

![Figure 103 The Unsettling Eros of Contact Zones, 2015. Acts of consumption. Photos on left and right reproduced by permission from Megan Schlipalius. Centre photo by author.](image)
Like *Surface Dynamics of Adhesion*, the consumer correlates the organisms being consumed with those in/on their body and the bodies of those around them. Some choose to not consume and they are not required to do so. Rather, the work invites them to consider why they do not—aesthetics or ethics? My sister, for example, could not bring herself to eat the bread, although she had helped bake it. She spent a day elbow-deep in dough that contained living candida but was unable to cognitively overcome her visceral rejection of the baked bread (Figure 104). She could not reconcile voluntarily ingestion with her lifelong struggle to eliminate candida from her body.

![Figure 104 My sister demonstrating her irreconcilable cognitive dissonance while preparing *The Unsettling Eros of Contact Zones*, 2015. Photo on left by author; photo on right reproduced by permission from Megan Schlipalius.](image)

Like *Surface Dynamics of Adhesion*, *The Unsettling Eros of Contact Zones* is more *ars erotica* than *scientia sexualis*. However, it is deeply implicated in the microbiopolitics of transmission and consumption, through the technoscientific methods and facilities used to produce it, the experiments and documents generated to minimise public health risks and its preparation and public serving. I referred to research to determine that candida could leaven the bread (Thaweboon, Thaweboon, and Tri 2011), conducted carbohydrate catabolism (or fermentation) tests using a standard protocol to determine the fermentation efficiency of the strains used (Reiner 2012) and combined candida with the familiar, industrialised and mass-produced *S. cerevisiae* (baker’s yeast) to ensure a pleasurable flavour experience for the human consumer. *S. cerevisiae* is one of the mainstays of industrial and scientific microbiopolitics and one of our oldest “messmates” (Haraway 2008, 4), having “helped” us to produce bread, beer and wine for millennia (Hamelman 2004).

We have monitored and disciplined its reproduction for thousands of years—caring for “mothers,”

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A “mother” is a fermented mixture of flour and water, containing primarily wild yeasts and lactobacilli, used to prepare sourdough (Hamelman 2004). Mothers are transferred between batches to leaven and develop the flavour of the bread. Note the gendered terminology and its implication of reproduction.
exchanging specialised strains between bakers and brewers and manipulating its evolution for our pleasure. Modern industrialisation and biotechnology have “improved” the efficiency of *S. cerevisiae* reproduction and fermentation and “instant yeast” has reduced the need for the care and maintenance of living cultures. Developed during WWII, “active dry yeast” does not require refrigeration and can leaven bread twice as fast due to higher reproductive rates and more efficient fermentation (Joachim and Schloss). In contemporary Australia, commercial bread is produced using only instant yeast.

To enable safe consumption of the bread, I conducted research to ensure all microorganisms used to leaven the bread were killed by the baking process, including the candida. Killing is a somewhat problematic term for pathogens, as many can seem dead but are merely dormant and a human immune response can be activated by surface moieties unaffected by death (Emerson et al. 2017). “Inactivation” is more commonly used by microbiologists. *C. albicans* is not virulent when inactivated and so the term “kill” was satisfactory for these circumstances and was used to alleviate public anxiety. *C. albicans* is almost universally described as inactivated at temperatures higher than 45–50°C. However, an obscure article by Wiley and Westerberg (1969) about human pathogen survival in composted sewage demonstrated that *C. albicans* is resistant to inactivation by temperature. They found that *C. albicans* “thermal death” occurred when exposed to 80°C for 30 minutes or 70°C for 60 minutes. These temperatures are significantly higher than reported in the pathology literature.

Consequently, I conducted two “kill tests” to demonstrate that candida was extremely unlikely to be able to survive the baking process. Kill Test Series #1 (Figure 105) determined the internal and external temperatures of loaves during baking at an oven temperature of 230° for 30 minutes, which are the baking temperature and duration recommended by the baguette recipe sourced online. I used internal baking thermometers calibrated with laboratory-standard thermometers to measure the surface and internal temperatures of the bread. The average maximum external and internal temperature of loaves were 210°C and 100°C respectively, well in excess of the thermal death temperatures observed by Wiley and Westerberg (1969). Consequently, the process was considered sufficient to inactivate the candida and serve the bread during the exhibition.
Kill Test Series #2 (Figure 106) tested whether any organisms were able to survive baking at 230°C for 30 minutes. Loaves were removed from the oven under sterile conditions and placed in a sterile cabinet. Samples were taken from three surface sites and two internal sites on each loaf. The surface sites were swabbed and samples transferred to Sabouraud Dextrose agar (SDA) plates and SD broth. Small samples of bread were removed from the internal sites and transferred to the broth or rubbed onto the surface of the agar. Inoculated broth and plates were incubated at 30°C and 37°C for three days. Samples were removed at 24-hour intervals from the broth and inspected microscopically for microbial growth. The agar plates were inspected visually for microbial growth at 12 hours, 24 hours, 36 hours and 48 hours. No growth occurred in any of the cultures and most importantly, no candida was evident, confirming that the baking process successfully inactivated candida. Samples of the loaves were stored at -20°C for future reference.
Kill Tests Series #1 and #2 confirmed that *C. albicans* is killed (or at least inactivated) by the baking process and demonstrated that human viewers could safely consume the loaves. As I intended to exhibit the artwork in public and offer the bread for consumption, I compiled a risk management plan, which provided several strategies for mitigating public anxiety about the possibility of infection. These strategies included the prominent display of Biosafety Caution notices (Appendix C) throughout the gallery, attachment of caution labels to the loaves of bread and clear display of cautions on the service table and service staff and gallery attendants were trained to discuss the leavening process with viewers before they consumed the bread. Interestingly, governmental public health officials were much more concerned about potential health risks from the soft cheeses served with the bread, supporting Paxon’s (2013) observations about the contemporary Pasteurisation ethics involved in cheese production and consumption.

Bread production is a sensual, communal process of interspecies separation and alliance. The recipe for this bread was sourced online (Cathy W. 2015), primarily because of its simplicity (only four ingredients) and its ease of preparation—very little kneading is required as the yeast does all the work. The dough is prepared over five hours (Figure 107): “pre-autolysed” for 15 minutes, “fermented” for three 20-minute sessions, quickly “folded” four times between each fermentation session, “bulk fermented” for two hours, weighed and shaped and finally “proofed” for 30 minutes, providing ample time for the living yeasts to catabolise the carbohydrates in the flour.

![Figure 107 The microbiopolitical labour of interspecies fermentation. Photos by author.](image)

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210 Refer to Appendix B.
Thirty loaves were required for service at the exhibition, so I adapted the recipe designed for three loaves for larger batch production, which included increased quantities of ingredients, logistics and assistance to minimise overall production time. Fortunately, I was able to persuade several friends to help mix ingredients and prepare the dough the night before the exhibition (Figure 108 and Figure 109). My sister then spent the following day shaping, proofing and baking. The process became a raucous, joyous proliferation of latex gloves, white lab coats, beakers, petri-dishes, baking oven, thermometers, mixing bowls, scales, timers, flour, water, sugar, bleach, puns, candida, baker’s yeast, human, fermentation, production and reproduction, feeding and killing.

Figure 108 Preparing candida-leavened dough for the exhibition. Photos reproduced by permission from Svenja Kratz.
The Unsettling Eros of Contact Zones has elicited three responses: firstly, people are hesitant to consume the bread, even though the yeasts are killed during baking; secondly, when I presented bread leavened only with baker’s yeast (no candida) during the development of this work, viewers were reluctant to consume it, even though they knew it did not contain candida; and finally, institutions have been reluctant to allow candida-leavened bread to be served in public, despite support from scientific evidence and the very comprehensive risk management plan.

Why are people reluctant to consume candida-leavened bread? The bread looks like “normal” bread and there is no chance of getting an infection. Despite this, the most common response has been immediate and intense disgust. Clearly, this is not just a case of an evolved pathogen disgust, as the bread does not possess any of the “visual, olfactory, tactile or auditory cues that reliably indicated pathogen presence in our ancestral past” (Tybur, Lieberman, and Griskevicius 2009, 105). Rozin and Fallon (1987) have argued that the prospect of ingesting an offensive object causes revulsion and disgust, regardless of its pathogenicity. They found that even brief contact with an offensive object causes rejection of normally acceptable food, i.e., a corruption effect. Haidt et al. (1997, 110) agree, suggesting that some “essence or residue is transmitted.” Candida-leavened bread is an example of this “sympathetic contagion magic,”
where “things which have once been in contact with each other continue ever afterwards to act on each other” (Frazer 1959, 35). Having been in contact with an “offensive object” (living candida) (Rozin and Fallon 1987), the bread elicits a disgust response even though the bread itself does not look disgusting.

Recent studies show a clear, embodied relationship between morality, hygiene and disgust and conclude that disgust evolved as an evolutionary adaption for food discrimination and disease avoidance (Haidt et al. 1997; Curtis 2007; Schnall et al. 2008; Tybur, Lieberman, and Griskevicius 2009; Curtis 2011; Tobia 2014). Although most of these studies acknowledge a social aspect to disgust, disgust is usually couched in evolutionary terms and the studies assume that all human cultures experience disgust in similar ways. However, Haidt et al. (1997) found significant cultural differences in disgust responses and inferred that since disgust is rarely experienced by young children, it must, at least in part, be taught: “disgust may have its roots in evolution, but it is also clearly a cultural product” (111). Therefore, an offensive object is more than just the immediate physical object. It must be conceptually/socially/culturally offensive as well as materially offensive. Hence, candida-leavened bread entangles “pathogen” and “sexual” disgust when faced with due to the metonymy of candida and women’s genitals.

The reluctance to consume bread leavened only with baker’s yeast is a subtler manifestation of the material-semiotics of disgust. This bread was offered in the context of research about candida, in an art gallery with other artworks about (although not containing) candida and visitors knew that I intended to make bread with candida. It is possible that the proximity of the other artworks and my own experimentation with candida caused a sympathetic contagion response described by Frazer (1959). However, it is also possible that the disgust response is not just about proximity, but the affective, imaginative reaction triggered, not by sensory cues or by contact with an “offensive” object, but by “ideational concerns about what it is” (Haidt et al. 1997, 109). The thought that candida could be present in the bread brings about an immediate awareness of all organisms within all bread. Our suspension of disbelief that we ingest fungi, bacteria, molds, etc and that we are in turn consumed by such creatures, our messmates, fails at this moment and all bread, possibly all food, becomes unacceptable.

The Unsettling Eros of Contact Zones is, in many ways, the synthesis of all the other artworks and of this thesis. It is a seriously playful, playfully serious intra-active phenomenon—an incorporation of the microbiopolitics of the CandidaHomo ecology and a (in)digestion of what and who is at stake in this commensal pleasure. It is the attraction and repulsion, the specific caress—the eros of kind (Figure 110).
3.6 CONCLUSION

3.6.1 Summary
This chapter, *Queer Kind*, wove the cat’s cradle shown in Figure 111, untangling the stands of nonvisual, haptic communication, multispecies cohabitation, kin selection, families of choice, impersonal intimacy, eros and the ambiguities of interiority and exteriority, production and consumption that comprise the *CandidaHomo* ecology. The review of current research into *C. albicans* haptic sociality demonstrated that the principal modes of communication within the *CandidaHomo* ecology are tangible—chemical and physical contact zones of sensual semiotics. Quorum sensing and cell wall moieties coordinate population level behaviours and promote aggregation into multispecies communities and biofilm formation. The vast majority of *C. albicans* research is with monospecies biofilms, which cannot provide information about interspecies social behaviours. A small number of studies focused on human health have demonstrated that interkingdom interactions involving *C. albicans* can be mutualistic, antagonistic and synergistic. Very little is known about the social dynamics and selection pressures within biofilms, although biofilm level behaviours have been observed, including antimicrobial resistance. *C. albicans* is an ideal model for understanding the ecological and evolutionary dynamics of interspecies social behaviours within the human body and for reconfiguring individualistic and competitive gene-centric theories of community and kinship.
As discussed, theories of genetic essentialism and individualism have dominated evolutionary theories. Kin selection theory, developed in the 1970s, explains social behaviours such as altruism and cooperation through kin recognition and proximity mechanisms that rely on gene-driven competition and economic transactional models. The theory proposes that an individual is more likely to engage in behaviours that provide a direct benefit if the beneficiary is a close genetic relative. It asserts that genetic relatedness can be recognised, either by a phenotypic trait or population viscosity, i.e., those close to you are more likely to be close genetic relatives. Such an understanding assumes that social behaviours will be exploited and selected against, divides relationships into kin and not-kin and draws on heteronormative kinship structures. However, interspecies social behaviours are the mainstay of microbial interactions and multispecies symbiotic cohabitation is the norm rather than the exception. Consequently, an opportunity exists to reconfigure the gene-centrism and individualism of kin selection for a more diverse, interspecies model of social interaction and relatedness.

Queer families of choice provide an alternative to the dominant biogenetic model of kinship. Queer families recognise kinship as nature-cultural and include the more–than–human. However, families of choice are not inherently radical and homonormativity lurks in calls for same-sex, two by two marriage equality and the use of reproductive technologies to reinforce biogenetic relatedness. Eros offers a sensual, intra-active performative doing of kinship through the body. It is a haptic, more–than–human making of kind with possibilities for impersonal intimacy and heterotopic alliances within the Candida Homo ecology.

### 3.6.2 Takeaways

1. *C. albicans* communicates with and makes meaning of its world through touch via its cell surface. Proteins in its cell wall produce quorum sensing molecules that coordinate population level

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211 Like Butler and Davis, I am concerned about who is left out of these practices and how they reinscribe heteronormative structures of family and kinship.
behaviours, enabling cooperation between individuals. Other proteins sense chemical signals from other species and still others connect to surfaces and differentiate surface qualities.

2. *C. albicans* dwells in multispecies biofilms, which include myriad mutualistic, synergistic and antagonistic social interactions. Little is known about these biofilms, despite being the default lifestyle in the *CandidaHomo* ecology and important for *H. sapiens* health and antimicrobial resistance.

3. Gene-centric theories of kin selection, developed during the cold war period, reinforce cultural understandings of competition, individualism and genetic essentialism as natural behaviours. Social behaviours are attributed to genetic relatedness, reinforcing heteronormative, biogenetic kinship systems.

4. The discovery of the ubiquity of microbial and multispecies sociality has radically changed evolutionary biology and microbiology. Social behaviours are the norm rather than the exception but are not adequately explained through selection theories that rely on individualism, competition and biogenetic relatedness.

5. The nascent study of selection pressures in multispecies microbial biofilms offers the potential for reconfiguring the evolutionary dynamics of cooperation and other social behaviours.

6. Queer families of choice challenge biogenetic kinship systems by emphasising the importance of choice and non-biogenetic relatedness. They demonstrate the heteronormative and biogenetic biases of dominant kin selection theories.

7. Homonormativity and biogenetic relatedness lurk in the depths of queer families of choice, evident in calls for suburban domesticity and “own” children.

8. Queer families of choice include more–than–human kind and haptic modes of intimacy as a matter of course and challenge kin selection theories founded on genetics and species boundaries.

9. The haptic sociality of the *CandidaHomo* ecology can be understood through Luce Irigaray’s figuration of eros as a sensual, intra-active production of kind.

10. Artistic resolutions of *CandidaHomo* kind-making enfold the microbiopolitics of *scientia sexualis* and *ars erotica* to embrace more–than–human caresses and intimacies and the complex ambiguities of microbiopolitical production and consumption.

3.6.3 **Re-stringing the cradle**
And so, on an overfull and unsettled stomach, the cat’s cradle woven in this chapter settles into the final figuration, *Conclusion: Confessions, Commensalism and Dispersal* as a resolution to this *CandidaHomo* entanglement. This conclusion restrings sexual, natural and kin selection and the sexuality, trans* and kind-making of the *CandidaHomo* ecology into the whatnow and wherenext.
Figure 112 Re-stringing the cradle for *Conclusion: Confessions, Commensalism and Dispersal*. Illustration by Furness Jayne (1906, fig. 750).

Figure 113 Preparing artist’s blood agar plates. Photo reproduced by permission from Benjamin Warner.
CONCLUSION: CONFESSIONS, COMMENSALISM AND DISPERALS

CONFESSIONS

I have struggled for much of this project with scholarly and artistic guilt. I lurk in a lineage of feminist scholars and artists who put their bodies on the line, speaking the truths of their bodies. Thrush is not the truth of my body. I do not have chronic candidiasis. I have had vaginal thrush once in my life and that was over 25 years ago. Some of my closest friends and family have suffered from recurrent candida infections and I deeply respect and admire their pain and frustrations. They have generously shared their stories of CandidaHomo worlding and I am grateful. I have also become a confessor for strangers. Whenever, wherever I speak about this work, at least one person gets an intent, sheepish look and lingers. “So…I have never told anyone this…” is a frequent coda to my talks. Almost exclusively by women, these confessions are often humiliating and usually hilarious and always intimate and painful.

I spent several of the early years of this project struggling with inauthenticity. Then I began candida-writing, extending hyphae, dripping, tickling, soothing. Or more correctly, I began transcribing candida worldings, re-presenting the agential cuts made by candida and me in our laboratory living/working together. I realised (shamefully late) that my body is more–than–itself. It is also where it is and what it does and who it does that to—it is an apparatus, a figuration, a cat’s cradle. I try to be a modest witness for candida—growing, caring, nourishing, starving, controlling, manipulating, recording, seeing, killing—I read about it, write about it, make with it, perform with it, discipline it, kill it. There is no authority here, just more stories.212

Candida put their bodies on the line—or more correctly, I put their bodies on the line. They speak the truth of their bodies. They do not confess—they have no shame. They caress the truths of their bodies, extending hyphae, dripping, tickling, soothing, irritating.

RE-STRINGING

The material-semiotics of the apparatuses of C. albicans biology, evolutionary ecology, queer theory and art-making are untangled in this thesis, with each chapter performing a different figuration of the CandidaHomo ecology (Figure 114). The introduction, Matterialisng Candida albicans (Figure 114A), discusses the human body as a queer ecology and the importance of practice-led research in the exploration of this ecology. Chapter 1, Queer progeny: Re-producing sexual selection in the CandidaHomo ecology (Figure 114B), orientates sexuality as the first principle of a queer ecology and unwinds the strands

212 Thanks to Kirsten Hudson for pointing this out.
of sex and reproduction, sexual selection and sexuality. Chapter 2, *Queer affordances: Trans*forming natural selection in the CandidaHomo ecology* (Figure 114C), untangles the threads of bodies and environment, natural selection and trans* theory, exploring the performative affordances of the CandidaHomo ecology and chapter 3, *Queer Kind: Caressing kin selection in the CandidaHomo ecology* (Figure 114D), weaves sensual communications, haptic sociality and biogenetic kin selection through queer families of choice, tracing the eros of multispecies kinships formed in this nonvisual ecology. In each chapter, the cradles collapse and reform into transitory, material-semiotic artistic resolutions in which evolutionary theory rubs up against queer theory, queer theory strokes the biology of candida and candida nudges at evolutionary theory. *Candida* and *Homo* eat at the same table in heterotopic alliances, sporadically moving one place on, hoping to get a clean cup. These alliances, figurations, cradles and apparatuses offer seriously playful and playfully serious re-orientations of the microbiopolitics of CandidaHomo ecologies.

Figure 114 Cat’s cradles of the chapters of *The Unsettling Eros of Contact Zones: Queering evolution in the CandidaHomo ecology*.

This concluding chapter re-strings the cat’s cradle of *C. albicans* biology, evolutionary ecology, queer theory and art-making introduced at the beginning of this thesis into a discussion of intimacy, urgency, commensalism and dispersal (Figure 115). My 2015 exhibition *The Unsettling Eros of Contact Zones, and other stories*, a figuration that re-oriented the artworks described in each chapter into a new ecology is explored. This exhibition was a material-semiotic apparatus and cradle formed by the artworks, the

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213 In reference to the Mad Hatter’s tea party in Lewis Carroll’s *Alice in Wonderland*, to which the Red Queen hypothesis refers.

214 Except for *The Tangled Field* discussed in chapter 1, which was produced in 2016 for the *Femel_Fissions* exhibition at The Block, Brisbane.
gallery, living candida, human viewers and documentation—an ephemeral resolution of CandidaHomo entanglements and a modest gesture of commensalism and alliance. I discuss potential dispersals for these gestures, engage in a slight polemic and conclude with a generous and commensal degustation of kind.

Figure 115 Cat’s cradle of Conclusion: Confessions, commensalism and dispersals.

