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Species: a praxiographic study

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Taxonomists, who describe new species, are acutely aware of how political, economic, and ecological forces bring new forms of life into being. Conducting ethnographic research among taxonomic specialists – experts who bring order to categories of animals, plants, fungi, and microbes – I found that they pay careful attention to the ebb and flow of agency in multispecies worlds. Emergent findings from genomics and information technologies are transforming existing categories and bringing new ones into being. This article argues that the concept of species remains a valuable sense-making tool despite recent attacks from cultural critics.

Multispecies ethnography contains a hidden ontology lurking within: that of 'species' (Kirksey & Helmreich 2010: 563). John Dupré (1992), a philosopher of science, suggests that the concept of a species gives rise to two principal questions: Is a species a natural kind that exists in nature independently of its discovery, or naming, by humans? Is an individual organism to be assigned to a particular species on the basis of morphological characteristics, reproductive links, evolutionary heritage, or some other features? Donna Haraway regards the idea of a species as a lovely oxymoron, 'always both logical type and relentlessly particular' (2008: 164). Building on this conversation, I will argue for the utility of 'species' as a valuable sense-making tool. Evidence in support of this argument will come from ethnographic research among taxonomic experts working in diverse branches of the tree of life. This article addresses a number of related questions: Where do species exist? How are species enacted? What practices bring species into being?

Annemarie Mol has described 'praxiography' as a method to 'stubbornly take notice of the techniques that make things visible, audible, tangible, knowable' (2002: 33). Praxiography involves the practicalities of *doing* disease, according to Mol's original study, *The body multiple: ontology in medical practice*. 'The disease' is never alone, by Mol's reckoning. It does not stand by itself. 'It depends on everything and everyone that is active while it is being practiced' (2002: 32). Departing from Mol, I ask: Can a species ever be alone; can it stand by itself? Do species depend on other beings, things, and apparatuses that are active in producing their existence? Do biologists just *make* species; do they simply *construct* them? Or are multiple agents involved in their

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ontologies? Using the methods of multisited ethnography, this article 'follows the thing', the notion of species, from the realm of Fungi to the kingdoms of Anamalia and Plantae, as well as to the domain of Bacteria. Travelling from the United States to Australia, I studied how species are enacted, how they are *performed* in specific ways.

My ethnographic research took place amidst shifting political, economic, and ecological circumstances. A bubble of hopeful economic speculation surrounded the idea of biodiversity in the 1990s. Drug companies teamed up with conservationists to investigate the potential pharmaceutical value of plants, animals, and microbes. But this bubble quickly burst. Despite the hype, few marketable drugs were actually produced (Hayden 2003; Helmreich 2009). By the early 2000s, taxonomy – the branch of science concerned with biological classification – had become 'low-status work', according to Geoffrey Bowker. Taxonomists using 'noncharismatic technology' like microscopes and callipers to measure morphological characteristics 'consistently lost out to more "exciting" areas of research that did not try to provide consistent names' (Bowker 2005: 146–7). Taxonomists who began using charismatic genetic technologies, novel techniques and practices that enabled them to read directly the DNA contained in organisms' genomes, briefly enjoyed a period of prestige within the scientific community. But, as genetic tools became cheaper and more ubiquitous, basic taxonomic research again became a low priority for most career-minded biologists.

While certain charismatic species get attention from policy-makers and the public, it has become more difficult to know about 'unloved others', who are slipping from sight (Rose & van Dooren 2011). In an era of extinction, as humans are directly or indirectly driving the mass death of others, it has become difficult to understand the scale of loss and to develop responsible practices of intervention (van Dooren 2014). Visibility as a 'species', for some animals, plants, or fungi, can mean opportunities for new ways of life. On the other hand, visibility can also mean exposure to exploitation, surveillance, or invasive regimes of control (Star & Strauss 1999: 9–10).[1] Multispecies ethnographers are starting to explore how novel technological prosthetics and descriptive practices make some organisms visible while obscuring others. Opening up the root of the word *ethnos* (Greek: ἔθνος), ethnographers are beginning to write about 'a multitude (whether of men or of beasts) associated or living together; a company, troop, or swarm of individuals of the same nature or genus' (see Kirksey, Schuetze & Helmreich 2014: 13; see reviews by Hamilton & Placas 2011; Locke & Münster 2015). Ethnographers are exploring how 'the human' has been formed and transformed amidst encounters with multiple species.

Timothy Ingold has suggested that we abandon approaches to multispecies ethnography since the notion of *species* is an anthropocentric imposition. 'Only in the purview of a universal humanity', he maintains, 'does the world of living things appear as a catalogue of biodiversity, as a plurality of species'. He argues: 'If we abandon this sovereign perspective, then the very notion that creatures can be grouped on the basis of similarity and divided on the basis of difference, and with it the concept of species itself, will need to be rethought' (2013: 19).[2] Such a position is not new, with others insisting 'the species rank must disappear' (Mishler 1999: 308). Despite such proclamations, however, the species concept continues to have a lively existence. Taking up Ingold's invitation to rethink the concept of species, I conducted ethnographic research among taxonomic specialists whose core work involves naming species of plants, animals, fungi, and microbes.

Many contemporary taxonomists accept the principle of pluralism articulated by John Dupré: that there are multiple plausible and defensible approaches to biological classification. Deciding how to classify a given group of organisms, according to Dupré, depends 'on both the purposes of the classification and the peculiarities of the organisms in question' (1993: 57). If some see classification practices as an external imposition on a stable material world that awaits description, I follow Donna Haraway, who insists that 'reality doesn't precede practices but is a part of them' (1997: 302 n. 12). Classification practices *torque* people, according to Geoffrey Bowker and Susan Leigh Star. Torque is generated at the intersection of competing classification projects. As boundaries are enacted, or drawn, these lines can twist objects into new configurations. When categories are aligned, there is no sense of torque or stress, according to Bowker and Star, but when competing classifications pull on populations, these forces can produce novel modes of being over time. In apartheid South Africa, people were torqued by 'a mixture of brute power, confused eugenics, and appropriations of anthropological theories of race' (Bowker & Star 1999: 27–8). Taxonomists, and multiple species of agential beings, can also transform other organisms with their practices of classification, recognition, and differentiation. As new species emerge, they can torque human practices, political and economic systems, as well as ecological communities (Kirksey 2015; Lowe 2010). Novel kinds of critters are generating order-forming assemblages as well as order-destroying disasters.

Chytrids

Chytrids are unloved microbes. They live all around you, beyond the purview of your everyday awareness. Many chytrid species perform critical ecological functions. Some break down chitin, the hard material in the exoskeleton of insects. Others, which live in the hind guts of ruminants, help digest cellulose, a tough molecule in dead plant matter. Since they are liminal critters that trouble our categories, they are a good place to start investigating the practices that bring species into being. Most microbiologists regard chytrids as fungi. But seemingly stable formations like 'fungi', or even 'the animal', fall apart when you look too close. When chytrids are young, in the zoosporic stage, they resemble human sperm and constantly swim about. Once they find a suitable substrate, like a grain of pollen or the skin of a vertebrate host, they put down root-like structures called rhizoids. When isolated, chytrids usually have stable morphologies as they grow. When surrounded by other beings and things, when living in microbial ecosystems, chytrids are often ontologically indeterminate (cf. Schrader 2010).