**THE UNSETTLING EROS OF CONTACT ZONES, AND OTHER STORIES**

The 2015 exhibition, The Unsettling Eros of Contact Zones, and other stories formed a cradle of five of the six artworks discussed in this thesis, Translational Ambiguity Tolerance (TAT), Ereignis, Gelassenheit und Lichtung: A love story (EGL), Control of Cell Morphology in vivo (COCMiv), Surface Dynamics of Adhesion (SDA) and The Unsettling Eros of Contact Zones (TUEoCZ). Viewers entered the gallery directly into EGL and were immediately immersed in the exhibition ecology. The other works were located in a second room, where viewers were free to approach them in any order to weave their own material-semiotic relationships with the artworks and re-orient personal narratives. Each work afforded distinct modes of physical interaction, which guided semiotic and semantic experiences. EGL projected animated images of magnified candida cells onto moving human bodies; TAT invited viewers to sit, play and chat; viewers stood slightly bent (depending on their height) at the COCMiv zoetrope and animated the candida micrographs using their upper bodies; hung at waist height on the wall, SDA required adult visitors to bend close and shuffle across the room; and TUEoCZ invited viewers to ingest the candida and attend to the labour of digestion. Heterotopic alliances were made and remade, attending to CandidaHomo ecologies and the broader microbiopolitics of re-production and consumption.

A catalogue accompanied the exhibition, providing viewers with some guidance. Designed to reflect the aesthetics of a book (Figure 116), the catalogue is an anthology, collecting brief descriptions (textual and photographic) of the artworks, poetry and a short essay generously written by two of my human kin, instructional artworks for preparing SDA and TUEoCZ and photographic timelapse sequences of these artworks being prepared. The content is a combination of scientia sexualis and ars erotica and the book is a reminder of apparatuses of knowledge production and transmission.

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215 The catalogue is provided in Appendix A

199
As discussed in the introduction, the display of living artworks creates practical and institutional challenges. The public display of disease-associated microbes like candida requires an additional layer of biosafety and risk management. Since the exhibition was designed to provide opportunities for gentle encounters with candida and prompt consideration of the microbiopolitics of bodies, it was important that the health of viewers was not at risk. I wanted to unsettle, not endanger. Minimising risk and affording informed consent was critical, given that some viewers may have had compromised immunity. Consequently, the exhibition (and the research) complied with the biosafety and risk management policies of The University of Western Australia and the gallery. The research was conducted according to “Safety in Laboratories. Part 3: Microbiological Safety and Containment” (Standards Australia 2010), The University of Western Australia biosafety and ethics approvals were obtained and a Risk Management Plan (RMP) was prepared, approved and displayed at the exhibition for viewers to examine (Figure 117).²¹⁶

²¹⁶ The RMP is provided in Appendix B.
The RMP describes how to minimise risk of exposure to the living candida in SDA and includes a section on minimising public anxiety about ingesting the candida-leavened bread of *The Unsettling Eros of Contact Zones*.\textsuperscript{217} Biosafety Caution notices were prominently displayed around the gallery and a caution was included on the label displayed with the bread.\textsuperscript{218} The notices and label informed viewers that living candida was in the gallery and dead candida was in the bread and advised them to approach the gallery attendant if exposed or contact the artist if concerned. The gallery attendants underwent an exhibition safety induction, which taught them how to respond if viewers were at risk of exposure to the living candida or if viewers became anxious about ingesting the bread.\textsuperscript{219} A spill hazard kit (SHK) was prepared as described in the RMP and attendants were taught how to use it. They were also provided with suggested responses to anticipated FAQs, so they could confidently manage public anxiety about the bread. A precautionary *Exhibition Informational* was provided to Gallery and University management so they could provide informed responses to any public anxiety or complaints.\textsuperscript{220} The *Informational* briefly describes the project and includes the anticipated FAQ and suggested responses. Collectively, these documents form a cat’s cradle of their own—a material–semiotic guide to navigating institutional interspecies encounters.

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\textsuperscript{217} Discussed in chapter 3.
\textsuperscript{218} The Notice text is provided in Appendix C.
\textsuperscript{219} The *Gallery Attendant Guide* is provided in Appendix D.
\textsuperscript{220} The *Exhibition Informational* is provided in Appendix E.
DISPERALS

For brevity, past and future dispersals are described in Appendix G. This research continues in the form of a postdoctoral research fellowship, which will examine the role of artificial and unnatural selection in the CandidaHomo ecology, including influences of technology, genetic engineering and selective breeding. The fellowship is based at SymbioticA at The University of Western Australia and is funded by The Seedbox environmental research project at Linköping University, Mistra and Formas, Sweden. This is an amazing opportunity and validation of this work and I am very grateful.

Potential dispersals of this work could include:

- Develop the figuration of human bodies as queer ecologies, including implications and limitations;
- Refine and apply the interdisciplinary research methodology used and theorised in this research. What are its limits and limitations? Is it applicable and/or relevant to other disciplinary combinations?
- What other apparatuses are relevant and/or interesting for exploring CandidaHomo ecologies?
- C. albicans is ripe for broader research, including but not limited to microbiological research into potential biological benefits or mutualisms of C. albicans in the human body, the ecological and evolutionary dynamics of multispecies biofilms in various host niche conditions, the effects of C. albicans phenotypic plasticity and niche construction on the evolution of other microbes and the human immune system and the sexual and social selection pressures to which C. albicans and the human microbiome are subject; a biocultural history of candida; consideration of candida and other microbiome species in feminist, queer, race, crip, age, childhood, masculinity and other body scholarship and environmental humanities; STS research regarding the microbiopolitics of the industrialisation of C. albicans and other non-albicans Candida species;221 and further artistic research.
- Expand evolutionary theory—heteronormative and gender biases apply not just to sexual selection but also to natural and kin selection; expand evolutionary theory into the human ecology; expand evolutionary biology re microsociobiology and social selection; develop a queer evolutionary theory; and develop a naturecultural evolutionary theory that embeds technology within its framework rather than as an exceptional and “unnatural” pressure.
- Explore queer theory through evolutionary theory and expand discussions of queer and trans* microbial entanglements.

221 Including C. krusei, C. kafir and C. antarctica.
• Explore the possibilities offered by eros for more-than-human ethics.
• Explore the possibilities and limitations offered by microbiopolitics, including understanding that they are not just out there, they are also “in here.”
• What do the intersections of commensalism, holobiontism and heterotopic alliances offer?
• Explore art as material-semiotic resolutions of microbiopolitics, including material, historical and theoretical discussions.

A SLIGHT POLEMIC

We become-with each other or not at all...Alone, in our separate kinds of expertise and experience, we know both too much and too little, and so we succumb to despair or to hope...Neither hope nor despair knows how to teach us to “play string figures with companion species.” (Haraway 2016, 4)

Environmental activism is futuristic and fundamentally heteronormative since futurity implies reproduction (Davis 2015). We are urged to save the environment for our children or even to consider seven generations ahead as indigenous cultures do. Lee Edelman (2004) has famously argued that since queers don’t reproduce, we have no obligation to the future. According to this logic, future-oriented environmentalism has no purchase for queers—why should we care? The motivation for changing our behaviour must hinge on more than reproduction, more than lineage, more than the future, since we are in it now. For, as Ahuja (2015) argues, queer humans are not immune from the parasitic exploitation of more-than-human sexualities and are complicit in the microbiopolitics of “reproduction and extinction, where racial divisions of climate emerge in the intimate scales of contact between human social forms and ecologies of production and waste” (369). Are reproductive futurity or nihilistic hedonism really our only options?

Davis (2015) provides a compelling argument for reconsidering queer spacetimematter, not as anti-futuristic, but as an always already present. We should care because we are here now, because extinctions are happening now, all around us, because our actions here now are killing here now, because our actions here now cause toxicities and climate change here now, because our actions here now exploit and damage lives here now, because our actions here now are unjust and unkind here now. If you are lucky enough to be white and middle or upper class and think you aren’t feeling the effects here now, care because your actions here now cause extinctions, toxicities and climate change there now and because your actions here now

222 Thanks to Ionat Zurr for this wonderfully ambivalent phrase, which so succinctly encapsulates this project.
223 Which is a disturbing and all too common example of enviro-cultural imperialism.
224 This assumption that queers do not have children is of course not true but is a prominent figuration in both queer and evolutionary discourses.
The Unsettling Eros of Contact Zones

affect your own body here-now. If we have only the now, what we do and who we do it to and with matters here-now.²²⁵

COMMENSALISM

You don’t get more here-now than CandidaHomo ecologies. These ecologies are as much a part of the “Anthropocene” as any other—life at all scales depends on biodiverse microbiomes from CandidaHomo to the planet. The spacetime matter scales of the Anthropocene matter. They are horrifying, urgent and overwhelming. In untangling and reconfiguring CandidaHomo, we re-orient to the response-abilities of our own ecologies and the “small bodies and intimate environments [that] often get lost in big atmospheric narratives” (Ahuja 2015, 371). The dramatic increase in the incidences of candidiasis and nosocomial life-threatening candidemia is human-induced, the result of increasing numbers of at-risk immune-compromised populations, use of catheters and other biomedical devices, broad-spectrum antibiotics, sterilising hand washes, feminine hygiene products and changing diets. The scientific discourse of CandidaHomo focuses on the life-threatening, the 30–50% mortality rates, largely neglecting the everyday living-with. However, as Haraway (2016) argues,

The details matter. The details link actual beings to actual response-abilities...Each time a story helps me remember what I thought I knew, or introduces me to new knowledge, a muscle critical for caring about flourishing gets some aerobic exercise. Such exercise enhances collective thinking and movement in complexity...We are all responsible to and for shaping conditions for multispecies flourishing in the face of terrible histories, and sometimes joyful histories too, but we are not all response-able in the same ways. The differences matter—in ecologies, economies, species, lives. (29)

Humans are these “terrible and joyful histories,” always already manipulating the evolution of others and manipulated in turn. However, we are re-orienting to an unprecedented scale of manipulation and industrialisation of yeasts and other microbes. For consumption certainly but increasingly we are exploiting their sexual and reproductive lives to mass produce industrial and commercial enzymes, pharmaceuticals and biofuels.

If “the details matter,” then every here-now is a moment to be response-able for how we want to eat at the table. As Haraway (2015, 161) argues, “making kin is perhaps the hardest and most urgent part.” We decide here-now how we want to eat at the table. Do we plead austerity, rationing and dispensing morsels based on capricious judgements, allowing some to gorge and others to starve? Or do we invite everyone to a generous table of mutual flourishing, an orgy of queer kind and deal with the hangovers and food poisoning, the fisticuffs and arguments, the STIs and accidental progeny?

²²⁵ Thanks to Mike Bianco for the provocation that initiated this rationale.
We—all of us on Terra—live in disturbing times, mixed-up times, troubling and turbid times. The task is to become capable, with each other in all of our bumptious kinds, of response...The task is to make kin in lines of inventive connection as a practice of learning to live and die well with each other in a thick present. (Haraway 2016, 1)

This project performs a CandidaHomo figuration by playing a cat’s cradle string game with some of the complex microbiopolitics between C. albicans and H. sapiens. Scavenged from microbiology, evolutionary ecology, queer theory, and art, amongst many, many, many others, this figuration has gathered and thickened the troubles of CandidaHomo naturecultures. It has made explicit Donna Haraway’s analytical methodologies of figuration and the cat’s cradle and integrated them with Karen Barad’s materialdiscursive apparatuses and the affective research methods of experimental microbiology and contemporary art, weaving a methodology for exploring naturecultures. It declares that CandidaHomo ecologies are “here to live with” (Haraway 2003, 5) and that our “being depends on getting on together” (50). I have transformed and reconfigured bodies, sex, kin, community, sexual, natural and kin selection, sexuality, trans*, kinship, eros, science, theory and art to attend to my response-ability as an ecology of companion species. In imminent dissolution, this figuration of more–than–human heterotopic alliances is a provocation to host the trouble, to break bread with our messmates and embrace the eros of the CandidaHomo ecologies within.

226 Parts of this discussion are adapted from “We have never been Homo sapiens” (Bates 2015c).
The Unsettling Eros of Contact Zones
CODA

So...

How do I feel about candida now, 5 years later?

I think I am over the heady intoxication of the initial romance—although there are still days when delight, wonder and gratitude surge through my body. I have settled into the deep love, respect and contentment that comes after long years of living-with. Of course, there are days when I just want to run and hide—and I do.

But I am in it for the long haul.
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The Unsettling Eros of Contact Zones


The Unsettling Eros of Contact Zones


The Unsettling Eros of Contact Zones


The Unsettling Eros of Contact Zones
The Unsettling Eros of Contact Zones and Other Stories

Tarsh Bates
October 2015
THE UNSETTLING EROS OF CONTACT ZONES

Tarsh Bates was born in 1973. She completed a Bachelor of Science with Honours from Murdoch University in 2000 and studied contemporary art at Edith Cowan University between 2003 and 2005. In 2012, she became Master Bates* after living in a public art gallery for 3 months with eight other scientific model organisms, exploring the aesthetics of care and alterity. She has worked variously as a pizza delivery driver, a fruit and vegetable stacker, a toilet paper packer, a researcher in compost science and waste management, a honeybee ejaculator, an art gallery invigilator, a raspberry picker, a lecturer/tutor in art/science, art history, gender & technology, and counter realism, an editor, a bookkeeper, a car detailer, and a life drawing model. Tarsh is currently a PhD candidate at SymbioticA, The University of Western Australia, where her research is concerned with the aesthetics of interspecies relationships and the human as a multispecies ecology. She is particularly enamoured with *Candida albicans*.

*Master of Science (Biological Arts), SymbioticA, UWA
ALSO BY TARSH BATES

Art Exhibitions

*Busied & bruised with looking*...
(with Audrey Appudurai, Emily Parsons-Lord & Devon Ward)

*Intra-actions: multispecies becomings in the Anthropocene*

*The Linden Postcard Show*

*SymbioticA LUMINOUSnight Print Retrospective*

*Creatures of the Future Garden*

*The Conservatorium*

*Sentience: hidden lives*

*Embodied Knowledges*

*in vitero*

*the descent of man*

Book Chapters

*Necessary expendibility: an exploration of nonhuman death in public* (with Megan Schliapalus)

Journal Articles

*Threats of life: Art in a post-biopolitical era*
(with Laetitia Wilson)

*Cutting together-apart the mould: notes on the intra-activity of slime mould/mold*

*Performance, bioscience, care: Exploring interspecies alterity*

*HumanThrush entanglements: Homo sapiens as a multispecies ecology*

*InterUterine: Exploring the reprotech body through an interspecies aesthetic of care*
TARSH BATES

The Unsettling Eros of Contact Zones

And Other Stories

WITH AN ESSAY BY
Dr Laetitia Wilson

&

FEATURING A POEM BY
Shannon Williamson
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Carrara, PaLM, UWA

Audrey Appudurai, Tiffane Bates, Christo Bester, Michael
Bianco, Moe Boetiks, Maddi Boyd, Lisa Brideson, Tony Brideson,
Philippa Cecil, Jane Coakley, Julian Frichot, Benjamin Forster,
Fiona Hart, JJ Hastings, Elena Hauri-Downing, Felix Hauri-
Downing, Ruedi Hauri-Downing, Sue Hauri-Downing, Dianne
Hawk, Sohan Ariel Hayes, Cat Hope, Jazmine Hope-Scuderi,
WhiteFeather Hunter, Eben Kirksey, Svenja Johnni Kratz, Loren
Kronemyer, Sue McElhinney, Soichiro Mihara, Karl Ockelford,
Deborah Onajah, Emily Parsons-Lord, Perdita Phillips, Megan
Schliaplius, Nina Sellars, Alison Stubbs, Elizabeth Sullivan,
Peter Todd, Max Vickery, Devon Ward, Shannon Williamson,
Beth Wilson, Laetitia Wilson & Stuart Wood

Australian Postgraduate Award
UWA Safety-Net Top-Up Scholarship
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Two characters are entangled, *Homo sapiens* and *Candida albicans*. If it were a love story, it would be unrequited. *Candida* shyly hides under folds and becomes ferocious once its environment, us, changes, whereupon it is felt, disliked and attacked. Like many love stories, this drama is complex. *Candida* has many faces, and shifts from being an innocuous companion to causing great irritation. The ways we comprehend our entanglements with this particular microorganism is the subject of Tarsh Bates’ artistic practice.

The concept of eros lies at the heart of Bates’ art, as a means of understanding the Other. Eros operates at the nexus between materials/bodies: in the case of *Candida*, between it and the surfaces it adheres to. It is about sensuality and sensations that are both pleasurable and uncomfortable. Plato considered Eros to be a figure somewhere between human and divine. He referred to Eros in Greek myth as a benevolent *Daimon*, in contrast to the Christian formulation of malevolent *Demons*. *Candida* itself thrives in indeterminacy as a shape-shifter, between *Daimon* and *Demon*, relative to the conditions of its habitat. Sexuality is at the core of this polymorphism; *Candida* exhibits multiple reproductive strategies. When cultured on a petri dish, it is benign, asexual (*Daimon*); within a host body *Candida* is omnisexual, shifting shape and becoming a highly promiscuous parasite (*Demon*).
Beyond Plato and such dichotomies, however, Bates draws from philosopher Luce Irigaray’s idea of eros as an ‘affective desire for interconnection and interaction’ that calls upon multiple forms of intimacy and sexual expression. Bates embraces the queerness of Candida, its ambiguity, its androgyny and its fecundity. She posits the relation as a complex mutual ‘caress’ between human and biome, rather than between human and good (*daimon*) or evil (*demon*). In the work *Ereignis, Gelassenheit and Lichtung: A love story*, for example, individual Candida cells are subtly projected onto the skin of viewers. Once within the room, viewers have no choice, they are ‘infected,’ yet this infection is as soft and gentle as air caressing a surface.

Candida not only has the misfortune of unrequited intimacy, but is culturally and scientifically misunderstood. It is imbued with many, mostly antagonistic, cultural and scientific assumptions that contrast with its own complex language of actualisation. It is labeled a ‘women’s problem,’ and as noted by Bates, ‘any attempts to observe or experiment on Candida impose spatio-temporal conditions on its behaviour and hence its worlding.’ In response, she creates a living still life using the first scientific illustration of Candida drawn by mycologist Charles Phillipe Robin in 1853. *Surface Dynamics of Adhesion* manifests as decorative wallpaper, as a rich red flocking-like pattern that is initially neatly composed upon a surface. Interaction with this surface causes the living Candida to escape the design. This piece questions the discipline and control of bodies, and the discomfort
that occurs when bodies stray from the norm as leaky excess. It allows Candida to ‘perform’ as the complex microorganism it is—living, animated, disorderly, rather than the fixed entity depicted in Robin’s illustration.

Bates considers, cultivates and provokes sensory responses with her art. In *The Unsettling Eros of Contact Zones*, the yeasty properties of Candida are used in the creation of bread. The notion of breaking and eating bread takes on an entirely new resonance with the knowledge that it has been prepared using maligned and icky body bugs. An everyday food is made strange, thus provoking consideration for the foods that we eat. Even though the Candida is dead, the bread still incites physical reactions and thoughts on the nature and various effects of minute, invisible ingredients in our food.

This unflinching art practice brings a misunderstood and disliked biome to the forefront of a discourse about bodies, sexualities, cultural and scientific assumptions. Candida is cared for, presented as beautiful and edible, and visualised in various states of being and becoming. Bates embraces ambiguities, opens up debate, and teases out and perverts complex cultural meanings.

Laetitia Wilson, 2015
Ereignis, Gelassenheit and Lichtung: A love story

A digital time-lapse video of Candida albicans reproducing and changing shape, taken on a live imaging microscope, fills the room, contaminating the architectural space (and any bodies within it) with animate images of Candida albicans cells. The title of this work combines terms used by the philosopher Martin Heidegger, whose work redefined understandings of “being-in-the-world.” Ereignis [trans. an event] describes the coming into being of “things” which is only possible through their relationships with each other. Gelassenheit [trans. letting-be] expresses the acceptance of the mystery of being-in-the-world, and Lichtung [trans. a clearing; illumination] refers to the necessity to clear a space in order to understand how it is to be-in-the-world. This work suggests that all three are intertwined, even in our own bodies.
Control of Cell Morphology
In Vivo

A zoetrope rotated using a hand-crank arouses static images of *Candida albicans* cells, which come alive, dancing and changing shape. The viewer observes the contained images from a safe distance, completely in control – a stark contrast with the unruly contamination of *Ereignis, Gelassenheit and Lichtung*. The simplicity of the analogue apparatus materialises the gaps in seeing between scales and explores the role of motion in seeing and knowing an Other.
Encased in a series of acrylic boxes, living *Candida albicans* grows in a pattern adapted from the first drawing of the organism by Charles Philippe Robin in 1853 and reminiscent of those popular on the wallpaper of parlours and art galleries in Europe at the time. The *Candida* grows on blood agar, a nutrient source that contains the blood of the human artist. The acrylic containment frames the artwork as an un-still-life and minimises the risk of contamination or infection. Within this containment, the living *Candida* escapes the constraints of the patterning during the exhibition, disrupting attempts to discipline it.
Many of the foods we consume are produced with or contain a variety of microorganisms, including the basics: cheese, bread, milk, and beer. The artist offers bread leavened with *Saccharomyces cerevisiae* and *Candida albicans*, brie, blue cheese, and hummus to share, inviting consideration of assumptions about microorganism, our bodies and the food we consume. All microorganisms used to leaven the bread are killed by the baking process, including the *Candida*, which is already present in or on most of us.
An artist’s book in the form of a pack of 52 cards with digital micrographs of the polymorphism of Candida albicans cells and colonies. The diversity and adaptability of this organism is revealed, compellingly sumptuous and repulsive. Translational ambiguity of RNA codons into multiple amino acids is thought to be detrimental to living organisms, but Candida has a high tolerance for the translational ambiguity of the leucine CUG codon into both serine and leucine. This ambiguity tolerance is associated with morphological changes and pathogenesis and confers on Candida a highly dynamic adaptability to its environment (us).
Where do I begin?
An opening; A tale of two bodies
(aA) other and a waxing mouth.

I open with lips against pin-pricks
a thickening behind the breast
somatic anchors that root and bloom like an artery

I open with the tale of a third party
second hand
Lamina/lamina
lopsided lovers bound in mutual defeat

Shannon Williamson, 2015
SURFACE DYNAMICS OF ADHESION PROTOCOL

1. Prepare Sabouraud Dextrose broth
   1.1. Prepare SAB broth
   1.2. Autoclave media
2. Prepare Blood agar
   2.1. Prepare blood base agar media
   2.2. Autoclave media
   2.3. Collect 20mL whole blood using EDTA anti-coagulant
   2.4. Mix blood into 50°C base agar
3. Sterilise customised growth dish and lid
   3.1. Soak dish and lid in 4% bleach for 10 minutes
   3.2. Rinse each with 600mL sterile DDI water
4. Pour blood media into dish and leave O/N at RT to set
5. Prepare C. albicans culture
   5.1. Inoculate 100mL SAB broth with C. albicans
   5.2. Incubate at 37°C with shaking for 18 hours
   5.3. Harvest cells by centrifugation 3,000xg for 5 minutes
      5.3.1. Transfer broth culture to 50mL centrifuge tubes
      5.3.2. Pelletize cells by centrifugation
      5.3.3. Wash pellet with 0.5vol sterile DDI water
      5.3.4. Pelletize
      5.3.5. Wash pellet with 0.05vol sterile DDI water
      5.3.6. Pelletize
      5.3.7. Wash pellet with 0.05vol sterile DDI water
      5.3.8. Pelletize
      5.3.9. Resuspend cells in 0.05vol SAB broth
6. Prepare artwork
   6.1. Autoclave stencil
   6.2. Place stencil on agar and press gently
   6.3. Pour C. albicans suspension onto stencil
   6.4. Incubate dish overnight at 30°C
   6.5. Remove stencil and soak in 4% bleach for 10 minutes
7. Sterilise base and outer lid in bleach solution
8. Assemble containers and add dessicant
9. Display
The Unsettling Eros of Contact Zones Protocol

1. Autolyse
   1.1. Mix flour and water and let stand for 15 minutes at room temperature
2. Prepare leavening agent
   2.1. Activate fresh yeast (*S. cerevisiae*) in warm water
   2.2. Add generous loopful of *C. albicans*
   2.3. Allow to ferment for 15 minutes
3. Mix dough
   3.1. Add leavening agent and salt to dough and mix
   3.2. Transfer to greased bowl
   3.3. Cover and proof for 20 minutes at 30°C
4. Fold dough
   4.1. Uncover and fold dough
   4.2. Cover and proof for 20 minutes at 30°C
   4.3. Repeat
5. Bulk ferment
   5.1. Uncover and fold dough
   5.2. Cover and proof for 2 hours at 30°C
   [or 1 hour at 30°C then overnight at 4°C]
6. Pre-shaping
   6.1. Split dough and form into 3 logs
   6.2. Mist with spray oil
   6.3. Cover and stand for 15 minutes at room temperature
7. Shaping
   7.1. Shape into batards
   7.2. Fold top down and seal
   7.3. Fold bottom up and seal and turn over
   7.4. Roll from middle out to extend into baguette shape
8. Final proof
   8.1. Preheat oven to 210°C
   8.2. Transfer dough to baguette pan
   8.3. Cover and proof for 30 mins at RT
9. Uncover and score
10. Insert temperature probes into loaves
11. Bake at 210°C for 20 minutes
12. Test for *C. albicans* inactivation
13. Cut and serve
Tarsh Bates explores what it means to be human when we recognise our bodies as multi-species ecologies, with a particular focus on the relationships between *Homo sapiens* and *Candida albicans*. She uses scientific and artistic methodologies to explore physical, emotional, cultural and political relationships between humans and *Candida*. Works comprise sculptural, photographic and filmic works, dead and living organisms, and were developed during Bates’ PhD research at SymbioticA and the University of Western Australia.
Human Thrush Entanglements
Risk Management Plan

Tarsh Bates
2015
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GLOSSARY


**ATCC** American Type Culture Collection; supplier of *Candida* stock; an independent, private, non-profit biological resource centre (BRC) and research organisation

**Baking** process of cooking bread; temperature exceeds 200°C, cooking duration exceeds 30 minutes

**Class II Biological Safety Cabinet (BSC)** an enclosed, ventilated workspace for safely working with materials contaminated with (or potentially contaminated with) pathogens in the laboratory

**Candida albicans (Candida)** commensal yeast commonly present in the gastrointestinal tract and genitals of humans; Risk Group 2 human infectious organism; opportunistic pathogen

**Candida allergy/syndrome** a controversial and undefined poly-symptomatic disorder, where a wide range of related health concerns are attributed to a chronic, systemic *Candida* infection.

**Candida spill (spill)** *Candida* culture container is accidently opened or broken; not involving human contact

**Candidiasis** infection by *Candida albicans*; also called *thrush*, effective treatment and preventative measures are readily available

**Display Unit** secure, double-layer culture container for public display designed according to AS2243.3 PC2 standards

**HTE RMP** This Risk Management Plan

**Kill temperature** temperature at which *Candida albicans* is inactivated; 80°C; also time dependant (refer to thermal death time)

**OGTR** Office of Gene Technology Regulations

**PC2** Physical containment level 2; applicable to practices where work is carried out with organisms or material likely to contain microorganisms that are classified as Risk Group 2 microorganisms.

**Personal Protective Equipment (PPE)** required during *Candida* culture handling, spill cleaning or public exposure; as per OGTR, AS/NZS 2243.1 & AS/NZS 2243.3 (Appendix C)

**Public exposure** *Candida* container is accidently opened or broken; involves human contact

**Risk Group 2 human infectious organism** (low individual and community risk) a microorganism that is unlikely to be a significant risk to laboratory workers, the community, livestock, or the environment; laboratory exposures may cause infection, but effective treatment and preventive measures are available, and the risk of spread is limited (AS/NZS 2243.3:2010, p20).

**Spill Hazard Kit (SHK)** kit containing PPE and equipment necessary for cleaning a *Candida* culture spill (Appendix D)

**Thermal death time (TDT)** duration required to kill a specific microorganism at a specific temperature; for *C. albicans* this is 60 minutes at 70°C/158°F or 30 minutes at 80°C (Wiley and Westerberg 1969, 998).

**Transport unit (TU)** Sealed unit to contain the display unit during transportation compliant with the IATA DGR transport guidelines.
**INTRODUCTION**

*HumanThrush Entanglements* is artistic research contributing to the researcher’s PhD. The project explores the cultural and material relationships between *Homo sapiens* and *Candida albicans*. The project includes growth of and experimentation with *Candida albicans* cultures in a PC2 laboratory environment, and growth and display of *Candida albicans* in artworks in a public art gallery. All work conducted complies with ANZS 2243.3:10 and OGTR regulations.

This risk management plan has been written to address the possible risks associated with handling *Candida albicans*, as it is classified as a Risk Group 2 human infectious organism under the Australian/New Zealand Standard 2243.3:10. *Candida albicans* is present in 80% of the human population as one of many harmless organisms that live in our mouths and guts with no harmful effects. It is not airborne and is rarely contracted by touch. Humans with healthy immune systems are unlikely to be infected, but those with compromised immune systems may be susceptible to infection. Consequently, special handling is required to minimise exposure and treatment if exposure occurs. Handling during this project for growth and experimentation occurs in a PC2 environment and with Personal Protective Equipment. Exposure prevention during exhibition involves PC2 containment measures, including customised display units for artworks that contain living *C. albicans*. Infection as a result of exposure is highly unlikely, however the risk of infection increases if someone with a compromised immune system is directly exposed. First aid treatment for exposure involves disinfection with Povidone-Iodine (Betadine) for 10 minutes. Medical treatment for an infection involves anti-fungals prescribed by a GP.

This document provides a protocol for minimising and managing exposure to *Candida* in order to minimise risk of infection during the project. The protocol complies with the Office of Gene Technology Regulations and the Australian/New Zealand Standard 2243.3:10 *Safety in Laboratories, Part 3: Microbiological safety and containment*. It is supported by a Health Safety and Environment Assessment and Control of Work form (Appendix H). The University Biosafety Manager, the Risk Management and the Safety, Health and Welfare Divisions, along with the Western Australian Health Department have reviewed the risk mitigation strategies and are happy for the exhibition to proceed.

**PROJECT CONTACTS**

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<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>Location</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarsh Bates</td>
<td>Researcher</td>
<td>UWA</td>
<td>0432 324 708</td>
</tr>
<tr>
<td>Dr Ionat Zurr</td>
<td>Supervisor</td>
<td>UWA</td>
<td>6488 3293</td>
</tr>
<tr>
<td>Dr Kate Hammer</td>
<td>Supervisor &amp; Lab manager</td>
<td>UWA</td>
<td>6383 4363</td>
</tr>
</tbody>
</table>
**LOCATIONS & RISK ACTIVITIES**

The project occurs in three locations which have different activities and exposure risks:

**L Block, QEII Medical Centre, Nedlands**

*Activity:* Handling and maintenance of *Candida* cultures; artwork preparation, including media preparation and culture growth; bread leavening and baking  
*Exposure Risk:* Researcher only; medium  
*Risk Management Controls:* established, best practice controls & compliant with OGTR & AS2234.3:2010; engineering controls established; Class II Biosafety cabinet & PPE used; researcher is trained in First Aid and OGTR

**Transport between QEII and exhibition venue**

*Activity:* Transport of contained *Candida* cultures  
*Exposure Risk:* Researcher and public; low  
*Risk Management Controls:* sealed transport unit designed in compliance with IATA DGR transport guidelines; spill hazard kit in vehicle; alternate emergency contacts provided; researcher is trained in First Aid and OGTR

**Exhibition venue**

*Activity:* Display of contained *Candida* cultures & service of bread leavened with *C. albicans*  
*Exposure Risk:* Researcher and public; low-medium  
*Risk Management Controls:* sealed display unit designed in compliance with AS2234.3:2010 containment measures; bread tested to ensure absence of live *C. albicans*; visitors informed of bread ingredients to ensure informed ingestion; spill hazard kit present in gallery; alternate emergency contacts provided; researcher is trained in First Aid and OGTR

**ACTIVITIES THAT POSE POTENTIAL RISK**

**Culture handling and maintenance**

Handling and maintenance of *Candida* cultures for experimentation and artwork preparation is conducted in a PC2 laboratory at the QEII Medical Centre, Nedlands. Handling and maintenance occurs in compliance with AS2234.3:2010 to minimise the risk to the researcher and other lab users.

**Wallpaper Artwork**

Living *Candida albicans* is grown in a pattern adapted from the first drawing of the organism in 1853 and reminiscent of wallpaper popular in parlours and art galleries in Europe at the time. The artwork is installed on the gallery wall to form a dado border. The *Candida* is grown on blood agar, a nutrient source that contains the blood of the human artist. The *Candida* in these works are alive during the exhibition and contained according to relevant biosafety requirements to eliminate risk of contamination or infection in customised acrylic containment units as per the Physical Containment measures described below. The
artworks are prepared in the QEII PC2 facility and transported between lab and gallery in a customised transportation unit to minimise risk of exposure during transportation as per the Transport protocol below. Any spills that occur will be managed according to the Spill Management and Public exposure protocols below.

**Bread artwork**

Bread leavened with the yeasts *Saccharomyces cerevisiae* and *Candida albicans* is offered to gallery visitors for consumption, inviting them to consider their assumptions about microorganisms, our bodies and the food we consume, much of which is produced with or contains a variety of microorganisms. The baking process kills all microorganisms, including *Candida*, so there is no risk of infection. The risk of acquiring a “*Candida* allergy” or “*Candida* syndrome” from ingesting the bread is also highly unlikely as very low concentrations of Candida are used to prepare the bread. Visitors will be given full information on the ingredients, cooking process and risk, and will be never be forced to consume the bread. Visitors are not “tricked” into eating a pathogen, rather they are asked to be more conscious of the decisions they make around the food they eat. The artwork is prepared in the QEII PC2 facility.

---

**RISK MANAGEMENT MEASURES**

**Culture handling and maintenance**

*Culture Maintenance*

All culture maintenance will be conducted in a PC2-certified laboratory at the QEII Medical Centre. *Candida* subculturing will be conducted in compliance with the AS2234.3:2010 and the culture protocol supplied by the ATCC.

*Culture Transportation*

Cultures will be transported between QEII Medical Centre and the exhibition venue. Transport will occur at all times according to the transport protocol to minimise risk of exposure and will be transported in the transport unit.

**Bread preparation and testing**

*Bread Preparation*

The bread will be prepared in a PC2-certified laboratory at the QEII Medical Centre in compliance with the AS2234.3:2010. Preparation utensils will be disinfected with bleach, cleaned and autoclaved.

*Bread Baking and Testing (Refer to Appendix F)*

The bread will be baked at 200°C for 50 minutes in an oven in a PC2-certified laboratory at the QEII Medical Centre. The temperature of the interior of the bread will be monitored during baking to ensure kill temperature has been reached. As the TDT for *C. albicans* has been shown to be 30 minutes at 80°C, all *C. albicans* should be inactivated by the cooking process. At the end of the 50 minutes a sample of the baked bread will be spread onto growth media to test for living *C. albicans*. If living *C. albicans* are found, the
bread will not be served. These samples will be kept for a week in the event that a visitor does become ill and the bread needs to be re-tested to determine the possibility that the illness resulted from consuming the bread.

Physical containment measures

**PRINCIPLES OF PHYSICAL CONTAINMENT**

This project complies with the principles of containment outlined in Section 4 of AS 2243.3: 2010: Containment of microorganisms involves a combination of buildings, engineering function, equipment, and worker practices to handle microorganisms safely. Physical containment is the term used to describe procedures and structures designed to reduce or prevent the release of viable organisms into the outside environment (p. 35).

**TRANSPORT UNIT**

The organisms will be transported between the QEII Medical Centre and the exhibition venue in a transport unit designed according to the requirements of the IATA *Dangerous Goods Regulations* and AS 4834 *Packaging for surface transport of biological material that may cause disease in humans, animals and plants* (Section 13 of AS/NZS 2243.3:2010). The transport of *C. albicans* is regulated by a number of documents outlined in Section 13 and is based on the United Nations *Recommendations on the Transport of Dangerous Goods. Model Regulations* (p. 130).

*C. albicans* is considered a Category B Infectious substance (AS/NZS 2243.3:2010 p. 134) as it does not comply with the criteria for Category A, specifically that it is not “capable of causing permanent disability, life-threatening or fatal disease in otherwise healthy humans or animals” (p. 132). *C. albicans* is only potentially life-threatening to immuno-compromised humans, that is humans with healthy immune systems are unlikely to be infected, but those with compromised immune systems may be susceptible to infection. It is assigned to UN3373 (BIOLOGICAL SUBSTANCE, CATEGORY B). Packing instructions P650 (UN) or PI 650 (IATA) apply to these substances. The transport unit is leak proof and unbreakable, and labelled according to AS/NZS 2243. Alternative emergency contact information is also provided on the outside of the unit in case the researcher is incapacitated.

**Transport protocol**

**BETWEEN PC2 LABORATORY QEII MEDICAL CENTRE AND THE EXHIBITION VENUE**

1. PPE donned
2. Exterior of growth container disinfected using bleach as per OGTR & AS2243.3:2010 Table F2
3. Display unit disinfected
4. Disinfected growth container placed into disinfected display unit
5. Exterior of display unit disinfected
6. Disinfected display unit placed into transport unit
7. PPE removed
8. Transport unit secured in vehicle
9. Transport unit removed from vehicle and transported to the exhibition venue
10. Display unit removed from transport unit and installed

**In case of vehicle accident during transport**

If a vehicle accident occurs during transport, the transport unit should be secured. If the transport unit has broken and a spill has occurred, the *Candida* Spill Management protocol should be followed by the researcher. If the transport unit is intact, the unit should be returned to the PC2 laboratory for decontamination.

**Candida spill management**

All cultures are grown on solid media, so for this project a spill is defined as a situation where a *Candida* culture container or the display unit is accidently opened or broken and does not involve human contact with the organism. As the transport and display units are unbreakable, it is highly unlikely that a *Candida* spill will occur during transportation. In addition, humans with healthy immune systems are unlikely to be infected, but those with compromised immune systems may be susceptible to infection. However, risk management protocols are provided for these improbable situations and in case of a spill in the PC2 laboratory during culture maintenance.

**In case of spill in laboratory**

As per OGTR & Section 9.3 of AS2234.3:2010: *Spills inside a biological safety cabinet* are generally considered to be a lower hazard than those outside the cabinet as they are contained and aerosols are swept away by the cabinet air stream. Clean-up may be commenced immediately and may be done by the worker herself. In addition, the researcher has a healthy immune systems and is unlikely to be infected.

Small spills, i.e. droplet-size spills or those up to 1mL, may be treated easily by wiping with disinfectant-soaked absorbent material or flooding with a suitable disinfectant solution.\(^1\) Allow time for the disinfectant to take effect.

The suggested procedure for a larger spill or breakage is as follows:

(a) Ensure that the cabinet remains operating to retain aerosols during Steps (b), (c), (d), and (e).

(b) Place absorbent material wetted with suitable disinfectant or proprietary absorbent materials that release hypochlorite over the spill. Allow approximately ten minutes to effect disinfections.

(c) Disinfect gloved hands and remove protective gloves in the cabinet. Remove any contaminated clothing for decontamination and wash hands and arms. Replace with clean gloves and protective clothing for carrying out the remainder of the clean up.

(d) After initial disinfection of the spill, remove any sharp objects with forceps and discard as contaminated sharps then remove excess fluid with absorbent material and discard into a container

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\(^1\) The appropriate disinfectant for *Candida albicans* is bleach (AS/NZS 2243.3:2010, Appendix F)
for decontamination. Discard culture bottles, petri dishes and sold material associated with the spill into the appropriate container. Decontaminate cultures, media and disposable materials adjacent to the spill.

(e) Wipe down the work floor, cabinet work zone and remaining items of equipment with fresh disinfectant solution. For Class II cabinets, disinfect both sides of the front grille and work floor within the cabinet. Check that the spillage has not contaminated the sump. If the spill is large, use sufficient disinfectant to dilute and inactivate the infectious material.

(f) Consider whether the cabinet should be decontaminated before further use. The safety officer should be consulted for guidance.

(g) Complete an incident report in accordance with any institutional requirements (Appendix E).

**In spills external to BSCs,** low hazard infectious material that is spilled without generating significant aerosol, and does not contain a human pathogen spread by the respiratory route, should be cleaned up with a paper towel or other absorbent material soaked with an effective chemical disinfectant (AS/NZ 2243.3: 2010 Section 9.4.2).

Material containing microorganisms that is being moved in or between facilities or service areas shall be contained in secondary sealed, unbreakable containers.

The response should be as follows:

(a) Remove the laboratory gown and any other garment suspected of being contaminated, and place in a biohazard bag for subsequent decontamination. If it is suspected that shoes are contaminated, remove and place in a separate biohazard bag.