Joyce Longcore, one of a handful of humans who care for chytrids, invited me to her laboratory at the University of Maine in August 2012. Chytrids captured Joyce's imagination at an early age. After receiving an undergraduate degree in biology at the University of Michigan in 1960, she worked for Professor F.K. Sparrow, an eminent student of zoosporic fungi. A letter written by Joyce to Sparrow at the age of 21 reveals unbridled enthusiasm and a determination to devote her professional life to these fungi. But her passion for studying chytrids was put on hold by love for another human. Marriage to a US Fish and Wildlife field biologist – a researcher who made key findings about DDT and thin bird eggshells – meant that her professional vision was postponed for nearly thirty years. After raising a family, she went back to graduate school and earned her Ph.D. in 1991, at the age of 52. She has never been the lead investigator of a major grant for her research, and is not on the university payroll, but after buying and borrowing equipment she started her own lab at the University of Maine.

Joyce is a taxonomist, someone whose core work involves ordering organisms. She has described many new species of chytrids and has placed them in bigger groupings – like genera, classes, and orders. She is self-reflexive about her work. 'Species are human constructs,' Joyce intimated 'They aren't things unto themselves. For non-mycologists, for people who work on animals or plants, a species is a group of interbreeding organisms. But there are a lot of organisms in the world that don't have sex'. Joyce was indirectly referring to Ernst Mayr's influential definition of the species as an 'interbreeding population'. This definition treats species as 'groups of actually or potentially interbreeding natural populations which are reproductively isolated from other such groups' (Mayr 1942: 120). Mayr's definition, long popular with biologists who study animals and plants, does not work well for chytrids or other microbes. For the most part, chytrids are clones. These tiny animalcules usually reproduce asexually – generating spheres nested within other spheres, clear bubbles containing darker bubbles. Genetic recombination in chytrids is messy. Variation is constantly taking place and taxonomists like Joyce are struggling to keep up. Strange new forms are constantly competing for her attention.

Joyce named one chytrid *Batrachochytrium dendrobatidis* in 1999 after being enlisted in an international hunt for an emergent disease driving thousands of amphibians to the brink of extinction. The story about the description of this chytrid species is unusual, because it involved much media fanfare. Amidst mass die-offs of amphibians, tiny lesions in the skin of dead frogs were independently discovered in Central America and Australia. Scanning electron micrographs were made of skin from poison dart frogs kept in the National Zoo in Washington. Veterinary pathologists at the zoo suspected that they were microscopic fungi. These images worked their way through the community of fungal experts and eventually landed in Joyce's inbox. 'They got lucky with their scanning electron micrograph', she told me. 'One shot happened to be right through a zoospore and it was easy for me to see taxonomic clues. When I saw the images I knew right away that they pictured a chytrid'. When the *New York Times* printed another scanning electron micrograph of frog skin, from a different population, she could see that it was the same thing. Everyone began to speculate that this yet-unidentified chytrid was running wild in a global pandemic.

Once Joyce determined that this pathogen was a chytrid, she began describing it as a species. While regarding species as 'human constructs' seems to suggest that biological categories can be made and unmade according to our whims, careful attention to Joyce's laboratory practices reveals that *enacting* a new species is not a capricious project. Stubborn attention to seemingly mundane laboratory routines reveals that characterizing a new chytrid involves learning how to care for it. Each new microbe needs to be isolated in a sterile flask, so that its morphology becomes stable, suitable for description in taxonomic papers. Joyce creates genetically homogeneous populations of living fungi, or *isolates*, by selecting out pure strains, keeping each in a sealed vial. The first step in isolating chytrids usually involves baiting, laying out nutritious food to encourage them to emerge from 'gross culture', an indistinguishable microbial morass. Only after learning what an undescribed chytrid species likes to eat, or discovering other conditions that promote their flourishing, can taxonomists begin to grasp organisms of interest with technologies of visualization.

Caring for the chytrid running wild in a global pandemic involved offering it different food sources. Joyce initially suspected that the undescribed pathogen liked to eat frog or reptile skin. The microbe arrived in her lab on the bodies of dead poison dart frogs (*Dendrobates azureus* and *Dendrobates auratus*) and a White's tree frog (*Litoria caerulea*), shipped on ice from the National Zoo. Working with the tissue of these dead frogs, Joyce initially tried sterile snake skin as bait. But she found that the snake skin was quickly overrun by bacteria and water moulds. Rather than try other common baits – like chitin from shrimp exoskeletons, spruce pollen, hemp seeds, and onion skin – she tried a different method for promoting chytrid flourishing. She created a special petri dish with nutritious substances – peptonized milk, tryptone, glucose sugar, and agar – while also including antibiotics to kill unwanted microbes from other phyla. After dragging a small piece of skin through the dish, she used a needle to lift a healthy chytrid colony into a vial of nutritious broth. The yet-unnamed chytrid flourished in this new microcosm. After sixteen days, Joyce noted the 'broth was opalescent from the growth of the fungus' (Longcore, Pessier & Nichols 1999: 220).

Each Joyce E. Longcore (JEL) isolate receives a number which is written down in a dog-eared notebook alongside some jottings about its characteristics. For example, JEL 352, a chytrid with a 'ghostly veil' of wall material, was found in detritus collected from the rainforest canopy along Butcher's Creek near Malanda, in northern Australia. JEL 569 was collected from a pile of horse manure in Maine. In describing the new chytrid, the one suspected to be killing frogs, Joyce created isolates from each of the dead animals sent to her lab: JEL 197 from a blue poison dart frog; JEL 198 for a black-and-green dart frog; JEL 203 from a false tomato frog; JEL 206 from a White's tree frog. Comparing each of these new isolates, she determined that they had the same growth habits, general morphology, and ultrastructure. Opening her lab refrigerator, the place where she stores chytrid species as living isolated cultures, she compared these new isolates with others already at hand – confirming that she had never seen this particular organism before.

After Joyce carefully detailed the characteristics of this new chytrid, she sent a paper off to the journal *Mycologia* (co-authored with Don Nichols and Allan Pessier of the National Zoo), formally proposing a species name: *Batrachochytrium dendrobatidis*. After submitting this paper, she deposited the new species in her refrigerator, which contains the largest collection of isolates in the world. This fridge is one key place where chytrid species exist. Joyce's living collection inside is fragile, needy of care. It is dependent on constant renewal – colonies must be regularly transferred into new vials, with fresh media. Most isolates need to be transferred every thirty days. Others can be left to their own devices for up to one hundred days. In addition to maintaining many species as living cultures in this refrigerator, Joyce keeps some representatives frozen in liquid nitrogen. This is not for reasons of biosecurity – she is not worried about frog pathogens or other microbes escaping into the environment. The refrigerators already have enough biosecurity, she says. Some samples are kept frozen to ensure their genetic stability. If anyone needs a living chytrid isolate, she can simply defrost the samples and reanimate the cultures.