(b) Put on appropriate protective clothing such as gowns, gloves and eye protection.

(c) Place absorbent material wetted with suitable disinfectant over the spill. Allow at least 10 min to effect disinfection. Remove any sharp objects with forceps and discard as contaminated sharps.

(d) Use the same disinfectant solution to wipe over the area likely to have been contaminated, allowing ten minutes for disinfection time.

(e) Carefully mop up the spill and disinfection solution, and transfer all contaminated materials for decontamination by pressure steam sterilization.

(f) Remove protective clothing and decontaminate hands.

(g) Complete an incident report form (Appendix E) in accordance with any institutional requirements.

**In case of spill during transport**

A spill is highly unlikely to occur during transportation as the transport and display units are leak proof and unbreakable. However, if the display unit is compromised because of an accident or breakage during transportation, the following Spill Management protocol will be implemented. This protocol is adapted from the protocol for low hazard infectious material spills external to BSCs in AS/NZ 2243.3: 2010 Section 9.4.2 (p. 109). In addition, the researcher is trained in first aid and a spill hazard kit is present in the transport vehicle (Appendix D). The researcher will be accompanied by a trained colleague who will implement the
following protocol in the event that the researcher is incapacitated during transport.

1. The researcher will remove any garment suspected of being contaminated, and place in a biohazard bag (SHK) for subsequent decontamination. If it is suspected that shoes are contaminated, they will be removed and placed in a separate biohazard bag. If exposure has occurred the Public Exposure Management protocol will be followed, however, as previously noted humans with healthy immune systems are unlikely to be infected, but those with compromised immune systems may be susceptible to infection.

2. Put on PPE found in the Spill Hazard Kit (Appendix C).

3. Place absorbent material wetted with bleach over the spill as found in the Spill Hazard Kit. Allow at least 10 min to effect disinfection. Remove any sharp objects with forceps (SHK) and discard as contaminated sharps (SHK).

4. Use the bleach solution to wipe over the area likely to have been contaminated, allowing 10 min for disinfection time.

5. Carefully mop up the spill and bleach solution, and transfer all contaminated materials into a biohazard bag (SHK) for subsequent decontamination.

6. Remove PPE and place in a biohazard bag (SHK) for subsequent decontamination. Decontaminate hands (SHK).

7. Complete an incident report form (Appendix E).

8. Dispose of biohazard bag as per AS/NZ 2243.3: 2010.

Public exposure management

Humans with healthy immune systems are unlikely to be infected, but those with compromised immune systems may be susceptible to infection. If a member of the public comes into direct contact with the *Candida* culture in the wallpaper artwork, the following protocol should be implemented:

1. Secure the area, i.e. members of the public will be asked to leave the area unless they have been exposed.

2. Once area is secure, the researcher will remove any garment suspected of being contaminated, and place in a biohazard bag (SHK) for subsequent decontamination. If it is suspected that shoes are contaminated, these will be removed and place in a separate biohazard bag.

3. The researcher and the person that has been exposed will don PPE found in the Spill Hazard Kit (Appendix C).

4. Any spill will be isolated and contained using the SHK.

5. Appropriate on-site first aid will be administered to the exposed person by the researcher – if skin or an open wound is exposed betadine antiseptic ointment or liquid will be administered as per manufacturer instructions; if the person’s eyes are exposed the eyes will be irrigated to wash out the contaminant and the exposed person will be advised to visit their GP for treatment.

6. The researcher will transport the exposed person to a doctor for treatment if necessary.

7. Contaminated objects will be disposed of as per AS/NZ 2243.3: 2010.
HumanThrush Entanglements Risk Management Plan

**In case of researcher incapacitation**

In the event that the researcher is incapacitated, an alternate emergency contact should be notified immediately and will attend the site as soon as possible to deal with the organism. If a *Candida* spill or public exposure has occurred, the transport or display unit should not be handled until the emergency contact arrives. The *Candida* Spill or Public Exposure Management protocols will then be followed by the emergency contact.

**Disposal and decontamination**

1. Don appropriate PPE.
2. Collect any biohazard bagged waste into a second biohazard bag.
3. Place any contaminated sharps waste into the second biohazard bag.
4. Secure second biohazard bag with autoclave tape.
5. Place double-bagged biohazard waste into unbreakable transport container.
6. Transport to disposal facility at QEII Medical Centre.

**Public anxiety management**

Although humans with healthy immune systems are unlikely to be infected if exposed, *Candida* typically elicits strong responses from people. It is possible, even likely, that some anxiety will be expressed by gallery visitors or concerned members of the public regarding potential health risks. This anxiety is especially likely to be evoked by the bread leavened with *Candida* which will be presented for ingestion during the exhibition. As previously stated, the *Candida* bread is offered to visitors for ingestion to ask them to consider their assumptions about microorganisms, our bodies and the food we consume, much of which is produced with or contains a variety of microorganisms. As the baking process kills the *Candida*, the visitor is not at risk of infection. The risk of acquiring a “*Candida* allergy” or “*Candida* syndrome” from ingesting the bread is also highly unlikely In any case, *Candida* is already present in or on most of the visitors and visitors will be informed of the risk (see below for methods of information) and offered a choice as to whether to consume the bread. The following measures have been implemented to minimise public anxiety about infection risk:

1. This risk management plan
2. Didactic panels that list the bread ingredients and production process will be placed in appropriate positions around the gallery. The panels will inform visitors of the following:
   - the bread was leavened with *Candida* and normal baking yeast
   - if they choose to consume the bread, they are not at risk of infection from ingesting the bread, as all microorganisms were killed during the baking process.
   - samples of the bread have been taken before service and tested for the presence of living *Candida*. If found, the bread was destroyed.
   - humans with healthy immune systems are unlikely to be infected, but those with compromised immune systems may be susceptible to infection.
3. The researcher will be available to answer any questions and respond to any concerns from gallery visitors.
4. Any member of the public who approaches the researcher with questions and concerns before or after the exhibition will be verbally informed about the infection risk, ingredients and production process and provided with this risk management plan if they require more information. They will be assured that the researcher is not interested in “tricking” the public into ingesting a pathogen, rather she is asking the public to be more conscious of the decisions they make around the food they eat.

5. Gallery management, SymbioticA management and UWA PR will be provided with a copy of this risk management plan and verbally informed of the infection risk, ingredients and production process to ensure they have the appropriate information to answer questions or reassure a concerned visitor or member of the public.
## APPENDIX A ATCC *CANDIDA ALBICANS* PRODUCT DESCRIPTION

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<thead>
<tr>
<th>ATCC® Number</th>
<th>90028™</th>
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<tr>
<td>Preceptrol® Culture</td>
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<tr>
<td><strong>Organism:</strong></td>
<td><em>Candida albicans</em> (Robin) Berkhout, anamorph</td>
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<tr>
<td><strong>Designations:</strong></td>
<td>NCCLS 11</td>
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<tr>
<td><strong>Isolation:</strong></td>
<td>blood, Iowa</td>
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<td><strong>Depositors:</strong></td>
<td>MA Pfaller</td>
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<tr>
<td><strong>Biosafety Level:</strong></td>
<td>1</td>
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<tr>
<td><strong>Shipped:</strong></td>
<td>freeze-dried</td>
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<tr>
<td><strong>Growth Conditions:</strong></td>
<td>ATCC medium 200: YM agar or YM broth</td>
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<tr>
<td></td>
<td>Temperature: 35.0°C</td>
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</tbody>
</table>
APPENDIX B ATCC CULTURE REVIVAL PROTOCOL

REVIVING FREEZE-DRIED CULTURES

Check each culture thoroughly upon receipt. If a culture is unsatisfactory, notify ATCC so that the strain in question can be investigated. Store freeze-dried cultures at 5° C or lower if they are not immediately rehydrated (except plant viruses, which should be stored at -20° C). Use the medium and incubation conditions specified in the catalog when first reviving strains to ensure optimal conditions for recovery.

Use a Pasteur pipette to add approximately 0.3 ml sterile water to the inner vial of a double vial or to a serum vial (Preceptrol®). Then draw up the entire contents into the pipette and transfer to a test tube with about 5 ml sterile water.

Let the yeast or fungus rehydrate for at least a couple hours (overnight is not too long) before transferring to broth or solid agar. Incubate at the recommended temperature. Keep in mind that some cultures may exhibit a prolonged lag period and should be given twice the normal incubation time before discarding as nonviable.

Save the mixture of lyophilized material and water until you know you have growth. If not contaminated, it will keep several days in a refrigerator. If you do subsequently contaminate your culture, you can recover the desired microorganism by serial dilution and picking single colonies.

Source:
APPENDIX C PERSONAL PROTECTIVE EQUIPMENT (PPE)

Personal protective equipment and clothing can act as a barrier to minimise the risk of exposure to aerosols, splashes and accidental inoculation and shall be worn when working in microbiological containment facilities (AS/NZS 2243.3:2010 p. 114). All PPE shall be removed and hands decontaminated prior to leaving the laboratory.

PPE shall be worn in the event of a spill or public exposure.

- Closed footwear, i.e. footwear that covers the toes and heels.
- Protective eyewear
- Nitrile gloves shall be worn when working in the BSC and when conducting procedures with materials that contain or potentially contain human Risk Group 2 microorganisms.
- Disposable gowns
APPENDIX D CANDIDA SPILL HAZARD KIT (SHK)

The *Candida* Spill Hazard Kit is comprised of materials necessary to minimise the risk of exposure to *Candida* following a spill event. The kit container is unbreakable and clearly labelled. The kit has been compiled based on the Spill Management protocol and AS/NZS 2243.3: 2010. Kits are located in the transport vehicle and the gallery.

- PPE (Appendix C)
- Spare clothing for exposed personnel.
- Clean-up materials and equipment
- ‘Biohazard’ signs with ‘DO NOT ENTER’ written underneath the symbol.
- Hand disinfectant – Povidone-Iodine (Betadine antiseptic ointment or liquid) for 10 min (AS/NZS 2243.3: 2010 Table F1)
- Spill disinfectant – bleach (AS/NZS 2243.3: 2010 Table F2)
- Absorbent materials
- Autoclave tape
- Tweezers for sharps
- Biohazard bags for contaminated waste
- Sharps containers
- Unbreakable container for transport of biohazard wastes for decontamination.
- Copies of Incident Report Form & pen
- Emergency contact details
- First aid kit
- Copy of Risk Management Plan
APPENDIX E INCIDENT REPORT FORM

CANDIDA ALBICANS INCIDENT/ILLNESS REPORT FORM
(Adapted from AS/NZ 2243.3:2010 Appendix B Example Incident/Illness Report Form)

DATE AND LOCATION OF INCIDENT EXPOSURE

NATURE OF INCIDENT:
What was the affected person doing and how did the incident exposure occur? (Describe the work being performed, list sequence of events)

__________________________________________________________________________________________________________________________________________________________________________________________

PERSONNEL INVOLVED
(Names) 1.  
  2.  

NATURE OF INJURY, FIRST AID/MEDICAL TREATMENT/ILLNESS

__________________________________________________________________________________________________________________________________________________________________________________________

SPILLS CLEAN-UP PROCEDURE
(Include names of personnel involved, PPE and disinfectant used).

WITNESSES
(Names) 1.  
  2.  

State what witness saw occur

__________________________________________________________________________________________________________________________________________________________________________________________

SUPERVISOR
Name Signature Date

FOLLOW UP PREVENTATIVE ACTION

Signature Completion Date

This completed form must be submitted to Dr Kate Hammer within 48 hours of the incident occurring.
The temperature range that kills *C. albicans* has been found by most researchers to be 42 to 55°C.\(^2\)

However, Wiley & Westerberg (1969) found that *C. albicans* present in human sewage was more resistant to heat than other human pathogens. They determined that *C. albicans* was killed only when exposed to 70°C for 60 min or 80°C for 30 min.\(^3\)

Oven baking at 200°C for 50 minutes is well in excess of all these temperatures and should effectively kill all *C. albicans* contained within the bread. However, experiments will be conducted to ensure this and each loaf will be monitored and tested for living *C. albicans* before serving. If found, the bread will either be disposed of or contained in a display unit during the exhibition.

---


APPENDIX G HEALTH, SAFETY AND ENVIRONMENT ASSESSMENT AND CONTROL OF WORK FORM, INCLUDING ASSESSMENT OF OHS RISKS

This form is a tool to assist Staff, Supervisors and Managers in the following:
- Identification of health and safety hazards that staff and others may be exposed to at work and environmental aspects associated with activities.
- Assessment of OH&S and environment risks.
- Identification / implementation of existing / proposed controls.

This form consists of six parts:

Part A - Assessment (Sections 1-5)
- To be completed for all projects, activities or major plant or equipment being assessed (or reassessed following major changes).
- Sections 1 – 4 are to be completed by the Line Manager responsible in consultation with staff and the Health and Safety Representative involved. Assistance may be sought from the OHSE staff where necessary.
- Section 5 is to be completed by staff and Line Managers as indicated and endorsed by the relevant OHSE staff and management.
- Where ionizing and non-ionising radiation or biological material is used, Parts C1, C2 and/or D must be completed (see below).

Part B - Annual Review Supplement
- To be completed annually or when changes that involve different OHSE risks to the workplace, procedures, plan or equipment are proposed.

Part C1 - Ionising Radiation Supplement
- To be completed when ionizing radiation is used.

Part C2 - Non-Ionising Radiation Supplement
- To be completed when non-ionising radiation is used.

Part D - Biological Supplement
- To be completed when biological materials are used.

Part E - Project Closure
- Online Tip: Type directly into shaded text boxes. Use F1 for help when cursor is on any shaded box.
### Part A: Section 1. Project, Work or Equipment details

<table>
<thead>
<tr>
<th>Department/Section</th>
<th></th>
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<tbody>
<tr>
<td>SymbioticA, APHB</td>
<td></td>
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<table>
<thead>
<tr>
<th>Project Title</th>
<th>Number/code</th>
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<tr>
<td><em>HumanThrush Entanglements</em></td>
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<table>
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<table>
<thead>
<tr>
<th>Start date of project</th>
<th>End date of project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Description of work area and work tasks, eg water laboratory, analysis of sediment. (If applicable, attach a separate short project outline with work methods and equipment used)

1. PC2 Biological Laboratory, Rm 1.4 L-Block QEII Medical Centre, culture of *Candida albicans* and production of artworks
2. Gallery Central, exhibition of *Candida albicans*

<table>
<thead>
<tr>
<th>Line Manager/ Supervisor</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oron Catts, Director, SymbioticA</td>
<td></td>
</tr>
<tr>
<td>Staff Names</td>
<td>Relationship/Position</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Asst/Professor Ionat Zurr</td>
<td>Academic Supervisor/CI SymbioticA</td>
</tr>
<tr>
<td>Tarsh Bates</td>
<td>Researcher</td>
</tr>
<tr>
<td>Dr Kate Hammer</td>
<td>Supervisor/ Laboratory Manager</td>
</tr>
</tbody>
</table>

External collaborators (include names of personnel working on site)
- Gallery Central Shopfront
- Sue Hauri-Downing

Location(s) of work, eg field site, building room number, external location
1. PC2 Biological Laboratory, Rm 1.4 L-Block QEII Medical Centre, culture of *Candida albicans*
2. Gallery Central, exhibition of *Candida albicans*
### Part A: Section 2a. Workplace Hazards Identification

Using tick boxes identify all hazards associated with workplace, system of work, equipment and substances used.

<table>
<thead>
<tr>
<th>Mechanical (Plant)</th>
<th>7. Biological</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vehicles, transport</td>
<td>☒ 7.1 Biological materials (Refer to Part D)</td>
</tr>
<tr>
<td>1.2 Plant, machinery, equipment in motion</td>
<td>☐ 7.2 Biological materials (refer to Part D)</td>
</tr>
<tr>
<td>1.3 Compression/tension/stored energy</td>
<td>☐ 7.3 Allergens / sensitisation</td>
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<tr>
<td>1.4 Noise</td>
<td>☐ 7.4 Irritants</td>
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<td>1.5 Vibration</td>
<td>☒ 7.5 Genotoxins (mutagens, teratogens)</td>
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<tr>
<td>1.6 Firearms</td>
<td>☐ 7.6 Zoonoses (refer to Part D)</td>
</tr>
<tr>
<td>1.7 Pressure equipment (high/vacuum)</td>
<td>☐ 7.7 Handling of small animals</td>
</tr>
<tr>
<td>1.8 Tools, sharps, cutting implements</td>
<td>☒ 7.8 Handling of large animals</td>
</tr>
<tr>
<td>7. Biological</td>
<td>☒ 7.9 Handling of human samples (refer to Part D)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Radiation</th>
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<td>2.1 Ionising (refer to Part C1)</td>
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<td>2.2 Ultraviolet (refer to Part C2)</td>
</tr>
<tr>
<td>2.3 Infrared (refer to Part C2)</td>
</tr>
<tr>
<td>2.4 Laser (refer to Part C2)</td>
</tr>
<tr>
<td>2.5 Radiofrequency (refer to Part C2)</td>
</tr>
<tr>
<td>2.6 Electromagnetic field (refer to Part C2)</td>
</tr>
<tr>
<td>2.7 Extremely low frequency (refer Part C2)</td>
</tr>
<tr>
<td>2.8 Generation of dusts, vapours, fumes etc.</td>
</tr>
<tr>
<td>2.9 Asbestos</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical/Hazardous Substances</th>
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<tr>
<td>3.1 Flammable substances</td>
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<tr>
<td>3.2 Explosives</td>
</tr>
<tr>
<td>9. Gases</td>
</tr>
<tr>
<td>9.4 Gas cylinders / tanks</td>
</tr>
<tr>
<td>9.6 Toxic/harmful substances</td>
</tr>
<tr>
<td>9.8 Solvents</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Hazardous Environments</th>
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<tr>
<td>5.1 Confined spaces</td>
</tr>
<tr>
<td>5.2 Working at heights</td>
</tr>
<tr>
<td>5.3 Working at sea or in water bodies</td>
</tr>
<tr>
<td>5.4 Heat/cold stress</td>
</tr>
<tr>
<td>6. Electrical</td>
</tr>
<tr>
<td>6.1 High voltage equipment</td>
</tr>
<tr>
<td>6.2 Live electrical equipment</td>
</tr>
<tr>
<td>6.3 Static charge</td>
</tr>
<tr>
<td>6.4 Live electrical equipment</td>
</tr>
<tr>
<td>6.5 Static charge</td>
</tr>
</tbody>
</table>

### 11. Other - Specify:

---

Bio2ic wishes to acknowledge the assistance of CSIRO in the development of this form
Part A: Section 2b. Description of Methodology

| e.g., inactivate the MTB culture by heating at XX °C for Y minutes,...... |

1. Maintenance of *C. albicans* cultures
   1.1. Remove maintenance culture from 30°C incubator.
   1.2. Remove colony from maintenance culture plate using an inoculation loop and streak onto a clean maintenance plate.
   1.3. Place plate into 30°C incubator and incubate for 2-3 days.
   1.4. Discard old culture into biohazard bag and dispose as per OGTR & AS2243.3:2010 S12
   1.5. Repeat as necessary.