Joyce is articulate about how human concerns bring species, 'human constructs', into being. Economic interests and political forces are constantly transforming existing categories and bringing new ones into existence. When there is active interest in a given form of life, categories proliferate. 'Pathogens require different descriptors', Joyce told me. 'They need more specific names. It all depends on human need and use'. Her philosophical position is radically different from that of John Stuart Mill, whose 1884 proclamation about *natural kinds* claims: 'In so far as a natural classification is grounded on real Kinds, its groups are certainly not conventional; it is perfectly true that they do not depend upon an arbitrary choice of the naturalist' (Mill 2009

[1884]: 879).[3] Joyce instead tacitly subscribes to elements of an opposing philosophical position, *nominalism*, which assumes that categories are imposed on reality, rather than intrinsic to it (see, e.g., Goodman & Quine 1947). She also accepts the basic tenets of John Dupré's *promiscuous realism*, which maintains that the reality of biological kinds persists even though promiscuous economic and scientific interests guide classification projects (Dupré 1981: 82; 1993: 36, 57–8). Joyce Longcore assumes, like Dupré, that distinctions among taxonomic species are always made at the intersection of specialized interests.

With thousands of chytrids that could be described as distinct species, Joyce and the handful of other chytrid specialists need to be strategic about where they focus their attention and scarce resources. Scores of known unknowns – chytrids that have already been isolated but not named as species – are stored in her refrigerator. 'Some chytrids simply don't need to be named', Joyce said. Others get described simply for novelty's sake. Rabern Simmons, who completed his Ph.D. under Joyce, became interested in the JEL 569 isolate, the one collected from a pile of horse manure. He used it to describe a new species, *Fimicolochytrium jonesii*, which, he explained, is Latin for 'the horse-shit chytrid of Jones'. This name honoured Kevin G. Jones – a botanist, mycologist, and associate professor of biology at University of Virginia's College at Wise.

Did these different kinds of microbes exist before Joyce Longcore and her colleagues began naming them? Were they part of reality 'out there' which scientists 'discovered' with their astute observations and increasingly sophisticated instruments? Bruno Latour, who has written of related questions as they pertained to nineteenth-century scientists, would likely argue that they were not. Latour suggests that ferments 'did not exist' before Louis Pasteur came along to describe them (1999: 145). Ferments – and, by extension, species of chytrids – certainly depend on other beings, things, and apparatuses to produce their existence in human society. But perhaps Latour has been playing too fast and loose with reality. 'The opposition of "knowing minds," on one hand, and "material reality" awaiting description, on the other hand, is a silly setup', in the words of Donna Haraway (1997: 302 n. 12). This silly set-up has been dismantled by Ian Hacking in a review of *Laboratory life* (Latour & Woolgar 1979), Latour's initial study of the 'social construction of facts' (Hacking 1999: 80–1, 94). In this debate I side with Hacking (and Haraway), who assume(s) that reality is eminently material and solid, yet still pliable enough to be torqued by human practices.

Hacking suggests that classification practices can have 'looping effects'. He describes how different *species* of people – like overweight patients, anorexic models, or homosexuals – are transformed as labels change the way they behave. Looping effects emerge as the new behaviours result in further changes in the classifications and knowledge about them. But Hacking maintains that nonhumans, like microbes, are indifferent to classification projects (1999: 34, 104–6). Mary Douglas, the pre-eminent British social anthropologist, took issue with Hacking on this point. If Hacking suggests that 'microbes' possibilities are delimited by nature, not by words' (Hacking 1986: 230), Douglas counters that 'the contrast is not so clear, for it is not the words that do things to the people. The label does not cause them to change their posture and rearrange their bodies' (Douglas 1986: 101). Microbes, plants, and animals are no less responsive to words than humans, according to Douglas. The labelling process 'is part of a larger constraining action', she argues, and nonhumans often 'respond even more vehemently than humans' (1986: 101).

Pushing Hacking's insights into a realm where he feared to tread himself, I insist that diverse kinds of critters engage in classification work and are often transformed as they are categorized by others. Microbes, and other living beings, clearly interact with our classification practices. Chytrids are certainly torqued as taxonomic scientists care for them by isolating distinct strains, culture them on sterile media, and store collections in refrigerators. Malevolent microbes certainly also respond to human practices of classification and attempts to combat them. Looping effects emerge when microbes mutate, in response to deadly antibiotics, resulting in the proliferation of new kinds of organisms as well as novel scientific and medical practices (cf. Hacking 1999: 105).

Long before Joyce Longcore formally described *Batrachochytrium dendrobatidis*, the deadly chytrid fungus, it had been torqueing ecological communities – twisting and stressing established assemblages by killing populations of frogs. Previous to Joyce's paper, a number of theories had emerged to explain catastrophic declines of amphibians – global warming, pesticides, and habitat loss were all known threats. Earlier conservation initiatives tried to protect frogs by defending ecological communities from commercial development, or limiting pollution. Once Joyce gave *Batrachochytrium dendrobatidis* a name, her act of classification produced a sudden shift in conservation practices. Conservationists began building The Amphibian Ark, a transnational network of biosecure holding facilities to save frogs from the freshly described pathogenic fungus (Kirksey 2015). Legions of scientists who were amphibian specialists also began studying chytrid fungi, with an aim to understand the disease better. They began referring to the disease with its initials, Bd, since *Batrachochytrium dendrobatidis* is too difficult to say.

Looping effects emerged as researchers found Bd zoospores circulating the globe in commercial shipments of live amphibians. Two kinds of commercially valuable frogs were found to harbour Bd infections without becoming noticeably sick: bullfrogs (*Lithobates catesbeianus*), which are raised for frog legs, and African clawed frogs (*Xenopus laevis*), which are widely used as experimental animals. These findings led to new political regulations which torqued existing economic systems. Some countries, like Australia, banned further imports of these non-native amphibians and embarked on a campaign to kill those already in the country. Other nations with more *laissez-faire* economic systems, like the United States, left it up to the producers and consumers of frog legs and experimental organisms to test their amphibians for the Bd fungus.

As researchers studied amphibian immune responses to Bd infections – the ability of different kinds of frogs to recognize, differentiate, and destroy this emergent pathogen – they began to speculate that this microbe was not a stable entity from site to site. While some strains of Bd were deadly, others were benign – not noticeably making vulnerable species of frogs sick. Further studies revealed much genetic heterogeneity wriggling within the seemingly stable species name of *Batrachochytrium dendrobatidis*. Sequencing the whole genome of chytrid isolates being stored in Joyce Longcore's refrigerator and in other labs revealed a genetically heterogeneous global strain of Bd, a deadly 'pandemic lineage', as well as multiple non-virulent strains.

Genetic components of Bd seem to be fluid, ever changing. Studies of the Bd genome found that some strains had just one copy of each chromosome, while others had two, three, or even four copies of gene suites. While chytrids usually reproduce by cloning themselves, with each zoospore an exact copy of its parent zoosporangium, Joyce suspects some unusual sexual dynamics have been taking place. Rather than having straightforward sex, she suspects that Bd clones have had a number of 'para-sexual' events in the recent past. Para-sexuality, which has been documented in other species

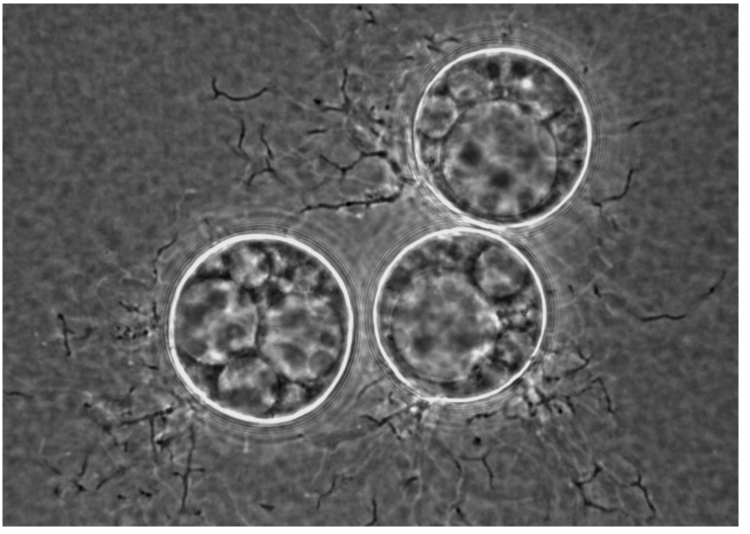

Figure 1. Chytrids have rhizoids, or root-like structures, that burrow into their substrates. In some species, the rhizoids of two individual chytrids can fuse and exchange genetic material. (Photograph and microscopy by Joyce Longcore.)

of chytrids, happens when two zoospores encyst next to one another. Some kinds of chytrids have genders, usually indicated by +/– in the literature, while others are gender neutral. When zoospores live in close proximity, and send out rhizoids, they might touch one another (Fig. 1). If compatible, the rhizoids fuse. The cell nuclei, which contain the organism's DNA, intermingle as the fused rhizoid begins to swell. This mass then turns into a resting spore – with a thick cell wall resistant to temperature extremes and drying. Para-sexual encounters among siblings, or even other chytrids from distantly related strains, thus might occasionally germinate hopeful monsters – new generations of chytrids with a novel suite of genetic resources.[4]

As specialists began to wonder if the species name *Batrachochytrium dendrobatidis* might not be specific enough, amphibian biologists continued to detect its presence with tools available ready to hand. A standard practice developed for detecting the presence of Bd. This technique for enacting a species involved researchers rubbing cotton swabs on their frogs to collect microbial DNA and then mailing off the swabs for identification at diagnostic laboratories. Jodi Rowley, of the Australian Museum in Sydney, told me about a collaborative study of Bd in Asia, which involved sending off some 2,500 swabs for identification. When the laboratory results came back, Jodi and her team learned that Bd was present in the skin of seventy-nine frogs collected from sites throughout Asia. Despite getting these positive results back, the team found little evidence of epidemic disease. Amphibian biologists working in the United States and Central America had previously described how Bd spread in a steady wave across some regions, leaving large populations of frogs extinct in its wake. Jodi and colleagues described different patterns in Asia. While this team discovered Bd was widespread – ranging from the Philippines, to Indonesia, South Korea and Sri Lanka – the fungus was not associated with amphibian declines in Asia (Swei *et al.* 2011). Following Jodi

Rowley beyond the realm of microbes, I considered the question of whether she was creating kinds of beings as she named and described frogs.

Frogs

The list of amphibians threatened by Bd is fast growing, already approaching 200 species that are in rapid decline or already extinct. Other forces – habitat loss and the collection of wild animals for sale as pets – are also driving frogs extinct in concert with *Batrachochytrium dendrobatidis.* Nearly one-third of all described frogs, salamanders, and caecilians – some 1,950 species – are threatened according to the International Union for Conservation of Nature (IUCN) Red List of Endangered Species. When animals are grabbed by the label 'endangered species', this designation often subjects them to the uncertain prospects of 'being saved through a regulatory and technological apparatus of ecological and reproductive management' (Haraway 2014: 250). But what are frog 'species'? Are they human constructs, brought into being at the intersection of human values and practices? Do frog species ever stand alone, by themselves? How do practices, beings, and things forge their existence? In conversations with Jodi Rowley, at the Australian Museum in Sydney, I found that she was also keenly curious about these questions. Ethical concerns, as well as a critical awareness of political history and market forces, were shaping her practice of describing frogs.

Jodi studies what she calls 'confusing small brown frogs from Vietnam'. Describing these species involves travel to interstitial spaces – places on the margins of urban centres and on the edge of expanding coffee plantations and agricultural estates. If early biologists in Southeast Asia imagined that they were travelling in a wilderness largely untouched by human civilization, Jodi situates her own travel practices within legacies of violence and dispossession. As she keeps her vision narrowly focused on undescribed frog species in Vietnam, a country where she has forged enduring ties with collaborators, she also notices the bomb craters pockmarking the landscape, and speculates on the lasting effects of Agent Orange. Jodi is leveraging her expertise to protect creatures that have survived being blasted by modern war, but are under renewed threats in the contemporary world system. She is working to make frogs with a precarious existence visible, audible, tangible, and knowable.

Jodi has become an expert on the genus *Leptolalax*, a group of well-camouflaged frogs with few obvious morphological characteristics that can be used to tell them apart (Figs 2, 3, and 4). Their calls sound like crickets, katydids, or grasshoppers. The genus *Leptolalax* had once been known as a possible 'cryptic species complex', a group with the appearance (to humans) of the same form, but containing hidden groups of species within. Emerging practices for describing species – involving new technical apparatuses and modes of listening – started to unravel this cryptic complex in recent decades, making diverse beings tangible and knowable. With the advent of high-end Sony cassette tape recorders, and readily-available computer programs capable of analysing sound, biological taxonomists began using calls to describe new *Leptolalax* species in the late 1990s. Jodi described her first species of *Leptolalax* in 2009, using an MP3 recorder to record its distinctive call digitally. Now her own ears are an important piece of the scientific apparatus. Jodi found Botsford's leaf-litter frog (*Leptolalax botsfordi*) while climbing Mount Fansipan, a popular destination for adventure tourists who attempt to climb 'the roof of Indochina'. 'I had a pretty good idea that the species was undescribed the moment I heard its faint chirp', she said (Mann 2014).

Figures 2, 3, and 4. *Leptolalax* frogs are difficult for humans to spot – they live among dead leaves and other detritus littering the forest floor in Southeast Asia. Invisibility can mean protection from predators, or from commercial exploitation by humans, but it can also spell vulnerability in an era of extinction. These are just three of the cryptic species described by Jodi Rowley: *Leptolalax applebyi*, top; *Leptolalax botsfordi*, middle; and *Leptolalax bidoupensis*, bottom. (Photographs courtesy of Jodi Rowley.)

Did Botsford's leaf-litter frog exist before Jodi described and named it? For the frogs themselves, I argue that the answer is yes. It would be a mistake to follow Latour's work on Pasteurian ferments and ask: Were these frogs part of reality 'out there' before scientists 'discovered' them? It is better to ask: What sorts of beings, bodies, and minds are involved in the worlds of frogs? How do they discover each other and interact? In tussling with Latour on this question, I ally myself with Eduardo Kohn, who insists that 'the world beyond the human is not a meaningless one made meaningful by humans'. Ecological communities involve other beings with 'relations, strivings, purposes, telos, intentions, functions, and significance' (Kohn 2013: 72). Like humans, frogs live in an *umwelt*, a bounded phenomenological world of perception and action (Buchanan 2008; von Uexküll 1992 [1934]). When male frogs call, they are trying to get inside the perceptual space of females – they are singing songs to stir amorous desires in others (Ryan & Rand 2003). Members of the same frog species grasp each other against the backdrop of the unknown cosmos (cf. Stengers 2005: 995).