2. Preparation of Wallpaper artwork
   2.1. Prepare media
      2.1.1. YEPD liquid culture media
         2.1.1.1. Prepare YEPD liquid culture media as per manufacturer’s instructions
         2.1.1.2. Autoclave culture media to sterilise
         2.1.1.3. Store at 4°C if not being used immediately
   2.1.2. Blood agar culture media
      2.1.2.1. Prepare blood agar base culture media as per manufacturer’s instructions
      2.1.2.2. Autoclave culture media to sterilise
      2.1.2.3. Collect 4% blood using citrate or EDTA tubes from Clinipath
      2.1.2.4. Add blood to 50°C culture media
   2.2. Sterilise customised petri-dish in 4% bleach solution for 10 minutes
      2.2.1. Rinse customised petri-dish with DDI water
      2.2.2. Pour blood agar culture media into the customised petri-dish and leave in BCII safety cabinet to set.
   2.3. Prepare *C. albicans*
      2.3.1. Remove maintenance culture from 30°C incubator.
      2.3.2. Remove colony from maintenance culture plate using an inoculation loop and inoculate into liquid YEPD culture media.
      2.3.3. Place culture into 30°C incubator and incubate for 24 hours.
      2.3.4. Remove culture from incubator and harvest cells by centrifugation at 3000xg for 5 minutes.
      2.3.5. Wash cells with 0.5 volume DDI water.
      2.3.6. Harvest cells by centrifugation at 3000xg for 5 minutes.
      2.3.7. Resuspend pellet in 0.01 volume DDI water and harvest cells by centrifugation.
      2.3.8. Resuspend pellet in 0.01 volume DDI water.
   2.4. Prepare artwork
      2.4.1. Autoclave stencil and sterilise customised display unit in 4% bleach solution for 10 minutes.
      2.4.2. Place stencil onto solidified blood agar.
      2.4.3. Pour resuspended *C. albicans* pellet over the stencil to form a lawn.
      2.4.4. Incubate overnight at 30°C.
      2.4.5. Remove stencil.
      2.4.6. Secure customised petri-dish within customised display unit.
      2.4.7. Clean and autoclave stencil as per OGTR & AS2243.3:2010 S12.
   3. Transportation of Wallpaper artwork between PC2 laboratory and Gallery Central as per IATA DGR transport guidelines
      3.1. Transportation unit designed to conform to IATA DGR transport guidelines for Category B infectious substance (Refer to HTE Risk Minimisation Plan).
      3.2. Disinfect exterior of customised display unit.
      3.3. Disinfect transportation unit.
      3.4. Place disinfected display unit into transportation unit and close.
      3.5. Secure transportation unit in vehicle.
      3.6. Transport to Gallery.
      3.7. Remove display unit from transportation unit.
      3.8. Secure display unit to wall of gallery.
   4. Public exhibition of artwork
      4.1. The exhibition unit will not be opened during the exhibition.
4.2. The public will be informed as to the biohazard and a spill hazard kit will be stored in an appropriate location within the exhibition space (Refer to HTE RMP)

5. Transportation of Wallpaper artwork between Gallery Central and PC2 laboratory at the end of exhibition
   5.1. Remove display unit from wall of gallery
   5.2. Disinfect exterior of customised display unit
   5.3. Disinfect transportation unit
   5.4. Place disinfected display unit into transportation unit and close
   5.5. Secure transportation unit in vehicle
   5.6. Transport to PC2 laboratory
   5.7. Remove display unit from transportation unit

6. Wallpaper artwork disposal
   6.1. Remove customised petri-dish from display unit
   6.2. Dispose of agar and \textit{C. albicans} into an autoclave bag and dispose as per OGTR & AS2243.3:2010 S12
   6.3. Clean and autoclave stencil and sterilise petri-dish and display unit in 4% bleach for 10 minutes

7. Bread artwork
   7.1. Prepare YEPD liquid culture media as in 2.1.1
   7.2. Prepare \textit{C. albicans} as in 2.3
   7.3. Prepare leavening agent
       7.3.1. Prepare commercial instant baker’s yeast as per manufacturer instructions
       7.3.2. Add 5\% \textit{C. albicans} to the baker’s yeast
       7.3.3. Allow to ferment for 10 minutes
   7.4. Prepare bread dough as per standard recipe:
       7.4.1. Mix 500g flour & 1.5 teaspoon salt in a clean bowl
       7.4.2. Add leavening agent to mixture and leave for 15 minutes
       7.4.3. Add 200-250mL water and mix
       7.4.4. Knead for at least 5 minutes
       7.4.5. Cover with a cloth and leave to rise for 1 hour at room temperature
       7.4.6. Knead briefly
       7.4.7. Leave to rise for 30 minutes at room temperature
   7.5. Bake at 200°C for 50 minutes to bake bread and inactivate all yeasts
       7.5.1. Test temperature of interior of the loaf during baking several times and at the end of the baking time.
   7.6. Test for \textit{C. albicans} inactivation
       7.6.1. Sample baked loaf
       7.6.2. Spread sample onto YEPD growth media to test for living \textit{C. albicans}
       7.6.3. If living \textit{C. albicans} are present, ensure bread is not ingested and exposure protocols followed or dispose of as per OGTR & AS2243.3:2010
   7.7. Clean and autoclave preparation utensils
   7.8. Transport bread to gallery and serve
       7.8.1. The public will be informed as to the ingredients to ask them to make a conscious decision about their ingestion of the bread
   7.9. Any bread remaining at the end of the exhibition will be disposed of as per OGTR & AS2243.3:2010.
## Part A: Section 3a. Assessment of OHS Risks

This page is used to record each of the occupational health and safety hazards identified in Section 2 (ticked boxes) and to record the risk ratings associated with each hazard.

Refer to the Risk Assessment module for assistance in completing this section.

Transfer all high hazards, i.e., those with a catastrophic consequence inherent risk and/or high residual risk rating to column 1 in Section 3b and give details of current and proposed controls.

<table>
<thead>
<tr>
<th>No</th>
<th>Description of task/activity</th>
<th>Specific Hazard</th>
<th>Inherent Risk*</th>
<th>Controls – Existing and Proposed</th>
<th>Residual Risk*</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Culture maintenance</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1</td>
<td>Subculture stock as necessary to maintain primary culture</td>
<td>spill occurs during subculturing: injury</td>
<td>I 2 L</td>
<td>Undertake in PC2-certified laboratory, Class II Biosafety cabinet, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010 Spill isolated and cleaned in compliance with OGTR &amp; AS2243.3:2010 Conduct first aid if necessary</td>
<td>VG Low</td>
</tr>
<tr>
<td>1.1.2</td>
<td>Contamination of C. albicans stock during subculturing: work delay</td>
<td>I 2 L</td>
<td>Undertake culture in PC2-certified laboratory, Class II Biosafety cabinet in compliance with OGTR &amp; AS2243.3:2010 Maintain replicates and stock culture Dispose of contaminated culture as per OGTR &amp; AS2243.3:2010 Subculture from stored stock culture</td>
<td>VG Low</td>
<td></td>
</tr>
<tr>
<td>1.1.3</td>
<td>Biological contaminated waste exposure: injury</td>
<td>I 1 L</td>
<td>Undertake in PC2-certified laboratory, Class II Biosafety cabinet, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010 Dispose of contaminated culture as per OGTR &amp; AS2243.3:2010 Conduct first aid if necessary Notify supervisor</td>
<td>VG Low</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Media preparation</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Preparing media ingredients</td>
<td>Dry spill occurs: injury</td>
<td>I 1 L</td>
<td>Ingredients are not hazardous or toxic Appropriate PPE worn at all times Spill isolated and cleaned in compliance with OGTR &amp; AS2243.3:2010 Conduct first aid if necessary</td>
<td>R Low</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Hot agar preparation</td>
<td>Hot agar spill occurs: spill hazard</td>
<td>I 3 L</td>
<td>Follow handling best practice Ingredients are not hazardous or toxic Appropriate PPE worn at all times Spill isolated and cleaned in compliance with OGTR &amp; AS2243.3:2010</td>
<td>R Low</td>
</tr>
<tr>
<td>2.2.2</td>
<td>Hot agar spill occurs: injury</td>
<td>I 2 L</td>
<td>Follow handling best practice Ingredients are not hazardous or toxic; possible burn injury Appropriate PPE worn at all times Notify supervisor Conduct first aid treatment on site, medical treatment if necessary</td>
<td>R Low</td>
<td></td>
</tr>
<tr>
<td>Section</td>
<td>Scenario</td>
<td>Likelihood</td>
<td>Impact</td>
<td>Risk</td>
<td>Mitigation Strategies</td>
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</tr>
<tr>
<td>2.2.3</td>
<td>Hot agar spill occurs: injury &amp; work delay</td>
<td>2</td>
<td>1</td>
<td>L</td>
<td>Follow handling best practice. Ingredients are not hazardous or toxic; possible burn injury. Appropriate PPE worn at all times. Notify supervisor. Conduct first aid treatment on site, medical treatment if necessary. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.2.4</td>
<td>Media flask breaks: injury</td>
<td>2</td>
<td>2</td>
<td>L</td>
<td>Ingredients are not hazardous or toxic; possible burn injury. Appropriate PPE worn at all times. Follow handling best practice and sharps hazard protocol in compliance with OGTR &amp; AS2243.3:2010. Conduct first aid if necessary. Notify supervisor. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.2.5</td>
<td>Media flask breaks: injury &amp; work delay</td>
<td>2</td>
<td>2</td>
<td>L</td>
<td>Ingredients are not hazardous or toxic; possible burn injury. Appropriate PPE worn at all times. Follow handling best practice and sharps hazard protocol in compliance with OGTR &amp; AS2243.3:2010. Conduct first aid if necessary. Notify supervisor. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Reheating stored media</td>
<td>2</td>
<td>2</td>
<td>L</td>
<td>Ingredients are not hazardous or toxic; possible burn injury. Appropriate PPE worn at all times. Follow handling best practice and sharps hazard protocol in compliance with OGTR &amp; AS2243.3:2010. Conduct first aid if necessary. Notify supervisor. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.3.3</td>
<td>Spill occurs: injury</td>
<td>1</td>
<td>2</td>
<td>L</td>
<td>Ingredients are not hazardous or toxic; possible burn injury. Appropriate PPE worn at all times. Spill cleaned in compliance with OGTR &amp; AS2243.3:2010. Conduct first aid if necessary. Notify supervisor. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Blood collection</td>
<td>2</td>
<td>3</td>
<td>M</td>
<td>Collection delayed due to collector unavailability: work delay. Arrange back up appointments. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.4.2</td>
<td>Injury occurs: injury</td>
<td>1</td>
<td>2</td>
<td>L</td>
<td>Collection conducted by a trained phlebotomist at a medical centre. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Injury occurs: injury &amp; work delay</td>
<td>2</td>
<td>1</td>
<td>L</td>
<td>Collection conducted by a trained phlebotomist at a medical centre. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.5</td>
<td>Blood agar preparation</td>
<td>2</td>
<td>2</td>
<td>L</td>
<td>Blood collection tubes defective or damaged: work delay. Collection conducted by a trained phlebotomist at a medical centre with excess supplies. Contingency time scheduled.</td>
</tr>
<tr>
<td></td>
<td>Blood collection tubes damaged during transport between clinic and lab: work delay</td>
<td>2</td>
<td>2</td>
<td>L</td>
<td>Transport in sealed bag and unbreakable transport unit. Arrange back up appointments. Contingency time scheduled.</td>
</tr>
<tr>
<td>2.5</td>
<td>Blood agar preparation</td>
<td>2</td>
<td>3</td>
<td>M</td>
<td>Agar too hot/too cold during preparation: work delay. Monitor temperature closely and prepare or reheat base media at the appropriate time. Reheat if necessary. Discard and prepare new media. Contingency time scheduled.</td>
</tr>
</tbody>
</table>

C. albicans culture for artworks
### Human Thrush Entanglements Risk Management Plan

<table>
<thead>
<tr>
<th>Section</th>
<th>Event</th>
<th>Likelihood</th>
<th>Impact</th>
<th>Description</th>
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<tbody>
<tr>
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<td>Media inoculation</td>
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<td></td>
<td>2</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Culture flask breaks: injury</td>
<td>1</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Culture flask breaks: work delay</td>
<td>1</td>
<td>1</td>
<td>L</td>
</tr>
<tr>
<td>3.1.3</td>
<td>Spill occurs: injury</td>
<td>1</td>
<td>2</td>
<td>L</td>
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<td>2</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td>3.2.1</td>
<td>Culture incubation</td>
<td>1</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Culture flask breaks: injury</td>
<td>1</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Culture flask breaks: work delay</td>
<td>1</td>
<td>1</td>
<td>L</td>
</tr>
<tr>
<td>3.2.3</td>
<td>Spill occurs: injury</td>
<td>1</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td>3.2.4</td>
<td>Spill occurs: work delay</td>
<td>1</td>
<td>1</td>
<td>L</td>
</tr>
<tr>
<td>3.2.5</td>
<td>Culture fails to grow or dies: work delay</td>
<td>2</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td>3.2.6</td>
<td>Inadequate culture production: work delay</td>
<td>2</td>
<td>4</td>
<td>M</td>
</tr>
<tr>
<td>3.3.1</td>
<td>C. albicans pelletisation</td>
<td>1</td>
<td>2</td>
<td>L</td>
</tr>
<tr>
<td>3.3.2</td>
<td>Culture flask breaks: work delay</td>
<td>1</td>
<td>1</td>
<td>L</td>
</tr>
<tr>
<td>3.3.3</td>
<td>Centrifuge tube breaks: injury</td>
<td>1</td>
<td>1</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td>M</td>
</tr>
</tbody>
</table>

Bio2ic wishes to acknowledge the assistance of CSIRO in the development of this form
| 3.3.4 | Centrifuge tube breaks: work delay | 1 | 2 | L | Follow handling best practice  
Maintain replicates and/or prepare replacement culture  
Notify supervisor  
Contingency time scheduled | R | Low |
| 4 | Customised display unit for wallpaper artwork | | | | | | |
| 4.1 | Unit construction | Unit poorly constructed: work delay | 2 | 1 | L | Ensure design is appropriate  
Ensure reputable fabricator  
Ensure prototype is of good quality  
Check unit for quality | R | Low |
| | Unit construction or delivery delayed: work delay | 3 | 4 | M | Ensure reputable fabricator  
Ensure design is clear and supplied to fabricator in relevant format  
Order early in project timeline  
Frequent communication with fabricator  
Contingency time scheduled | R | Moderate |
| 4.2 | Unit transport | Unit breaks during transportation: work delay | 2 | 1 | L | Follow handling best practice and use secure packaging  
Order replacement unit  
Notify supervisor  
Contingency time scheduled | R | Low |
| 4.3.2 | Media preparation and incubation | Unit damaged: work delay | 2 | 1 | L | Follow handling best practice  
Order replacement unit  
Notify supervisor  
Contingency time scheduled | R | Low |
| 4.3.3 | Installation & exhibition | Unit damaged: work delay | 3 | 2 | M | Follow handling best practice  
Order replacement unit  
Notify supervisor  
Contingency time scheduled | R | Moderate |
| 4.3.4 | Unit damaged: injury | 1 | 2 | L | Follow handling best practice  
Conduct first aid if necessary  
Notify supervisor | R | Low |
| 4.3.5 | Light unit fails: work delay | 1 | 2 | L | Test prior to installation  
Purchase extra units  
Notify supervisor | R | Low |
| 4.4.1 | Disinfection | Bleach spill occurs: injury | 1 | 3 | L | 4% bleach solution not harmful if rinsed off skin immediately  
Follow handling best practice  
Appropriate PPE in compliance with OGTR & AS2243.3:2010  
Spill isolated and cleaned in compliance with OGTR & AS2243.3:2010  
Conduct first aid if necessary  
Notify supervisor | R | Low |
| | Unit damaged: work delay | 2 | 2 | L | Follow handling best practice  
Order replacement unit  
Notify supervisor  
Contingency time scheduled | R | Low |
| | Unit disinfection inadequate & public exposure occurs: injury | 2 | 1 | L | Follow disinfection procedure in compliance with OGTR & AS2243.3:2010  
Disinfection technique tested prior to installation  
Implement public exposure management plan (Refer to HTE RMP) | R | Low |
| | Unit disinfection inadequate & public exposure occurs: political | 3 | 1 | M | Follow disinfection procedure in compliance with OGTR & AS2243.3:2010  
Disinfection technique tested prior to installation  
Implement public exposure management plan (Refer to HTE RMP) | R | Moderate |
<table>
<thead>
<tr>
<th>4</th>
<th>Wallpaper artwork preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.1</td>
<td>media preparation</td>
</tr>
<tr>
<td></td>
<td>Spill occurs: injury</td>
</tr>
<tr>
<td></td>
<td>Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010</td>
</tr>
<tr>
<td></td>
<td>Follow handling best practice</td>
</tr>
<tr>
<td></td>
<td>Spill isolated and cleaned in compliance with OGTR &amp; AS2243.3:2010</td>
</tr>
<tr>
<td></td>
<td>Conduct first aid if necessary</td>
</tr>
<tr>
<td></td>
<td>Contingency time scheduled</td>
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<tr>
<td></td>
<td>R</td>
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<tr>
<td>4.1.2</td>
<td>Spill occurs: work delay</td>
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<tr>
<td></td>
<td>Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010</td>
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<tr>
<td></td>
<td>Follow handling best practice</td>
</tr>
<tr>
<td></td>
<td>Spill isolated and cleaned in compliance with OGTR &amp; AS2243.3:2010</td>
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<td></td>
<td>Prepare replacement media</td>
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<td></td>
<td>Contingency time scheduled</td>
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<tr>
<td></td>
<td>R</td>
</tr>
<tr>
<td>4.1.3</td>
<td>Media flask breaks: injury</td>
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<tr>
<td></td>
<td>Follow handling best practice and sharps hazard protocol in compliance with OGTR &amp; AS2243.3:2010</td>
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<tr>
<td></td>
<td>Conduct first aid if necessary</td>
</tr>
<tr>
<td></td>
<td>R</td>
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<tr>
<td>4.1.4</td>
<td>Media flask breaks: work delay</td>
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<tr>
<td></td>
<td>Follow handling best practice</td>
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<td></td>
<td>Prepare replacement media</td>
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<td></td>
<td>Contingency time scheduled</td>
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<td>R</td>
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<tr>
<td>4.1.5</td>
<td>Petri-dish breaks: work delay</td>
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<td></td>
<td>Follow handling best practice and sharps hazard protocol in compliance with OGTR &amp; AS2243.3:2010</td>
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<td></td>
<td>Repair or replace dish and prepare replacement media</td>
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<td>Contingency time scheduled</td>
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<td>R</td>
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<tr>
<td>4.1.6</td>
<td>Agar fails to cure: work delay</td>
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<td></td>
<td>Prepare as per manufacturer instructions</td>
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<td></td>
<td>Prepare replacement media</td>
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<td>Contingency time scheduled</td>
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<td>R</td>
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<tr>
<td>4.1.7</td>
<td>Blood coagulates during curing: work delay</td>
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<td></td>
<td>Prepare as per manufacturer instructions and monitor temperature of agar closely</td>
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<td>Prepare replacement media</td>
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<td>Contingency time scheduled</td>
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<td>R</td>
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<td>4.1.8</td>
<td>Culture media contaminated: work delay</td>
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<td>Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010</td>
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<td></td>
<td>Prepare replacement media</td>
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<td></td>
<td>Dispose of contaminated media as per OGTR &amp; AS2243.3:2010</td>
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<tr>
<td></td>
<td>Contingency time scheduled</td>
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<td></td>
<td>VG</td>
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<tr>
<td>4.2.1</td>
<td>Culture incubation</td>
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<td></td>
<td>Culture contaminated: work delay</td>
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<tr>
<td></td>
<td>Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010</td>
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<tr>
<td></td>
<td>Prepare replacement media and culture</td>
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<td></td>
<td>Dispose of contaminated culture as per OGTR &amp; AS2243.3:2010</td>
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<tr>
<td></td>
<td>Contingency time scheduled</td>
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<tr>
<td></td>
<td>VG</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Culture fails to form lawn or dies: work delay</td>
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<td></td>
<td>Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010</td>
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<tr>
<td></td>
<td>Prepare excess culture</td>
</tr>
<tr>
<td></td>
<td>Prepare replacement media and culture</td>
</tr>
<tr>
<td></td>
<td>Dispose of culture as per OGTR &amp; AS2243.3:2010</td>
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<tr>
<td></td>
<td>Contingency time scheduled</td>
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<tr>
<td></td>
<td>R</td>
</tr>
</tbody>
</table>
| 4.3 | Stencil sterilisation | Stencil damaged: work delay | 2 | 2 | L | Follow handling best practice  
Order replacement stencil  
Contingency time scheduled | R | Low |
<table>
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</thead>
<tbody>
<tr>
<td>5</td>
<td>Wallpaper artwork transport between PC2 laboratory and exhibition venue</td>
<td></td>
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</tbody>
</table>
| 5.1.1 | Transport | Spill occurs: injury | 1 | 1 | L | Display unit secured in IATA DGR transport requirement compliant Transport Unit  
Transport Unit safely secured in vehicle  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary | R | Low |
| 5.2.1 | Car accident | spill occurs: injury | 1 | 1 | L | Display unit secured in IATA DGR transport requirement compliant Transport Unit  
Transport Unit safely secured in vehicle  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary | R | Low |
| 5.2.2 | Researcher injured: injury | | 2 | 2 | L | Follow driving best practice  
Conduct first aid if necessary  
Notify supervisor | R | Low |
| 5.2.3 | Researcher injured: work delay | | 3 | 2 | M | Follow driving best practice  
Notify supervisor | R | Moderate |
| 5.2.4 | Researcher injured: injury & work delay | | 4 | 2 | M | Follow driving best practice  
Conduct first aid on site, medical treatment if necessary  
Notify supervisor | R | Moderate |
| 5.3.1 | Car accident & transport unit opens | spill occurs: injury | 1 | 1 | L | Display unit secured in IATA DGR transport requirement compliant Transport Unit  
Transport Unit safely secured in vehicle  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary | R | Low |
| 5.3.2 | Public exposure occurs: injury | | 2 | 1 | L | Display unit secured in IATA DGR transport requirement compliant Transport Unit  
Transport Unit safely secured in vehicle  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Implement public exposure management plan (Refer to HTE RMP) | R | Low |
| 5.3.3 | Public exposure occurs: political | | 3 | 1 | M | Display unit secured in IATA DGR transport requirement compliant Transport Unit  
Transport Unit safely secured in vehicle  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Implement public exposure management plan (Refer to HTE RMP) | R | Moderate |
| 6 | Exhibition of wallpaper artwork | | | | | | | |
| 6.1.1 | Display unit leaks | Spill occurs: injury | 1 | 1 | L | Design unit to minimise leaks  
Test for leaks prior to installation  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary | R | Low |
| 6.1.2 | Public exposure occurs: injury | 2 | 1 | L | Design to minimise leaks  
Test for leaks prior to installation  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary  
Implement public exposure management plan (Refer to HTE RMP) | R | Low |
|---|---|---|---|---|---|---|---|
| 6.1.3 | Public exposure occurs: political | 3 | 1 | M | Design to minimise leaks  
Test for leaks prior to installation  
Public informed as to their risk of infection verbally and by signs within the gallery  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary  
Implement public exposure management plan (Refer to HTE RMP) | R | Moderate |
| 6.2.1 | Display unit falls and damaged | 1 | 1 | L | Follow hanging best practice  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary | R | Low |
| 6.2.2 | Public exposure occurs: injury | 2 | 2 | L | Follow hanging best practice  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary  
Implement public exposure management plan (Refer to HTE RMP) | R | Low |
| 6.2.3 | Public exposure occurs: political | 3 | 2 | M | Follow hanging best practice  
Public informed as to their risk of infection verbally and by signs within the gallery  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary  
Implement public exposure management plan (Refer to HTE RMP) | R | Moderate |
| 6.3.1 | Fire in gallery and display unit is damaged | 1 | 1 | L | Minimise flammable materials within gallery  
Ensure fire extinguisher and blanket are available  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary  
Notify supervisor | R | Low |
| 6.3.2 | Public exposure occurs: injury | 2 | 1 | L | Minimise flammable materials within gallery  
Ensure fire extinguisher and blanket are available  
Public informed as to their risk of infection verbally and by signs within the gallery  
Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)  
Conduct first aid if necessary  
Implement public exposure management plan (Refer to HTE RMP)  
Notify supervisor | R | Low |
### HumanThrush Entanglements Risk Management Plan

| 6.3.3 | Public exposure occurs: political | 3 | 1 | M | Minimise flammable materials within gallery<br>Ensure fire extinguisher and blanket are available<br>Public informed as to their risk of infection verbally and by signs within the gallery<br>Spill isolated and cleaned using SHK and spill management plan in compliance with OGTR & AS2243.3:2010 (Refer to HTE RMP)<br>Conduct first aid if necessary<br>Implement public exposure management plan (Refer to HTE RMP)<br>Notify supervisor | R | Moderate |
| 6.3.4 | Unit damaged: work delay | 4 | 1 | M | Minimise flammable materials within gallery<br>Ensure fire extinguisher and blanket are available<br>Notify supervisor | R | Moderate |

### Wallpaper artwork disposal

| 7.1.1 | Culture and media disposal | Spill occurs: injury | 1 | 2 | L | Undertake in PC2-certified laboratory, Class II Biosafety cabinet, wearing appropriate PPE, in compliance with OGTR & AS2243.3:2010<br>Spill isolated and cleaned in compliance with OGTR & AS2243.3:2010<br>Conduct first aid if necessary | VG | Low |
| 7.1.2 | Biological contaminated waste exposure: injury | 1 | 1 | L | Undertake in PC2-certified laboratory, Class II Biosafety cabinet, wearing appropriate PPE, in compliance with OGTR & AS2243.3:2010<br>Conduct first aid if necessary<br>Notify supervisor | VG | Low |

### Bread artwork preparation

| 12.1.1 | Leavening agent preparation | Spill occurs: injury | 1 | 2 | L | Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR & AS2243.3:2010<br>Spill isolated and cleaned in compliance with OGTR & AS2243.3:2010<br>Conduct first aid if necessary | R | Low |
| 12.1.2 | Spill occurs: work delay | 1 | 1 | L | Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR & AS2243.3:2010<br>Spill isolated and cleaned in compliance with OGTR & AS2243.3:2010<br>Prepare replacement culture<br>Contingency time scheduled | R | Low |
| 12.2.1 | Dough preparation | Skin exposed: injury | 1 | 2 | L | Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR & AS2243.3:2010<br>Conduct first aid if necessary | R | Low |
| 12.2.2 | Skin exposed: work delay | 1 | 1 | L | Undertake in PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR & AS2243.3:2010<br>Contingency time scheduled | R | Low |
| 12.3.1 | Baking | Oven fails to reach kill temperature: work delay | 2 | 2 | L | Use properly maintained oven<br>Test oven temperature prior to baking<br>Conduct tests early in project timeline<br>Organise oven repair and prepare replacement dough<br.Dispose of undercooked dough as per OGTR & AS2243.3:2010 | R | Low |
### 12.3.2 Interior of loaf fails to reach kill temperature: work delay

| R | M | 4 | 2 | Moderate |

**12.3.3 Loaf fails to reach TDT: work delay**

| R | M | 4 | 2 | Moderate |

**12.3.4 Biological contaminated waste exposure: injury**

| R | M | 1 | 1 | Low |

**12.4.1 Inactivation testing**

| R | M | 1 | 1 | Low |

**12.4.2 Living C. albicans present in test samples: work delay**

| R | M | 4 | 1 | Moderate |

**12.4.3 Biological contaminated waste exposure: injury**

| R | M | 1 | 1 | Low |

### 13 Exhibition of bread artwork

**13.1.1 Ingestion of Candida bread Public exposure: injury**

| R | H | 1 | 1 | Low |

**13.1.2 Public exposure: political**

| R | H | 3 | 5 | High |

### 14 Bread artwork disposal
## HumanThrush Entanglements Risk Management Plan

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Probability</th>
<th>Likelihood</th>
<th>Risk Management Plan</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.1</td>
<td>Artwork disposal</td>
<td>Biological contaminated waste exposure: injury</td>
<td>I</td>
<td>L</td>
<td>Not hazardous or toxic if TDT has been reached and no living <em>C. albicans</em> found in test samples&lt;br&gt;Dispose of left-over bread as per OGTR &amp; AS2243.3:2010&lt;br&gt;Conduct first aid if necessary&lt;br&gt;Notify supervisor</td>
</tr>
</tbody>
</table>

### Public anxiety

| 15.1.1  | Public complaint received | Complaint received by researcher during exhibition: political | 2 | 3 | M | Public informed as to their risk of infection verbally and by signs within the gallery<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Moderate |
| 15.1.2  | Complaint received by researcher prior to or after exhibition: political | 2 | 2 | L | Public informed as to their risk of infection verbally and supplied with the HTE RMP if requested<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Low |
| 15.1.3  | Complaint received by gallery management during exhibition: political | 3 | 3 | M | Gallery management informed as to the risk of public infection verbally and supplied with a copy of the HTE RMP<br>Public informed as to their risk of infection verbally and by signs within the gallery<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Moderate |
| 15.2.1  | Complaint received by gallery management prior to or after exhibition: political | 3 | 2 | M | Gallery management informed as to the risk of public infection verbally and supplied with a copy of the HTE RMP<br>Public informed as to their risk of infection verbally and supplied with the HTE RMP if requested<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Moderate |
| 15.2.2  | Complaint received by SymbioticA during exhibition: political | 3 | 2 | M | SymbioticA management informed as to the risk of public infection verbally and supplied with a copy of the HTE RMP<br>Public informed as to their risk of infection verbally and by signs within the gallery<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Moderate |
| 15.2.3  | Complaint received by SymbioticA prior to or after exhibition: political | 3 | 2 | M | SymbioticA management informed as to the risk of public infection verbally and supplied with a copy of the HTE RMP<br>Public informed as to their risk of infection verbally and supplied with the HTE RMP if requested<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Moderate |
| 15.2.4  | Complaint received by UWA during exhibition: political | 3 | 3 | M | UWA PR informed as to the risk of public infection verbally and supplied with a copy of the HTE RMP<br>Public informed as to their risk of infection verbally and by signs within the gallery<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Moderate |
| 15.2.5  | Complaint received by UWA prior to or after exhibition: political | 3 | 2 | M | UWA PR management informed as to the risk of public infection verbally and supplied with a copy of the HTE RMP<br>Public informed as to their risk of infection verbally and supplied with the HTE RMP if requested<br>Implement public exposure management plan (Refer to HTE RMP<br>Notify supervisor | R | Moderate |

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Bio2ic wishes to acknowledge the assistance of CSIRO in the development of this form
### HumanThrush Entanglements Risk Management Plan

<table>
<thead>
<tr>
<th>16</th>
<th>Any task</th>
<th>Trip, slip or fall</th>
<th>2</th>
<th>3</th>
<th>M</th>
<th>R</th>
<th>Moderate</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.1</td>
<td>injury</td>
<td></td>
<td>2</td>
<td>3</td>
<td>M</td>
<td>R</td>
<td>Moderate</td>
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<td>Appropriate clothing and footwear worn at all times</td>
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<td>Items transported using a trolley if they are heavy or likely to</td>
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<td>obstruct vision</td>
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<td>Trip hazards removed or minimised in laboratory and gallery</td>
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<td>wherever possible</td>
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<td>Conduct first aid on site, medical treatment if necessary</td>
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<tr>
<td>16.2</td>
<td>Work delay</td>
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<td>1</td>
<td>1</td>
<td>L</td>
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<td>Low</td>
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<td>Appropriate clothing and footwear worn at all times</td>
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<td>Items transported using a trolley if they are heavy or likely to</td>
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<td></td>
<td>Trip hazards removed or minimised in laboratory and gallery</td>
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<td>wherever possible</td>
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<td></td>
<td></td>
<td>Some contingency time scheduled</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.3</td>
<td>Injury &amp; work delay</td>
<td></td>
<td>2</td>
<td>2</td>
<td>L</td>
<td>R</td>
<td>Low</td>
</tr>
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<td></td>
<td>Appropriate clothing and footwear worn at all times</td>
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<td>obstruct vision</td>
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<td></td>
<td>Trip hazards removed or minimised in laboratory and gallery</td>
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<td>wherever possible</td>
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<td></td>
<td>Conduct first aid on site, medical treatment if necessary</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Some contingency time scheduled</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C – consequences; L – likelihood; IR – inherent risk; M – management control; RR – residual risk

**Online Tip:** To add new rows - Go to the last cell in the table and press the 'Tab' key
### Part A: Section 3b. High OHS residual risks and catastrophic consequence (life threatening) inherent risks, agreed additional risk controls and implementation of controls

<table>
<thead>
<tr>
<th>Hazards with high risks identified</th>
<th>Existing Controls (Procedures/Equipment)</th>
<th>Agreed additional risk controls</th>
<th>Dates for implementation / Person responsible</th>
<th>How will these risk and control options be monitored?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingestion of Candida bread: Political</td>
<td>Not hazardous or toxic if TDT has been reached and no living C. albicans found in test samples. Public informed as to their risk of infection verbally and by signs within the gallery. If living C. albicans found in test samples, bread will be contained in a display unit. Implement public exposure management plan (Refer to HTE RMP). Notify supervisor.</td>
<td>Using the Hierarchy of Control, list agreed controls after team consensus on the justification and optimisation of controls.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Part A: Section 4a. Assessment of Environmental Risks

Indicate environmental aspects such as forms of waste. Indicate quantities generated, potential environmental impacts and existing controls. Assess the inherent and residual risk.

Refer to the Risk Assessment module for assistance in completing this section.

Transfer all high environmental aspects, ie those with a **high residual** risk rating to column 1 in Section 4b and give details of proposed controls.

<table>
<thead>
<tr>
<th>Environmental aspects</th>
<th>Form &amp; quantity/year</th>
<th>Potential environmental impact</th>
<th>Inherent Risk*</th>
<th>Controls – Existing and Proposed</th>
<th>Residual Risk*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Waste chemical</td>
<td>1 kg 200L</td>
<td>Waste to sewer</td>
<td>Mod Likely Mod</td>
<td>nil</td>
<td>Poor High</td>
</tr>
<tr>
<td>6 Paper</td>
<td>20 kg</td>
<td>Landfill, some recycled</td>
<td>Insig Likely Mod</td>
<td>Landfill, some recycled</td>
<td>Reas Mod</td>
</tr>
<tr>
<td>1 Waste chemical</td>
<td>0.5kg</td>
<td>Waste to sewer</td>
<td>Insig Almost certain Mod</td>
<td>Common bacterial culture chemicals, not toxic or dangerous; disposal in compliance with OGTR &amp; AS2243.3:2010</td>
<td>V Good Mod</td>
</tr>
<tr>
<td>2 Paper</td>
<td>1kg</td>
<td>Landfill, some recycled</td>
<td>Insig Almost certain Mod</td>
<td>Landfill, some recycled</td>
<td>Reas Mod</td>
</tr>
<tr>
<td>3 Plastic petri dishes</td>
<td>0.5kg</td>
<td>Autoclaved, landfill</td>
<td>Insig Almost certain Mod</td>
<td>Landfill; disposal in compliance with OGTR &amp; AS2243.3:2010</td>
<td>Reas Mod</td>
</tr>
<tr>
<td>4 Biological waste</td>
<td>0.1kg</td>
<td>Autoclaved, incineration &amp; landfill</td>
<td>Insig Likely Mod</td>
<td>Incineration &amp; landfill; disposal in compliance with OGTR &amp; AS2243.3:2010</td>
<td>Reas Mod</td>
</tr>
<tr>
<td>5 Glass waste</td>
<td>0.5kg</td>
<td>Landfill, some recycled</td>
<td>Insig Poss Low</td>
<td>Landfill, some recycled; disposal in compliance with OGTR &amp; AS2243.3:2010</td>
<td>Reas Low</td>
</tr>
</tbody>
</table>

**C** – consequences; **L** – likelihood; **IR** – inherent risk; **M** – management control; **RR** – residual risk

Online Tip: To add new rows - Go to the last cell in the table and press the ‘Tab’ key
**Part A: Section 4b. Environmental Aspects with High residual risks, agreed additional risk controls and implementation of controls**

This page is used to record each of the high environmental aspects identified in Section 4a and to outline the proposed controls, agreed controls and details on the implementation of the controls.

<table>
<thead>
<tr>
<th>Environmental aspects with high residual risk</th>
<th>Existing Controls (Reuse, recycling / Procedures/ Equipment etc)</th>
<th>Agreed additional risk controls</th>
<th>Dates for implementation / Person responsible</th>
<th>How will these risk and control options be monitored?</th>
</tr>
</thead>
<tbody>
<tr>
<td>eg Waste acidic solvent discharged to sewer</td>
<td>nil</td>
<td>1. Seek alternative methods</td>
<td>1. Month xx (J. Smith)</td>
<td>Method assessment, training, inspections, review EMS reports.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Contain and recycle</td>
<td>2. Month yy (D. Brown)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Treatment by neutralisation</td>
<td>3. Month yy (A Jones)</td>
<td></td>
</tr>
</tbody>
</table>

Online Tip: To add new rows - Go to the last cell in the table and press the ‘Tab’ key
**Part A: Section 5. Comments / Endorsements**

**Staff identified in Section 1 to complete**

I have noted the (potential and high risk) OHS hazards and environmental aspects identified in Sections 2, 3 and 4 of this assessment and have been advised of their existence within the workplace and the necessary risk controls.

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asst/Professor Ionat Zurr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tarsh Bates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kate Hammer</td>
<td></td>
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</tr>
</tbody>
</table>

Online Tip: To add new rows - Go to the last cell in the table and press the 'Tab' key

**Line Manager, Supervisor (or officer completing assessment)**

This Project/Work has been examined in consultation with the staff members involved, OHSE staff and the Health and Safety Representative. The hazards / environmental aspects have been identified and the control measures indicated have been approved, initiated and/or implemented.

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
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</thead>
<tbody>
<tr>
<td>Oron Catts</td>
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</table>

**OHSE Manager / Officer**

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
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</table>

**Field EMS Officer**

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
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</thead>
</table>

**Specialist Safety Officer (eg Electrical, Diving, Boating, Chemical, Firearms)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
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</thead>
</table>

**Senior Manager**

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
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</thead>
</table>
**Part B Annual Review Supplement**

Project No.: ……………… Date: …../…../…..

Since the last assessment, have any changes occurred in personnel or the nature or degree of the hazards or environmental aspects associated with this work?

Yes ☐ No ☐

If Yes, give details below.
If significant, fill out a new Part A.

### 1. Staff Changes

<table>
<thead>
<tr>
<th>Name</th>
<th>Date Ceased</th>
<th>Date Commenced</th>
<th>Designated Work Group</th>
<th>Health and Safety Representative</th>
<th>OHS Induction (Y/N)</th>
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<tbody>
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</tbody>
</table>

### 2. Location Changes (eg new rooms / buildings / sites)


### 3. New / deleted / changed Hazards / Aspects

(refer to part A – include significant hazard details, environmental aspects and controls)

"enter ‘new’, ‘deleted’ or ‘changed’

<table>
<thead>
<tr>
<th>Hazards, Aspects from Part A</th>
<th>Status of hazard/Aspect*</th>
<th>Inherent Risk</th>
<th>Controls</th>
<th>Residual Risk</th>
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</thead>
<tbody>
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</tbody>
</table>

Note: If new high residual risks are identified, then complete new Part A assessments for Sections 3b and / or 4b to ensure risk controls are appropriate.

**Comments / Endorsements**
### Staff identified in Part A Section 1 and new staff to complete

I have noted the potential and significant hazards and environmental aspects identified in the assessment of work form and the annual review, and have been advised of their existence within the workplace.

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
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</table>

### Line Manager, Project Leader, Supervisor (or officer completing assessment)

This Project/Work has been examined in consultation with the staff members involved, OHSE staff and the Health and Safety Representative. The hazards / environmental aspects have been identified and the control measures indicated have been approved, initiated and/or implemented.

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature: _____________________________</th>
<th>Date <em><strong>/</strong></em>/___</th>
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</tbody>
</table>

### OHSE Manager / Coordinator/ OHSE Officer

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature: _____________________________</th>
<th>Date <em><strong>/</strong></em>/___</th>
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</tbody>
</table>

### EMS Officer

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature: _____________________________</th>
<th>Date <em><strong>/</strong></em>/___</th>
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</table>

### Specialist Safety Officer (eg Electrical, Diving, Boating, Chemical, Firearms)

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature: _____________________________</th>
<th>Date <em><strong>/</strong></em>/___</th>
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</tr>
</tbody>
</table>

### Chief / OIC

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature: _____________________________</th>
<th>Date <em><strong>/</strong></em>/___</th>
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</tbody>
</table>
**Part C1 Ionizing Radiation Supplement**

1. Ionizing Radiation Source and Apparatus Details

List all types of unsealed and sealed radiation sources and radiation apparatus used in the work. Give the type (eg $^{14}$C) and form (eg labelled thymidine or sealed source) of the radionuclide(s). For unsealed radiation sources estimate the maximum activity stored or used at any one time and total for one year.