The definition of a species as an 'interbreeding population', as formulated by Ernst Mayr, seems to be a good fit for *Leptolalax* and many other kinds of frogs. Frogs enact their own species with their own practices of classification, recognition, and differentiation. One experiment in Panama, involving Túngara frogs (*Physalaemus* species), offers evidence that members of the same species recognize each other before they mate. When female Túngara frogs (*Physalaemus pustulosus*) are presented with calls in an experimental arena, they predictably draw near speakers playing sounds made by their own kind. But the recognition system of *Physalaemus* is not completely species-specific. It is fuzzy around the edges. Calls of some closely related species (like *P. coloradorum* from Ecuador) also draw female Túngara frogs towards the speaker. Other species in the same genus (*P. pustulatus*, *P. petersi*, and *P. enesefae*) appear to be acoustically invisible to female Túngara frogs. Their calls do not elicit any responses that are different from noise (Ryan & Rand 1993: 651). These others exist in the unknown universe, beyond the grasp of the focal frog. Thus sometimes frog species stand alone amidst others in the world around them. Each frog might be understood as a 'subject' with an internal view of members of its own species and with a point of view about other species (Viveiros de Castro 2013: 5).

Standing alone in the world, beyond the grasp of taxonomic science, can spell extinction in the era of extractive capitalism. *Leptolalax* survived as US and Australian forces blasted the landscapes of Vietnam. But the existence of these frogs has lately become precarious – threatened by agricultural initiatives orbiting around coffee and rice. 'The problem is that there is not much forest left', Jodi Rowley says. More research needs to be done to determine if any *Leptolalax* should be formally listed as 'endangered species'. Jodi is currently the co-chair for Mainland Southeast Asia of the IUCN Species Survival Commission Amphibian Specialist Group, the institution that formally issues such designations. But she is an articulate critic of some approaches to reproductive management that 'save' species by simply keeping them in concrete holding tanks (cf. Haraway 2014). Within Vietnam there are no existing institutions standing by, ready to implement conservation programmes if Jodi were formally to recommend that certain kinds of *Leptolalax* be regarded as endangered. Nevertheless, she is collaborating with an ever-expanding network of Vietnamese counterparts who are figuring out how to care for animals whose lives and deaths are largely going unnoticed in a time of extinction (Rose & van Dooren 2011; Sodikoff 2012).

Documenting newly discovered frog species involves measuring collected specimens' snout-vent length (SVL), head length from tip of snout to rear of jaws (HDL), and the diameter of the exposed portion of the eyeball (EYE). *Doing* frog species now also involves banking DNA. Species have come to exist in 'information infrastructures' connecting different scientific specialties (Bowker 2005; Bowker & Star 1999). After a series of technical steps – extracting DNA from her frog specimens, singling out a particular gene, and then sending the sample to the Macrogen corporation in South Korea for sequencing – Jodi deposited 536 characters of code in GenBank as she described *Leptolalax applebyi*:

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  1 cgcctttgt ccattataaa aggtaacgcc tgcccagtga catagttcaa cggccgcggt
 61 attttaaccg tgcgaaggta gcataatcac ttgtttttta aataaagact agtatgaatg
121 gcatcacgag aactaagctg tctcccccct ctaatcagtg aaactgatct ccccgtgcag
181 aagcggggat atacccataa gacgagaaga ccctgtggag cttaaaatta aaaatcaact
241 gcggacgaac ctaaacatta ccacgcaaat atgatttaaa tttttagctg gggcgcctgc
301 ggagtaaaaa tcaccctccg cgaagaaaca caccaagaac caccattcta agtattaata
361 aatttaactt aattgaccca atttttgatc aacggaccaa gttaccccag ggataacagc
421 gcaatccact tttagagtcc ctatcgacaa gtgggcttac gacctcgatg ttggatcagg
481 gcatcctagt ggtgcagcca ttactaaagg ttcgtttgtt caacgattaa agccct
```

The GenBank database, founded in 1982, is maintained by the National Institutes of Health in Bethesda, Maryland. As of 2008, it boasted genetic sequences from more than 100,000 distinct species. The database has an exponential growth rate, doubling in size every eighteen months (Benson, Karsch-Mizrachi, Lipman, Ostell & Wheeler 2008). The complete genome of humans is stored in GenBank alongside thousands of our companion species, like rice (*Oryza sativa*), the fruit fly (*Drosophila melanogaster*), and the African clawed frog (*Xenopus tropicalis*). A multitude of other species, like the frog that Jodi was describing, are only banked in genetic fragments. The protein she selected for banking, the 16S ribosomal RNA from the frog's mitochondria, is widely used to describe animal species. While uploading her sequence, Jodi was also able to download sequences from closely related frogs. Comparing the sequences she found a significant genetic distance separating her new species from other *Leptolalax* frogs.

Descriptions of new *Leptolalax* species, confusing small brown frogs, go largely unnoticed. By contrast, in January 2012, when Jodi published a paper in the *Journal of Herpetology* describing Helen's Flying Frog (named after her mother), the new species was heralded with much fanfare. *National Geographic* reported: 'Fantastic new flying frog found – has flappy forearms'. With Helen's Flying Frog, Jodi ran into the opposite problem of *Leptolalax*. Press attention exposed the frogs to people who wanted to keep them as pets. Visibility made these frogs readily available for exploitation, giving entrepreneurial collectors the opportunity to make a quick buck (cf. Star & Strauss 1999: 9–10). A small Internet business based out of an apartment near Brooklyn College in New York City – Reptiles-N-Critters.com, Home of the Exotic Pet – began offering Helen's Flying Frogs for sale at $39.99.

Deadly looping effects, animated by consumers' desires for novel and exotic species, began to impinge upon populations of Helen's Flying Frogs. Loops of capital transformed these frogs into increasingly rare commodities, inspiring Jodi Rowley to do further classification work. Jodi began using her position on the IUCN Amphibian Specialist Group to oppose these effects strategically. She moved Helen's Flying Frogs to the front of the line of frog species waiting to be formally evaluated as endangered, ahead of the little brown *Leptolalax* species that were dear to her heart. Helen's Flying Frogs officially became classified as an endangered species in January 2014. This IUCN Red List designation effectively countered some deadly effects of classification and commercial enterprise. These charismatic frogs are now difficult to buy and sell on the open market. While critics characterize the IUCN Red List of Threatened Species as a colourful catalogue of biodiversity, or an instrument of dominant power, Jodi was using it to block some destructive effects of extractive capitalism. Rather than simply being imposed by humans, such lists can be useful tools for making our judicial and legal systems a bit less anthropocentric.

Figs, wasps, and *Wolbachia*

Following the idea of 'species' from Jodi Rowley's laboratory in the Australian Museum, where over 10 million specimens representing the animal kingdom are stored, I walked across the street into the Domain, a space with living plants managed by the Royal Botanic Gardens. Moreton Bay Fig trees, *Ficus macrophylla*, are an imposing presence in this city park. These trees, which are endemic to the region, were planted with enthusiasm by Charles Moore, who became director of the Royal Botanic Gardens in 1848. Moore planted fig trees to protect white settlers from the hot summer sun (Frawley 2010). Shaping the ecology of Sydney with periodic windfalls of fruit, figs feed a diverse assemblage of urban animals, like bats, birds, and rats. These convivial plants also form part of a living archive, figuring into local memory practices in the biological sciences (Bowker 2005). This lively collection of plants surrounds a standardized botanical archive, the National Herbarium, which is five minutes away from the Australian Museum as one walks towards the Sydney Opera House. This herbarium is the definitive collection of plant specimens for Australia's most populous state, New South Wales. The practice of describing regional species involves depositing a voucher specimen here.

About 1.2 million plant specimens – with leaves, fruits, and flowers pressed flat onto paper and stored in red plastic boxes – are archived in Sydney's National Herbarium. 'The actual fact is that we really don't know how many specimens we have', confesses Dale Dixon, a fig expert who is the Collections Manager. 'We are just predicting based on how many we have already entered into our databases'. Explaining part of his core work, Dale showed me a pressed fig specimen collected by Joseph Banks and Daniel Solander during Captain Cook's exploratory visit to Australia in 1770. The manuscripts of Banks and Solander originally named this plant *Ficus caudiciflora*. Over the centuries, however, others offered opinions. 'When I did my Ph.D. I said it was *Ficus congesta*', Dale said. 'The only way I could do that is by requesting material from all over Australia and comparing it'. The collecting practices of Banks and Solander were driven both by the commercial interests of the British Empire and by scientific curiosity (Schaffer 1996). But this particular *Ficus* species, like so many other plants gathered by colonial collectors, did not prove to be of any particular use to the mother country. The fruit, which is 'pedunculated, depressed, and globular' in botanical terms, is not particularly rich in sugars like its commercially grown cousin, *Ficus carica*.

Dried specimens lose colour, become stale and brittle, and have distorted morphologies when they are pressed flat. Part of the vision guiding the maintenance of the Royal Botanic Gardens outside the herbarium is to have living representatives of plant specimens ready to hand. Living trees and flowering plants in the gardens contain more morphological, chemical, and ecological information than the remains of their dead kin stored inside the herbarium. While *Ficus congesta* normally only grows in the tropical regions, the Royal Botanic Gardens have naturalized this species, fostering its growth in the mild climes of Sydney. Some thirty-five other species of fig are also growing in the gardens.

When Dale Dixon gave me a tour of the gardens in May 2014, fresh debates about science and commercial interests were playing out in local papers. A master plan released by the Royal Botanic Gardens Trust 'sparked a public brawl', according to the *Sydney Morning Herald*, with a proposal to build new toilets, buildings, and a permanent music dome. Labor Party politicians vowed to 'reject the commercialization agenda' and 'put the gardeners back in charge' (Needham 2014). While my conversations with Dale steered clear of controversies about commercialization, we both shared feelings of pleasure as we walked amongst the metamorphic forms of *Ficus* in the gardens. Dale showed me several examples of 'multispecies mash-ups', where two fig species had become entangled, growing together.[5] Many kinds of figs are famous for becoming stranglers – growing up and around host trees, eventually choking their hosts, killing them off. Dale pointed out knotted and gnarled figs, where two stranglers were tangled up in each other.

One fine specimen in the Royal Botanic Gardens – a gigantic Moreton Bay Fig (*Ficus macrophylla*), the same imposing tree species that first caught my eye across the street from the Australian Museum – was named the Children's Tree in the 1980s because it was regularly used as a living jungle gym by students at the nearby Plunkett Street School. Next to this huge Moreton Bay Fig, Dale showed me a kind of *Ficus* with a radically different form. Instead of being a proper tree, with a recognizable central trunk, it was a banyan (Figs 5 and 6). Like other banyans, it had a vast network of aerial roots forming a massive and chaotic interlocking structure. One of the root-cum-trunks of this particular tree formed a drunken arch that twisted up and over a concrete footpath. Charles Moore, the same person who planted Moreton Bay figs with enthusiasm in the 1840s, collected this tree from Lord Howe Island, some 370 miles off the coast of Australia. He described it as a new species in 1870: *Ficus columnaris.* When Dale Dixon examined these two kinds of trees in 2001, he had a different opinion. Dale concluded that they were the same species, even though they seemed to have completely different growth patterns.

Dale grouped these trees together after careful attention to the practices of animals involved in the enactment of fig species. Figs are generally pollinated by tiny specialized wasps. These small insects are attracted by distinctive chemical signals from the plants. Wasps enter the round fig fruit by squeezing through a small tunnel, which rips off their wings and closes behind, entombing them inside. Once inside, the wasp lays eggs and pollinates hundreds of tiny fig flowers. Wasp eggs then hatch into larvae, which, in turn, become winged adults. The wasps emerge through a hole they cut in the ripening fig to pollinate other plants. There are about 755 fig species world-wide. Many of these plants have a one-to-one association with species of pollinating fig wasps (Iziko Museums 2014; Janzen 1979; but also see Herre, Jander & Machado 2008). Without wasp pollinators, the fig trees cannot reproduce.