**Unsealed sources** (If insufficient space attach a list or refer to a file)

<table>
<thead>
<tr>
<th>ARPANSA Hazard Code eg Yellow</th>
<th>Radionuclide</th>
<th>Form</th>
<th>Physical (solid/liquid)</th>
<th>Chemical Compound</th>
<th>Maximum activity used (MBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Sealed sources** (If insufficient space attach a list or refer to a file)

<table>
<thead>
<tr>
<th>ARPANSA Hazard Code eg yellow</th>
<th>Radionuclide</th>
<th>Form</th>
<th>Activity</th>
<th>Frequency of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Irradiating Apparatus** (If insufficient space attach a list or refer to a file)

<table>
<thead>
<tr>
<th>ARPANSA Hazard Code eg. Blue</th>
<th>Apparatus</th>
<th>Make and Model</th>
<th>Output parameters</th>
<th>Frequency of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Staff approved to work with radiation dealing & personnel monitoring
### 3. Precautions Against Hazards

| Fume cupboard or glove box facilities used (indicate room no.) | N/A |
| Shielding used | N/A |
| Type of personal protective equipment used | N/A |
| Describe training undertaken by and/or experience of staff who will use sources or equipment | N/A |
| Describe storage of sources | N/A |
| Are written Operating Procedures available? | Yes ☐ No ☐ If Yes, attach copy |
| Other (eg contamination monitoring, spill kits) | N/A |
| Describe methods of waste disposal | N/A |
| Are emergency procedures in place? | Yes ☐ No ☐ If Yes, attach copy |
| Has environmental impact of accidental release been assessed and entered in Part 4 of Section A of form? | Yes ☐ No ☐ |

### 4. Radiation Safety Officer’s Comments/Endorsements & Radiation or OHS Committee minute acknowledgement

<table>
<thead>
<tr>
<th>Comments/conditions</th>
<th>N/A</th>
</tr>
</thead>
</table>

ARPANSA License No. (Source or Facility) under which use is conducted

<table>
<thead>
<tr>
<th>Work approved without conditions ☐</th>
<th>Approved with conditions ☐</th>
<th>Work not approved ☐</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name ___________________________</td>
<td>Signature __________________</td>
<td>Date _______________</td>
</tr>
<tr>
<td>Radiation / OHS Committee part C1 items minuted:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name ___________________________</td>
<td>Signature __________________</td>
<td>Date _______________</td>
</tr>
</tbody>
</table>
**Part C2 Non-Ionizing Radiation (NIR) Supplement**

1. **Non-Ionizing Radiation Apparatus Details**
   
   List all types of NIR apparatus used in the work. Attach a list or refer to relevant file if there are many apparatus. Give the details of the NIR apparatus and type of NIR eg UV, IR, laser, EMF.

<table>
<thead>
<tr>
<th>ARPANSA Hazard Code Green</th>
<th>Type of apparatus and class</th>
<th>Type of NIR</th>
<th>Output parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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</tr>
</tbody>
</table>

2. **Precautions Against NIR Hazards**

- Safety signs in place to warn staff of the NIR: N/A
- Type of shielding in place: N/A
- Safety interlocks in place: N/A
- Personal protective equipment used: N/A
- Describe training undertaken by, and/or experience of, staff who will use the apparatus: N/A
- Are written Operating Procedures available? Yes ☑ No ☐ If Yes, attach copy
- Are emergency procedures in place? Yes ☑ No ☐ If Yes, attach copy

3. **Test / Survey / Results**

N/A

4. **Radiation Safety Officer’s Comments/Endorsements & Radiation or OHS Committee minute acknowledgement**

Comments/conditions N/A

ARPANSA License No. (Source or Facility) under which use is conducted: ______________________

Work approved without conditions ☐ Approved with conditions ☐ Work not approved ☐

Name __________________________ Signature __________________________ Date ____________

Radiation / OHS Committee part C2 items minuted:

Name __________________________ Signature __________________________ Date ____________
**Part D Biological Supplement**

1. Biological Materials Used

<table>
<thead>
<tr>
<th>Does work fall under AQIS guidelines for the use of imported Biological Materials?</th>
<th>Yes ☐ No ☑</th>
<th>If Yes, provide Permit No. and Title:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is genetic manipulation work performed?</td>
<td>Yes ☐ No ☑</td>
<td></td>
</tr>
<tr>
<td>Is material of human origin used?</td>
<td>Yes ☑ No ☐</td>
<td></td>
</tr>
<tr>
<td>Has sample collection been approved by Human Ethics Committee?</td>
<td>Yes ☑ No ☐ N/A ☐</td>
<td></td>
</tr>
</tbody>
</table>

In the following table, list human materials used and containment and management procedures (eg PC2 labs, BSCII, Standard Operating Procedures):

<table>
<thead>
<tr>
<th>Type of human sample (eg blood)</th>
<th>Source (eg blood bank)</th>
<th>List containment facilities &amp; procedures to minimise/eliminate infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood</td>
<td>Researcher</td>
<td>Collection conducted by a trained phlebotomist at the UWA medical centre using appropriate collection tubes. Transported in secure container between UWA medical centre and PC2 laboratory. Used immediately following collection to prepare blood agar in a PC2-certified laboratory, wearing appropriate PPE, in compliance with OGTR &amp; AS2243.3:2010. Excess blood disposed of in compliance with OGTR &amp; AS2243.3:2010. Handled only by researcher, so no other person comes into contact with the blood.</td>
</tr>
<tr>
<td>Serum</td>
<td>Researcher</td>
<td>As per blood</td>
</tr>
</tbody>
</table>

In the following table, list all microorganisms, cell lines and primary cultures worked with or stored. In addition, list all plants and animals that fall under AQIS guidelines and/or OGTR regulations:

<table>
<thead>
<tr>
<th>Microorganism, cell line, plant, animal</th>
<th>Risk Group No.</th>
<th>IBC advice / approval sought? Y/N or N/A</th>
<th>Human Pathogen? Y/N</th>
<th>OGTR category (exempt, NLRD, NIR, DNIR) or N/A</th>
<th>OGTR approval number (or N/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candida albicans</td>
<td>2</td>
<td>Y</td>
<td>Y</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
2. Medical Monitoring

| E.g. antibody titre levels, immunisations |
| Self-examination of researcher prior to and following research |

3. Precautions Against Hazards

| List containment equipment used e.g. biological safety cabinets (indicate room no.): |
| 1. Class II Biological safety cabinet, PC2-certified laboratory, Rm 1.8, L-Block, QEII Medical Centre |
| 2. PC2 display unit (Refer to HTE RMP) |
| 3. Category B transport unit (Refer to HTE RMP) |

| Are facilities where GMO work is to be undertaken certified under OGTR e.g. PC2, PC3 laboratories? |
| Yes ☐ No ☐ N/A ☑ |
| Comments: |

| List personal protective clothing and equipment worn: |
| Refer to HTE RMP |

| Give details for control of aerosols e.g. during blending: |
| Solid media only; organism is not an airborne pathogen |

| Are written procedures available? |
| Yes ☑ No ☐ If no, provide details: |
| Refer to HTE RMP |

| List any specialist training undertaken or required: |
| 1. PC2-certified Laboratory induction |
| 2. OGTR training |
| 3. UWA Biosafety & OH&S training |

| Are treatment/disposal methods in accordance with AQIS and OGTR Regulations for all biological materials as well as the Australian Standard 2243 Part 3 Safety in Laboratories – Microbiological aspects and containment facilities (where applicable)? |
| Yes ☑ No ☐ Provide details: |
| Refer to HTE RMP |
### 4. Biological Safety Officer’s Comments/Endorsement

(Ensure that this is reviewed by the IBC Chair and person responsible for AQIS permits if these are different people.)

**Comments:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
</table>
Part E Project Closure Supplement

1. Work Area or Project Closure

Project Leaders are responsible for managing the clean up and safe decommissioning of the work area, facilities and equipment when work has been completed. This includes ensuring the suspension of services no longer required.

All ongoing health, safety and environmental hazards or risks are to be identified and eliminated.

- Stored mechanical or electrical energy in any apparatus has been discharged.
- Electrical equipment has been turned off and the power supply isolated and tagged.
- Gas supplies have been turned off.
- Equipment no longer required has been returned to storage or disposed of. Any malfunctions or problems detailed on tag attached to equipment. Location of equipment manuals and SOPs on tag attached to equipment.
- An inventory of all remaining chemical, biological and radioactive materials has been compiled and appropriate safety disposal methods arranged for those materials no longer required.

2. Inspection of Work Areas (Project Leader, HSR, Site Maintenance, OHSE Officer)

3. Health, Safety and Environment Records for Project

Records relating to the nature and magnitude of hazards, their annual review, supporting documents and provision of relevant information to staff must be kept for 75 years or permanently in project files.

These records include:

- HSE Assessment and Control of Work Form.
- Safe work practice documents developed for the project.
- List of material safety data sheets and/or chemicals used in project.
- All results of health and environmental monitoring.
- Records of personal protective equipment issued and training undertaken.

Location and reference details of the appropriate records:

4. Sign Off

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Leader</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OHSE Manager</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site Maintenance Mgr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chief/OIC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HEALTH, SAFETY & ENVIRONMENT ASSESSMENT and CONTROL OF WORK
RISK ASSESSMENT MODULE– PROCEDURE

Systematic identification of all OHS hazards and environmental aspects and control of the risks that they present is essential for the management of health, safety and the environment in the workplace and to reduce accidents and injury. This is an extremely important process. The approach provided by this tool is based on current best practice and consultations involving OHSE staff.

This tool meets the requirements necessary for an acceptable assessment process. These include:
- a systematic approach applicable across the organisation.
- comprehensive, graded lists of criteria covering all types of consequences
- a realistic guide to the likelihood of adverse consequences, and
- a scheme for rating the risks so that high risks are identified for immediate action

Using this procedure involves 6 steps:

1. Identify OHS hazards and environmental aspects using the checklist.

2. Use the table on the following page (Consequences) to rate the risk associated with each hazard/aspect by looking at the possible consequences in each column. Do not look only at health and safety risks or risks to your project or work. Consider every type of consequence. If you see that there are possible consequences that differ from those listed, consider a risk rating equal to the type of consequence that most closely matches. For each hazard/aspect, adopt the risk rating that is given by the column indicating the most severe consequences.

3. For each hazard/aspect, use the table on the next page (Likelihood) to rate the likelihood of an incident that will lead to the consequences that you have determined. Consider all of the options for each rating and use the most likely rating that is possible for the defined consequences. Remember that likelihood is related to exposure and exposure depends upon duration and frequency of exposure (or operation) as well as on the number of people exposed. For example, exposing eight people to a moving machinery hazard for one hour each is theoretically equivalent to exposing four people for two hours each.

4. Use the Inherent Risk table on the final page to plot the consequence against the likelihood to determine the inherent risk category associated with each hazard/aspect. These are the risks posed by the hazards in the absence of any consideration of risk control strategies.

5. Using the Residual Risk table, plot the inherent risks against your perceptions of the effectiveness of the risk management controls implemented so you can estimate the residual risk associated with each hazard/aspect. Your perceptions about the effectiveness of controls might be challenged by other members of your team or by, for example, the OHSE Officer.

6. Deal with high residual risks as a matter of urgency. Look at the notes on the final page about significant inherent and residual risks. Treat other risks as necessary to continuously improve your control of risks to health, safety and the environment.
### RISK ASSESSMENT MODULE – CONSEQUENCES

Note that any appropriate (or similar) criterion in a box gives a rating. Choose highest rating.

<table>
<thead>
<tr>
<th>RATING</th>
<th>POLITICAL &amp; CUSTOMER</th>
<th>INJURY/ILLNESS</th>
<th>ENVIRONMENT</th>
<th>PROGRAM</th>
</tr>
</thead>
</table>
| Catastrophic | • Ministerial investigation  
• Public/media outrage  
• Concern from public or industry association  
• Public pressure to cease operations | • One or more fatalities  
• Permanent or severe health effects for one or more staff members  
• Immediately dangerous to life & health | • Major impact-probably resulting in long-term damage to environment  
• Possibility of criminal proceedings under environmental legislation | • More than one department constrained for at least one month (eg. by damage to equipment or facility)  
• Termination of a stream of research or shutdown of a major facility  
• Total loss of Plant equipment |
| Major     | • Repeated concern from industry association or public group  
• Ministerial ‘please explain’  
• External investigation  
• Public/media concern  
• Reputation of organisation damaged | • Extended absence (one week or more) from work  
• Moderate to severe health effects | • Major impact-possibly resulting in long-term damage to environment  
• Likelihood of EPA action, civil action or compensation costs | • Project work constrained for at least one month (eg. by damage to equipment or facility)  
• Project terminated or shutdown of a laboratory  
• Partial loss of Plant equipment |
| Moderate  | • Major concern from industry association or client. Cannot show application of principles  
• Internal investigation  
• Decrease in public or industry support for project  
• Attracts public/media attention | • Temporary absences (of less than 1 week) for one staff member  
• Requires one or more visits to doctor for treatment | • Significant impact - possibly resulting in long-term damage to environment  
• Does not lead to EPA fine or court action | • Significant part of program's work delayed for less than one month (eg. by damage to equipment or facility)  
• Major refit of a laboratory |
| Minor     | • Minor concern from public  
• Claim of inadequate risk management or consultation in organisation  
• Department review | • First aid treatment required by doctor | • Transient impact - short-term breach of regulations  
• Required to inform EPA or third party of non-compliance | • Some project work delayed for less than one month (eg. by damage to equipment or facility)  
• Minor refit of a laboratory  
• Damage to plant repairable |
| Insignificant | • Concern within the Department  
• Review by program/project/section manager | • No injuries  
• Inconsequential damage to equipment | • Brief impact - contained on site and not requiring notification to third parties | • Minor delays to individual’s work (eg. by damage to equipment or facility) |
RISK ASSESSMENT MODULE - LIKELIHOOD

Note that likelihood not only depends upon the frequency but the duration of the activity and the number of simultaneous exposures or applications of the process. Any appropriate (or similar) criterion in a box gives a rating. Choose the most likely rating if more than one is possible, for the defined consequences.

<table>
<thead>
<tr>
<th>RATING</th>
<th>LIKELIHOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost Certain</td>
<td>▪ Defined consequences are very likely to occur</td>
</tr>
<tr>
<td></td>
<td>▪ Clear history of occurrence</td>
</tr>
<tr>
<td></td>
<td>▪ Typical operation of this type perhaps to satisfy external demands</td>
</tr>
<tr>
<td></td>
<td>▪ Expected to occur more often than daily to several times per week</td>
</tr>
<tr>
<td>Likely</td>
<td>▪ Difficult to control because of some external influences</td>
</tr>
<tr>
<td></td>
<td>▪ Some history of occurrence with the defined consequences</td>
</tr>
<tr>
<td></td>
<td>▪ Expected to occur once per month to several times per year</td>
</tr>
<tr>
<td>Possible</td>
<td>▪ Has occurred in the organisation with the defined consequences</td>
</tr>
<tr>
<td></td>
<td>▪ Would not be surprised if it occurred</td>
</tr>
<tr>
<td></td>
<td>▪ Expected to occur a few times every two years to once per year</td>
</tr>
<tr>
<td>Unlikely</td>
<td>▪ Possible but not expected to occur with the defined consequences</td>
</tr>
<tr>
<td></td>
<td>▪ Causal events have occurred within the organisation but effects have been controlled so that defined consequences did not occur</td>
</tr>
<tr>
<td></td>
<td>▪ No history in this department/section of situation which resulted in the defined consequences but has occurred in other Departments</td>
</tr>
<tr>
<td></td>
<td>▪ Expected to occur once every two to five years</td>
</tr>
<tr>
<td>Rare</td>
<td>▪ Possible but very unlikely to occur with the defined consequences</td>
</tr>
<tr>
<td></td>
<td>▪ Causal events have occurred within the Organisation but the risk is not difficult to control</td>
</tr>
<tr>
<td></td>
<td>▪ Expected to occur once every five years or less often</td>
</tr>
</tbody>
</table>

RISK ASSESSMENT MODULE – Management Controls

<table>
<thead>
<tr>
<th>Rating</th>
<th>Management control examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>Controls are best practice, involve explicit standards and are followed all of the time. Includes a high emphasise on elimination, substitution or engineering controls.</td>
</tr>
<tr>
<td>Reasonable</td>
<td>Controls are in place but not followed all of the time and may not include best practice. Includes a high emphasis on administration and protective equipment.</td>
</tr>
<tr>
<td>Poor</td>
<td>There are few or no controls in place. No standards have been identified. Controls do not address Hierarchy of Control principles.</td>
</tr>
</tbody>
</table>
RISK ASSESSMENT MODULE - DETERMINATION OF RESIDUAL RISK

INHERENT RISK (the risk that exists in the absence of control measures)
Find the ratings for the consequence and the likelihood then refer to the table below:

Consequence Table

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>DESCRIPTOR</th>
<th>CONSEQUENCE – DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Insignificant</td>
<td>No injuries, low financial loss</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>First aid treatment, on site release immediately contained</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>Medical treatment required, on site release contained with outside assistance, high financial loss</td>
</tr>
<tr>
<td>4</td>
<td>Major</td>
<td>Extensive injuries, loss of production capability, off site release with no detrimental effects, major financial loss</td>
</tr>
<tr>
<td>5</td>
<td>Catastrophic</td>
<td>Death, toxic release off site with detrimental effect, huge financial loss</td>
</tr>
</tbody>
</table>

Likelihood Table

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>DESCRIPTOR</th>
<th>LIKELIHOOD – DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rare</td>
<td>May occur only in exceptional circumstances</td>
</tr>
<tr>
<td>2</td>
<td>Unlikely</td>
<td>Could occur at some time</td>
</tr>
<tr>
<td>3</td>
<td>Possible</td>
<td>Might occur at some time</td>
</tr>
<tr>
<td>4</td>
<td>Likely</td>
<td>Will probably occur in most circumstances</td>
</tr>
<tr>
<td>5</td>
<td>Almost Certain</td>
<td>Is expected to occur in most circumstances</td>
</tr>
</tbody>
</table>

Risk Matrix

<table>
<thead>
<tr>
<th>LIKELIHOOD</th>
<th>CONSEQUENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insignificant (1)</td>
</tr>
<tr>
<td>(5) Almost Certain</td>
<td>M</td>
</tr>
<tr>
<td>(4) Likely</td>
<td>M</td>
</tr>
<tr>
<td>(3) Possible</td>
<td>L</td>
</tr>
<tr>
<td>(2) Unlikely</td>
<td>L</td>
</tr>
<tr>
<td>(1) Rare</td>
<td>L</td>
</tr>
</tbody>
</table>

Legend:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H:</td>
<td>High risk immediate action required</td>
</tr>
<tr>
<td>M:</td>
<td>Moderate risk; management responsibility must be specified (significant and moderate combined to be moderate)</td>
</tr>
<tr>
<td>L:</td>
<td>Low risk; manage by routine procedures</td>
</tr>
</tbody>
</table>
RESIDUAL RISK (the risk that remains after implementing measures to reduce it)
Plot inherent risk against the assessed quality of the existing management control of the risk

<table>
<thead>
<tr>
<th>I</th>
<th>N</th>
<th>High</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>E</td>
<td>Mod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>E</td>
<td>Low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>T</td>
<td>VERY</td>
<td>REASON</td>
<td>POOR</td>
</tr>
<tr>
<td>R</td>
<td>I</td>
<td>GOOD</td>
<td>ABLE</td>
<td>MANAGEMENT CONTROL</td>
</tr>
</tbody>
</table>

Residual risk is **high**
- attend to immediately

Residual risk is **moderate**
- attend to in short term

Residual risk is **low**
- attend to in longer term

**High indicates a high risk**
- it must be recorded and managed as a matter of urgency

Manage all other moderate risks and all low risks to achieve a continuous improvement in the longer term
The Unsettling Eros of Contact Zones, and other stories

Living *Candida albicans* is growing in the artwork entitled *Surface dynamics of adhesion*. The *Candida* in this work is contained within two layers of acrylic to eliminate risk of contamination or infection.

If you come into contact with the living *Candida albicans*, please see the gallery sitter for assistance. Humans with healthy immune systems are unlikely to be infected, but those with compromised immune systems may be susceptible to infection.

The bread artwork entitled *The unsettling eros of contact zones* was leavened with fresh yeasts including *Saccharomyces cerevisiae* (baker’s yeast) and *Candida albicans*. The bread was baked at 210°C for 25 minutes, killing all organisms. Living *Candida albicans* was not found in tested samples of the baked bread.

If you choose to consume the bread, you are not at risk of infection from the leavening process.

This exhibition has been approved by the UWA Institutional Biosafety Committee and the UWA Risk Management Office. If you have any questions, please approach the gallery sitter or contact Tarsh at natarsha.bates@research.uwa.edu.au
The Unsettling Eros of Contact Zones, and other stories explores what it means to be human when we recognise our bodies as multi-species ecologies, with a particular focus on the relationships between Homo sapiens and Candida albicans. This project comprises an exhibition of creative works developed during my PhD research which uses scientific and artistic methodologies to explore physical, emotional, cultural and political relationships between humans and Candida. The exhibition offers aesthetic experiences of the contact zones between these two radically different organisms – embodied encounters that are sensual, relational and often unconscious. The artworks presented articulate the more-than-human agency of encounters between bodies. They comprise sculptural, photographic, and filmic works, and include dead and living organisms (which are safely contained as per UWA biosafety regulations). This exhibition is part of the program for NeoLife, the inaugural conference for the Society for Literature, Science and the Arts, Rest of the World, and the National Experimental Arts Forum, both being organised by SymbioticA in October 2015.

Exhibition Concept

A normal human body is thought to be composed of over one trillion cells, of which only 10 percent are human. How do we understand subjectivity and identity in this cacophony if, as Donna Haraway suggests, “to be one is always to become with many?” The unsettling eros of contact zones, and other stories focuses on the intimate and fraught contact zones of biology, aesthetics, culture and care between Homo sapiens and Candida albicans. Candida albicans, the single celled opportunistic fungal pathogen commonly known as thrush, is one of the viral/bacterial/fungal/insect species that contributes to the complex ecosystem that is the human body. It has a unique and particularly evocative cultural valency for humans, especially for women. It is highly responsive to changes in its environment: usually invisible and innocuous, infections exude and inflame. The interspecies caresses between Homo and Candida are irresistible, irritating and irrational.
This exhibition includes a series of artworks that embraces philosopher Luce Irigaray’s understanding of eros as “the most extreme experience of sensation” to explore the uncomfortable, complex and intimate topologies of the posthuman ecosystem. Eros for philosopher Luce Irigaray is a sensual, affective desire for interconnection and interaction. This desire for alliance exists simultaneously and paradoxically alongside perception of otherness and desire for autonomy: a concurrent attraction and repulsion. Christopher Cohoon suggests that bodies subject to Irigarayan eros exist as potential energy, in states of immanent becoming, which results in fluid subjectivities. 

The works offer aesthetic experiences of the contact zones between the two radically different organisms, humans and Candida albicans. They articulate the embodied eros of encounters that are sensual, relational and often unconscious: more-than-human sensations between human, Candida and the materials used to explore the fraught entanglements of these bodies.

Most reflections on Candida are scientific and from the human perspective: the effects on a human body and emotions during an infection. In this project, a more-than-human fleshiness is activated through considerations of the aesthetic experiences of Candida during its encounters with the human body, arising from my current artistic research. This unique creative research uses scientific, contemporary art and cultural theory methodologies to explore Candida/Homo entanglements, in particular Donna Haraway’s companion species and Karen Barad’s queer performativity are used to explore the limits of subjectivities formed in these entanglements. Haraway’s companion species discusses the complex coevolution of humans with other organisms, including the bacteria within us and Barad’s queer performativity complicates notions of observation, representation and subjectivity.

This project draws on microbiology, performance, new media, aesthetics and cultural studies, positioning humans and Candida as co-evolved companion species involved in a biopolitical entanglement that is gendered, sexual and often ruthless. This exhibition instigates conversations between scientific and artistic knowledge creations and posthumanism, focusing on the entangled bodies of humans and Candida.

This innovative research project is one of the first art/science PhDs to come out of The University of Western Australia. During this time, I have developed an interdisciplinary research method, spanning microbiology, performance, new media, aesthetics and cultural studies. This novel research makes original contributions to considerations of human/non-human relationships, focusing on an organism that lives on and within human bodies, challenging both body and species boundaries. The unsettling eros of contact zones is the result of the unique opportunity provided by The University of Western Australia to link the disparate disciplines of contemporary art, microbiology, posthumanism, feminism, queer theory and biopolitics.
Works list

1) *Ereignis, Gelassenheit and Lichtung: A love story*, is an immersive projection of a digital time-lapse video of *Candida albicans* reproducing and changing shape, taken on a live imaging digital microscope. This work is projected so that it fills the whole room, contaminating the architectural space (and any bodies within it) with animate images of *Candida albicans* cells. The title of this work combines terms used by the philosopher Martin Heidegger, whose work redefined understandings of “being-in-the-world.” *Ereignis* [trans. an event] describes the coming into being of “things” which is only possible through their relationship with each other. *Gelassenheit* [trans. letting-be] expresses the acceptance of the mystery of being-in-the-world, and *Lichtung* [trans. a clearing; illumination] refers to the necessity to clear a space in order to understand how it is to be-in-the-world. This work suggests that all three are intertwined. It welcomes visitors to the exhibition.

2) *Control of cell morphology* in vivo, is combines the zoetrope, an old animation technology, with several of the digital micrographs from *Ereignis, Gelassenheit and Lichtung*. When a viewer rotates the zoetrope using a hand-crank the static *Candida* is aroused and comes alive, dancing and changing shape. The viewer observes the contained images from a safe distance, completely in control – a stark contrast with the unruly contamination of *Ereignis, Gelassenheit and Lichtung*. The simplicity of the analogue viewing apparatus materialises the gaps in seeing between scales and exposes the role of motion in seeing and knowing an Other.

3) *Surface Dynamics of Adhesion* forms a dado border on one wall of the gallery. Encased in acrylic boxes, living *Candida albicans* grows in a pattern adapted from the first drawing of the
organism in 1853 and reminiscent of those popular on the wallpaper of parlours and art galleries in Europe at the time. The acrylic containment frames the artworks as unstill-lifes and minimises the risk of contamination or infection. The living Candida escapes the constraints of the patterning during the exhibition, subtly disrupting attempts to discipline it. This work explores the complex relationship between Candida and the surfaces it grows on.

4) The Unsettling Eros of Contact Zones explores our assumptions about microorganisms and the food we consume. Many of the foods we consume are produced with or contain a variety of microorganisms, including the basics: cheese, bread, milk, and beer. Bread leavened with Saccharomyces cerevisiae and Candida albicans are offered, inviting consideration of the decision to consume or not. The baking process kills all microorganisms, including Candida, which is already present in or on most of the visitors.

5) Translational Ambiguity Tolerance is an artist’s book in the form of a pack of 52 cards. Digital micrographs of the polymorphism of Candida albicans cells and colonies. The diversity and adaptability of this organism is revealed, compellingly sumptuous and repulsive. Translational ambiguity of RNA codons into multiple amino acids is thought to be detrimental to living organisms, but Candida has a high tolerance for the translational ambiguity of the leucine CUG codon into both serine and leucine. This ambiguity tolerance is associated with morphological changes and pathogenesis and confers a highly dynamic environmental adaptability to Candida.
The unsettling eros of contact zones, and other stories is an art exhibition that explores what it means to be human when we recognise our bodies as multi-species ecologies, with a particular focus on the relationships between Homo sapiens and Candida albicans. Artworks were developed during Tarsh Bates’ PhD research and comprise sculptural, photographic and filmic works, as well as organisms. Bates uses scientific and artistic methodologies to explore physical, emotional, cultural and political relationships between humans and Candida. This risk minimisation induction is being conducted as part of the Health, Safety and Environment Assessment requirements for this project.

All research has been conducted in compliance with Office of Gene Technology Regulations and the Australian/New Zealand Standard 2243.3:10 Safety in Laboratories, Part 3: Microbiological safety and containment. The growth of living Candida albicans and the serving of bread leavened with C. albicans in the exhibition have been approved by the Institutional Biosafety Committee, the Risk Management and the Safety, Health and Welfare Divisions of the University of Western Australia. It is supported by a Risk Management Plan and a Health Safety and Environment Assessment and Control of Work form.

As a gallery attendant, this induction provides you with information and training regarding the unique safety provisions and protocols in order to minimise the risk of infection of yourself and the public. It should be noted that Candida albicans is present as one of many harmless organisms that live in the mouth and gut of humans. Under normal circumstances, Candida lives in 80% of the human population with no harmful effects. It is not airborne and can only be contracted by touch. Humans with a healthy immune system are unlikely to be infected, but those with compromised immune systems may be susceptible to infection. Consequently special handling is required to minimise exposure.

Living Candida albicans (aka thrush) is growing in the artwork entitled Surface dynamics of adhesion. The Candida is grown on blood agar, a nutrient source that contains the blood of the human artist. The Candida in this work is contained under two layers of acrylic display casing according to relevant biosafety requirements to eliminate risk of contamination or infection. The casing was also sterilised after installation.

The bread artwork entitled The unsettling eros of contact zones was leavened with fresh yeasts including Saccharomyces cerevisiae (baker’s yeast) and Candida albicans. The bread was baked at 210°C for 25 minutes after which samples were removed and tested for the presence of living Candida albicans. All Candida albicans were killed during baking, so if a viewer chooses to consume the bread, they are not at risk of infection from the leavening process.
In accordance with the project RMP, the following information has been provided to you depending on your involvement with the project. Please read this documentation to help make this project safe and enjoyable for everyone.

- Risk Minimisation Induction Checklist
- Risk Management Plan
- Emergency Contact List
- *Candida* Spill Risk Minimisation Protocol
- Public Exposure Management Protocol
- Researcher Incapacitation Protocol
- *Candida* Decontamination Protocol
- Sitter exhibition guide
- Exhibition informational & FAQ

Your involvement in this project is greatly appreciated.

__________________________________________________________

Tarsh Bates

*The Unsettling Eros of Contact Zones* researcher

0432 324 708
**THE UNSETTLING EROS OF CONTACT ZONES RISK MINIMISATION INDUCTION CHECKLIST**

<table>
<thead>
<tr>
<th>Name</th>
<th>Site</th>
</tr>
</thead>
</table>

Please Note: These actions should be completed prior to the start of the project or as soon as practicable after a new person commences work with the project. Tick off each action and sign when all actions have been completed. A copy of this checklist will be provided to you.

<table>
<thead>
<tr>
<th>Project explanation</th>
<th>Physical Containment measures demonstrated</th>
</tr>
</thead>
<tbody>
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If you have a medical condition which may be relevant in an emergency, please let the researcher know. This information will be kept in the strictest confidence.

Staff Signature: ______________________ Date: ________

Researcher’s Signature: ______________________ Date: ________
The unsettling eros of contact zones, and other stories

Informational text & FAQ for Public Anxiety Management

The unsettling eros of contact zones, and other stories is an art exhibition that explores what it means to be human when we recognise our bodies as multi-species ecologies, with a particular focus on the relationships between Homo sapiens and Candida albicans. Artworks were developed during Tarsh Bates’ PhD research and comprise sculptural, photographic and filmic works, as well as organisms. Bates uses scientific and artistic methodologies to explore physical, emotional, cultural and political relationships between humans and Candida. 

Candida albicans (commonly known as thrush) is present in 80% of the human population as one of many organisms that live in our mouths and gut with no harmful effects. It is not airborne and is rarely contracted by touch. Infection as a result of exposure is highly unlikely, however the risk of infection increases if someone with a compromised immune system is directly exposed.

All research has been conducted in compliance with Office of Gene Technology Regulations and the Australian/New Zealand Standard 2243.3:10 Safety in Laboratories, Part 3: Microbiological safety and containment. The growth of living Candida albicans and the serving of bread leavened with C. albicans in the exhibition have been approved by the Institutional Biosafety Committee, the Risk Management and the Safety, Health and Welfare Divisions of the University of Western Australia. It is supported by a Risk Management Plan and a Health Safety and Environment Assessment and Control of Work form.

Artworks that may elicit particular anxieties:

Living Candida albicans (aka thrush) is growing in the artwork entitled Surface dynamics of adhesion. The Candida is grown on blood agar, a nutrient source that contains the blood of the human artist. The Candida in this work is contained under two layers of acrylic display casing according to relevant biosafety requirements to eliminate risk of contamination or infection. The casing was also sterilised after installation.

The bread artwork entitled The unsettling eros of contact zones was leavened with fresh yeasts including Saccharomyces cerevisiae (baker’s yeast) and Candida albicans (aka). The bread was baked at 230°C for 30 minutes after which samples were removed and tested for the presence of living Candida albicans. All Candida albicans were killed during baking, so if a viewer chooses to consume the bread, they are not at risk of infection from the leavening process.

FAQ

Q. I touched/ate the bread. Will I get an infection?

The bread was baked at 230°C for 30 minutes after which samples were removed and tested for the presence of living Candida albicans. All Candida albicans were killed during baking, so if you touched or ate the bread, you are not at risk of infection from the leavening process.

Q. I touched/ate the bread and now I have an infection.

The bread was baked at 230°C for 30 minutes after which samples were removed and tested for the presence of living Candida albicans. All Candida albicans were killed during baking, so if you touched or ate the bread, you were not at risk of infection from the leavening process. It is highly unlikely that your infection was caused by touching or eating the bread. Your infection may be due to another microorganism or you may have been exposed elsewhere. Samples of the bread were stored and will be retested to determine whether C. albicans was present in the bread you ate. I suggest you visit your GP for advice.
Q. I touched/ate the bread. Will I get a Candida allergy/Candida syndrome?

The risk of acquiring a “Candida allergy” or “Candida syndrome” from ingesting the bread is highly unlikely as extremely low concentrations of Candida were used to prepare the bread.

Q. I touched/ate the bread and now I have a Candida allergy/Candida syndrome.

The risk of acquiring a “Candida allergy” or “Candida syndrome” from ingesting the bread is highly unlikely as extremely low concentrations of Candida were used to prepare the bread. Your health issue may be due to another microorganism. Samples of the bread were stored and will be retested to determine whether C. albicans was present in the bread you ate. I suggest you visit your GP for advice.

Q. I touched the living Candida. Will I get an infection?

Infection as a result of touching living Candida is extremely rare if you have a healthy/normal immune system. However, if you have a compromised immune system and/or are concerned, administer the following first-aid: wash exposed skin with Betadine surgical scrub for 2 minutes; Betadine antiseptic ointment or liquid will be administered as per manufacturer instructions for exposure to an open wound; if your eyes have been exposed, irrigate to wash out the contaminant and visit your GP. Medical treatment for an infection involves anti-fungals prescribed by a GP.

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Infection as a result of touching living Candida is extremely rare if you have a healthy/normal immune system. It is highly unlikely that your infection was caused by contact with the living Candida. Your infection may be due to another microorganism or you may have been exposed elsewhere. However, if you have a compromised immune system and/or are concerned, administer the following first-aid: wash exposed skin with Betadine surgical scrub for 2 minutes; Betadine antiseptic ointment or liquid will be administered as per manufacturer instructions for exposure to an open wound; if your eyes have been exposed, irrigate to wash out the contaminant and visit your GP. Medical treatment for an infection involves anti-fungals prescribed by a GP.

Q. The living Candida spilled on me. Will I get an infection?

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Q. This is so disgusting! The artist is just trying to shock people!

The artist is aware that *Candida* is usually seen as disgusting and shocking. However, she is asking you to consider that we already live with these organisms, and many others like them which are vital for our health and well-being. This exhibition invites you to think about them in a different way and to become more conscious that our bodies are complex and sensitive ecosystems. She would also like you to reflect on the timeless practices of using microorganisms to produce the food we eat.

Q. This is unsafe!

All research has been conducted in compliance with Office of Gene Technology Regulations and the Australian/New Zealand Standard 2243.3:10 *Safety in Laboratories, Part 3: Microbiological safety and containment*. The growth of living *Candida albicans* and the serving of bread leavened with *C. albicans* in the exhibition have been approved by the Institutional Biosafety Committee, the Risk Management and the Safety, Health and Welfare Divisions of the University of Western Australia. It is supported by a Risk Management Plan and a Health Safety and Environment Assessment and Control of Work form. A copy of the Plan and approvals is available at your request.

If you have further questions, please contact Tarsh Bates at natarsha.bates@research.uwa.edu.au.
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1-7 October, 10am-4pm daily
Opening event 3 October, 6-8pm RSVP: unsettling-eros.eventbrite.com.au

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APPENDIX F DISPERSALS, PAST AND FUTURE

PAST...

Artworks/exhibitions

Ereignis, Gelassenheit und Lichtung: A love story and Control of Cell Morphology in vivo were included in the Didactic Tools exhibition at Fremantle Art Centre, Perth in 2015–2016 (Figure 118); Surface Dynamics of Adhesion was included in The Other Selves. On the Phenomenon of the Microbiome exhibition at Art Laboratory Berlin in 2016 (Figure 119), the first exhibition in their NonHuman Subjectivities series; a limited edition The Unsettling Eros of Contact Zones was remounted during The Other Selves exhibition in Berlin for a local science-hack event (Figure 120); Translational Ambiguity Tolerance and The Unsettling Eros of Contact Zones Recipe Cards were included in the Emergent Ecologies exhibition at Kilroy Metal Ceiling, New York City; and an The Unsettling Eros of Contact Zones Recipe Card was included in the Animaladies exhibition at Interlude Gallery, Sydney in 2016; Surface Dynamics of Adhesion was remounted during the Pets Friends Forever exhibition at the Deutsches Hygiene-Museum Dresden 2017–2018 (Figure 121); a new artwork that explores the implications of genetically engineering yeast ecologies was been commissioned by the University of Edinburgh and exhibited in December 2017, in collaboration with Devon Ward and Erika Szymanski.

Figure 118 Ereignis, Gelassenheit und Lichtung: A love story and Control of Cell Morphology in vivo, 2015–2016, Didactic Tools, Fremantle Art Centre, Perth. Photo on left reproduced by permission from Elle Borgward; photo on right by author.
Figure 119 Surface Dynamics of Adhesion, 2016, The Other Selves. On the Phenomenon of the Microbiome exhibition, Art Laboratory Berlin. Photo by author.

Figure 120 The Unsettling Eros of Contact Zones limited edition, 2016, The Other Selves. On the Phenomenon of the Microbiome exhibition, Art Laboratory Berlin. Photo by author.
Figure 121 Surface Dynamics of Adhesion, 2017–2018, Pets Friends Forever exhibition, Deutsches Hygiene-Museum Dresden. Photo by author.

**Artistic residencies/workshops/collaborations**

In a research residency at the Biofilmzentrum, Deutsches Herzzentrum Berlin in 2016, I worked alongside microbiologists and pathologists and learned techniques for imaging mixed species biofilm infections on biomedical devices using RNAFISH technology.

I have conducted numerous workshops, including at *Didactic Tools*, Perth 2014, *Artists and Soup*, Berlin 2016 and *Somatechnics* Conference, Byron Bay 2016.

Collaborations include *Didactic Tools* 2014–2015 research collaboration with Keg de Souza, Sam Fox, Jake Oorloff and Kynan Tan; and SCRaMble yeast genetic engineering, environmental humanities and art
interdisciplinary research project 2016–2018 with Erika Szymanski, Engineering Life research group, The University of Edinburgh.

Scholarly articles


Conference presentations and artist talks


— — —. “We have never been human: HumanThrush entanglements.” Presentation at The International Science Festival Gothenburg, Sweden, 14 April 2016.

— — —. “Posthuman desire.” Presentation at The International Science Festival Gothenburg, Sweden, 14 April 2016.

— — —. “The unsettling eros of contact zones, and other stories: On being with Candida albicans.” Seed Box Visiting Scholar presentation, Linköping University, Sweden, 12 April 2016.


— — —. “We have never been Homo sapiens: CandidaHomo naturecultures.” Presentation at the NeoLife, SLSA Rest of the World Conference, Perth, 1–3 October 2015.

— — —. “to be one is always to become with many: the posthuman phenomenology of Candida albicans.” Presentation at the Fifth Meeting of the Organisation of Phenomenological Organisations, Perth, 8–12 December 2014.

— — —. “to be one is always to become with many: the posthuman phenomenology of Candida albicans.” Cultural Studies Association of Australia, Wollongong: University of Wollongong, 3–5 December 2014.


— — —. Biological Art Master Class, ZHdK Zurich, 25 May 2013.


Citations/reviews/press

Artworks presented in this thesis have been reviewed or discussed in:


My scholarly publications have been cited in:


The research methodology described in the introduction chapter and in "We Have Never Been *Homo Sapiens*" has been adopted for teaching at the University of Melbourne by Thao Phan, editor of the special issue of *Platform* in which the article was published, and at Goldsmiths, University of London by Lynn Turner. In 2016, I participated in a study about ethical issues related to bioart by Marianne Cloutier and François-Joseph Lapointe, Université de Montréal.

**FUTURE...**

**Artworks/exhibitions**

A work that genetically engineers *C. albicans* to produce a fragrance is currently in development and has been accepted into the *Unhallowed Arts* Festival, Perth 2018.

I am curating *This Mess We’re In*, an exhibition of feminist, queer and first nations artists responding to the legacy of Mary Shelley’s Frankenstein in 2018.

**Research residencies/workshops/collaborations**

I have several artistic and academic collaborations in development, including a project with Kira O’Reilly and Ionat Zurr exploring interspecies hormonal life-histories; a co-edited book about the history of Australian biological art with Svenja Kratz; and a microbiopolitical research project with Astrida Neimanis and Lindsey Kelley.
Scholarly publications


I have been invited to contribute a chapter for *Transdiscourse 3*, which will be co-edited by Jill Scott and Svenja Kratz, that responds to gender, interspecies and the nonhuman turn.

Conference presentations and artist talks

I am a co-organiser, with Ionat Zurr and Elizabeth Stephens, of the *Quite Frankly: It’s a monster conference*, SymbioticA & Somatechnics, Perth, 18–19 October 2018.