Dale found that the same wasp, *Pleistodontes froggatti*, was pollinating both of the iconic figs in the Royal Botanic Gardens – the gigantic Moreton Bay Fig known as the Children's Tree and the huge spreading banyan from Lord Howe Island. Having a shared pollinator indicated that these two forms of plants were probably 'not reproductively isolated', and therefore Dale concluded that they were members of the same *Ficus* species. He supposes that wasps historically facilitated gene flow among these forms of figs by

Figures 5 and 6. A gigantic Moreton Bay Fig (*Ficus macrophylla* f. *macrophylla,* top) grows next to a massive Lord Howe Island banyan (*Ficus macrophylla* f. *columnaris,* bottom) in Sydney's Royal Botanic Gardens. (Photographs by Eben Kirksey.)

very occasionally being blown from mainland Australia to Lord Howe Island. Following the wasps' lines of flight, Dale determined that both of these varieties were the same species: *Ficus macrophylla.* He downgraded Charles Moore's 1870 species designation for the banyan to a form: *Ficus macrophylla* f. *columnaris.* The form was differentiated on the basis of 'a single conspicuous morphological difference', namely the aerial roots giving the banyan its distinctive macro-structure (Dixon 2001).

Dale bases his species descriptions on morphological characteristics. Features of the fig trees he studies are certainly important. But for him it is more important to consider how wasps recognize fig species, rather than use a priori characteristics that we humans deem important. The concept of species, he says, is not a universal idea in biology – it must be shaped and tailored for each taxonomic group. Fig species depend on the other beings involved in producing their existence. Botanists do not make these species, or construct them. Wasps, not humans, are key agents involved in the *doing* of fig species. Rather than being a 'natural kind', waiting to be discovered by humans, *Ficus* species are brought into existence by their continual rediscovery by their wasp pollinators. Rather than being fixed in an Aristotelian order of difference, fig species exist in an entangled ecological network that extends beyond the plants. In other words, they are entailed in the 'becomings' of animate beings.

Becomings involve new kinds of relations, in the words of Gilles Deleuze and Félix Guattari, emerging with non-hierarchical alliances and 'symbioses that bring into play beings of totally different scales and kingdoms' (1987: 238). Departing from genealogical projects based on filiation and descent, Deleuze and Guattari celebrate becoming as a mode of 'expansion, propagation, occupation, contagion' (1987: 239). Dismissing classification projects, which group 'animals with characteristics or attributes' into genus or species, Deleuze and Guattari salute 'affect animals' that gather together to form packs and swarms, 'a multiplicity without the unity of an ancestor' (1987: 241). In rejecting the notion of species, Tim Ingold strikes out on a related line: 'to be animate – to be alive – is to become'. Ingold claims that the animal subject 'is not a bounded entity set over and against others of its kind, but just one trail of growth and development in a heterogeneous field of interests and affects' (2013: 20). Poaching some insights from Ingold, without buying all of the underpinning Deleuzian philosophy, I suggest that species emerge with becomings of animate beings who are entangled in ecological, political, and economic networks.

George Weiblen, a Professor of Biology at the University of Minnesota, offered me evidence of becomings and looping effects in biological systems. He told me that new insights from evolutionary ecology are prompting most researchers to rethink the concept of species. 'Our concepts impose divisions on ongoing evolutionary processes', George said. 'A plurality of processes drive the emergence of new species and these processes are distinct in different branches of the tree of life'. George is an expert on the figs and wasps of Papua New Guinea. His recent experimental work shows that distinct fig species can reproduce when artificially pollinated, but rarely do so because of wasp behaviour. When George teaches the concept of species to his first-year biology students, he asks them to think about the present, the past, and the future. Species, he said, are organisms with shared characteristics that can be observed in the present (morphological species concept); they are groups that diverged from other groups in the historical past (phylogenetic species concept); and they are biological populations with the potential to exchange genes in the future (interbreeding species concept). When any of these species concepts are taken on their own, George supposes that they might reify an Aristotelian notion of fixed difference. But George asks that his students consider all three concepts at once, to integrate them all into an understanding of ecological and evolutionary processes.

A preliminary reading of the 'code of life', a study that sequenced the DNA of these closely related forms of *Ficus*, seemed initially to challenge Dale Dixon's taxonomic determination. Genes associated with these two plant forms led at least one researcher, Nina Rønsted at Kew Gardens in London, to suspect they formed reproductively isolated populations (Rønsted, Weiblen, Savolainen & Cook 2008). Dipping into the GenBank database, Rønsted's collaborative team pulled out snippets of fig genes: ITS sequences, ETS sequences, and G3PDH sequences. While animals like frogs have a standard 'DNA barcode', consisting of ribosomal genes from mitochondria, there is not yet a single genetic sequence that has become the standard for plants. Rønsted's team extracted genomic DNA from a total of twenty-nine *Ficus* plants, in addition to using sequences that were already stored within digital archives. Once the sequences came back, Rønsted's team ran them through computer software and drew a small branch on the evolutionary tree.

'There is always something genealogical about a tree', suggest Deleuze and Guattari (1987: 8). Indeed, the evolutionary tree of life, at its core, is a genealogy. The small branch drawn by Rønsted *et al.* seems to suggest that the Morton Bay Figs (*F. macrophylla* spp. *macrophylla*) are distinct entities from the massive spreading banyan that originates from Lord Howe Island (*F. macrophylla* spp. *columnaris*). A diagram in their paper suggests that Moreton Bay Figs are more closely related to *Ficus pleurocarpa*, the banana fig which is found in northeast Queensland. But taking a more careful look reveals that this branch is a provisional hypothesis, subject to revision. A weak genetic signal, with a low 'bootstrap percentage' of 0.51, separates *F. macrophylla* spp. *columnaris* from these other *Ficus* forms. Scrutinizing the devilish details associated with the plants in this study also reveals that many of the specimens used for genetic sampling have uncertain origins.[6] George Weiblen, a co-author of this paper, intimated that this small branch of the tree of life will likely be redrawn again as further genetic studies offer new evidence. He also cautioned against taking genetic studies as the final word. Even if historical genetic connections do not link two forms in the past (the phylogenetic species concept), genetic evidence will never absolutely foreclose future possibilities (interbreeding species concept).

Figs and wasps are good to think with when considering how new kinds of organisms emerge within heterogeneous fields of interests. Host plants can shape the species of their pollinators. Wasps depend entirely on the figs for their own existence. Co-evolution, a process of becoming species together, has been well documented for many figs and their pollinating wasps, even if countervailing interests and affects sometimes pull them apart. While wasps play key roles in the enactment of fig species – being very selective with respect to the kinds of figs they pollinate – the plants also retain a degree of agency. Once wasps are inside the fig fruit, and bring pollen to the hundreds of flowers, the plants may have the ability to choose among possible co-parents by 'aborting figs pollinated by wasps that bore pollen that was "wrong" in some sense' (Janzen 1979: 25). In the case of the iconic figs in the Royal Botanic Gardens – described by Dale Dixon as *Ficus macrophylla* f. *macrophylla* (the fig tree) and *Ficus macrophylla* f. *columnaris* (the massive banyan) – the plants have chosen each other as co-parents. The banyan regularly produces viable seeds even though it is some 370 miles distant from its near kin on Lord Howe Island.

Amidst shifting sands – as branches of the tree of life appear, disappear, and then reappear again – one might be tempted to embrace Deleuze and Guattari's suggestion that we abandon arboreal images of genealogy and instead illustrate connections with rhizomes, plant stems that burrow underground. 'There are no points or positions in a rhizome', they write, 'such as those found in a structure, tree, or root' (1987: 8). Drawing on scientific findings of the 1980s, they described the scrambling of genealogical trees, writing: 'We form a rhizome with our viruses, or rather our viruses cause us to form a rhizome with other animals' (1987: 10). 'Much that is solid about the tree of life will melt into water', predicts Stefan Helmreich. Writing about deep ocean vents, where microbes are foiling attempts to root the tree of life by exchanging genes with one another, Helmreich has described forms of 'alien kinship' (2009:

72, 97). These forms of kinship are increasingly being found in other multispecies assemblages.

Digging even deeper into the entanglements involving figs and wasps reveals a multispecies story of exceeding complexity, where forms of alien kinship are being mediated by barely perceptible agents. Parasitic bacteria called *Wolbachia* live inside the body of most fig wasps. *Wolbachia* can insert their genes into insects, creating new alien kin. These bacteria, which are found in a variety of spiders, worms, crustaceans, and insects, also play with the reproductive dynamics of their invertebrate hosts. In the worlds of wasps and figs, *Wolbachia* are bringing plant and insect species into being. *Wolbachia* bacteria are too large to fit inside sperm and tend to be transmitted vertically, from 'mothers' to 'children', rather than horizontally by infection. If classic biomedical textbooks contain tales about human sperm and eggs that naturalize patriarchal stereotypes about productive men and wasteful women, the *Wolbachia* literature refracts related tales through the microbe's imagined point of view: 'Because males are not transmitters, they are "waste" from the perspective of the bacteria' (Stouthamer, Breeuwer & Hurst 1999: 82). Maximizing their transmission across generations, *Wolbachia* adjust and transform the bodies of their invertebrate hosts – bending gender, killing males, and sterilizing uninfected females (see also Kirksey, Costelloe-Kuehn & Sagan 2014).

Experts on fig wasps speculate that reproductive incompatibilities mediated by *Wolbachia* have led to partial or complete reproductive isolation, and therefore speciation (Cook & Segar 2010). In other words, these bacteria appear to be torquing wasp species with practices of classification, recognition, and differentiation. By extension, the bacteria are probably also indirectly manipulating speciation in fig trees. Wasps, figs, and bacteria are thus intimately entangled companion species that have captured one another in a reciprocal embrace. Together they have reached a symbiotic agreement, 'integrating a reference to the other for their own benefit' (Stengers 2010: 36; see also Haraway 2008). *Wolbachia* make life what it is for wasps, and vice versa. The same can certainly be said for the wasps and their *Ficus* hosts. They bring each other into being, as species, torqueing each other in intergenerational dances. Humans are also indirectly torqueing fig, wasp, and *Wolbachia* ontologies. By planting the Lord Howe Island banyan in a Sydney garden, Charles Moore changed the flow of genes from this form to Moreton Bay Figs. New hybrid forms are emerging as a result, liminal beings between the fixed points of a standard tree and the unruly banyan.

The tree of life has not completely melted. New modes of enacting species are instead enabling taxonomists to recognize a chaotic and polycentric structure in its place. Deleuze and Guattari's rhizomes, which ceaselessly establish connections with everything other (1987: 11), are not good figures for understanding emerging knowledge about ecological and evolutionary entanglements amongst diverse organisms. Moving from the form of a rhizome to a banyan might enable us to better understand alien kinships that trouble conventional understandings of evolution. Banyans can become mosaic organisms – when branches or roots of two plants touch, they slowly explore the possibility of physiological fusion, looking for molecular and histological compatibility. Banyans are different from rhizomes in that they contain definitive structures. Whereas rhizomes are not 'roots', banyans contain genealogical origins in their knotted entanglements, as well as the possibility of future contingent connections (Kirksey 2012: 56).

Coda: praxiography and the species multiple

Emerging findings about microbial companion species give a new twist to Annemarie Mol's suggestion that bodies are 'an intricately coordinated crowd' (2002: viii). Novel ways of performing and enacting taxonomic science reveal that bodies are species multiples, crowded with swarming forms of life. *The body multiple*, Mol's pioneering praxiography, describes a process of reconciliation when different medical tests, performed on the same body, give different outcomes. She studied atherosclerosis, a disease of blood arteries, which takes on different phenomenological forms: pain when walking, blood pressure drop, or an angiographic X-ray. Translations by doctors and patients co-ordinate the crowded field of phenomenology, producing a body that is 'more than one', but not 'fragmented into being many' (Mol 2002: viii). Species, unlike Mol's bodies, sometimes do fragment. Boundaries around populations of organisms expand and contract as obstacles come and go, as ecological relationships shift, as behaviours change, or as hopeful monsters emerge (Gould 1980; Mayr 1942).

Praxiography, for Mol, involves studying practices to push beyond the domain of epistemology (a concern with issues of representation and knowledge) to consider issues of ontology (modes of being in the world). Moving away from epistemology, which 'asks whether representations of reality are accurate' (Mol 2002: vii), Mol claims to study shifts in ontology itself as medical practices *enact* diseases differently (2002: 1–2). Studying practices associated with the emergence of species led me to retrofit the tools of Mol's praxiography, to refuse her distinction between the domains of ontology and epistemology (cf. Candea 2010: 175; Woolgar & Lezaun 2013). Considering species praxiographically led me to conclude that they come into existence at the intersection of entangled practices of knowing and being. Karen Barad's notion of onto-epistemology, a serious challenge to Cartesian habits of mind, insists that 'knowing is a direct material engagement, a practice of intra-acting with the world' (2014: 232). Subjects are ontologically inseparable in Barad's work – they do not precede their interaction, but, rather, emerge through particular intra-actions. 'Boundaries do not sit still', Barad writes. 'It is through specific intra-actions that a differential sense of being is enacted in the ongoing ebb and flow of agency' (2003: 817).

Species emerge as entangled agents torque one another in ongoing loops of multispecies intra-actions. Praxiographically studying species illuminates how some kinds of critters, like chytrids, come into being as they intra-act with humans, as they are isolated and stabilized by our technologies and practices. Yet humans are not the only thinking things or agential beings (cf. Kohn 2013). Other kinds of onto-epistemological agents, like frogs, bring themselves into being, beyond the purview of human perception and action. Coming together, against the backdrop of an unknown cosmos, members of different species grasp each other even if there are gaps in their gaze and disjunctures in their interests (cf. Kirksey 2013: 164; Stengers 2005). Relationships among figs, wasps, and *Wolbachia* clearly illustrate the idea that species emerge amidst intra-actions with companions. As entangled beings rediscover each other in intergenerational dances, species persist across time and space. If species sometimes appear to be in isolation, like chytrids frozen in liquid nitrogen or frogs that seem to be singing to themselves, perhaps it is just because of the limits of our own epistemologies and practices. Joe Dumit's microbiopolitical dictum states: 'Never think you know all the species involved in a decision. Corollary: Never think you speak for all of yourself' (2008: xii).

At the current historical moment, the continued existence of many species has become contingent on the practices of humans who learn to enact species *well*. Recognizing and naming species is an ethical imperative even if it opens up epistemological, technical, and ontological challenges. Making organisms visible that once existed independent of us can foster new modes of interdependence. Stabilizing the existence of species in techno-scientific worlds can help them endure hostile or indifferent political and economic forces. We are only dimly aware of how our own existence, as a species, is contingent on the lives and deaths of others. Abandoning the notion of species would mean losing a useful tool for grappling with other animate beings. Multispecies ethnographers are just beginning to use this tool to study the relational becomings of entangled plant, fungal, microbial, animal, and human communities. We are just beginning to study the technological and scientific practices that enable us to form contingent political articulations with other organisms against the background of an unknown cosmos.

NOTES

Lively intellectual communities in Sydney, New York City, and England helped catalyse my thinking on species. Members of the Environmental Humanities Saloon – particularly Thom van Dooren, Jennifer Hamilton, Judy Motion, and Laura McLauchlan – discussed an early version of this article. Jesse Prinz and Peter Godfrey-Smith brought my species thinking into conversation with the history of philosophy at the Science Studies Seminar they host at the City University of New York Graduate Center. Stimulating discussion in England – with Astrid Schrader, Elizabeth Johnson, John Dupré, and colleagues at Exeter as well as Jamie Lorimer and colleagues at Oxford – helped sharpen some points in the final stage of the essay. I am indebted to Alan Herre, of the Smithsonian Tropical Research Institute in Panama, for drawing me into the surprising worlds of *Wolbachia* and fig trees.

[1] Insights about the visibility of species might be derived from Susan Leigh Star and Anselem Strauss's writing on work. 'No work is inherently either visible or invisible', they write. 'Visibility can mean legitimacy, rescue from obscurity or other aspects of exploitation', while it can also 'create reification of work or opportunities for surveillance' (Star & Strauss 1999: 9–10).

[2] Elsewhere, in an essay called 'Interspecies love', I have explored how a certain kind of ant, *Ectatomma ruidum*, groups other kinds of creatures on the basis of similarity and divides them on the basis of difference (Kirksey 2013). *Ectatomma* ants navigate a world with a plurality of species by making consequential distinctions among kinds of beings.

[3] Richard Boyd has defended the naturalness (and the 'reality') of natural kinds. His notion of *homeostatic property cluster kinds* assumes that species involve properties that are 'contingently clustered in nature' (1999: 143). Underlying ecological mechanisms or evolutionary processes tend to maintain the presence of these properties, according to Boyd. Homeostasis is Boyd's metaphor for understanding the stability of clusters at the intersection of these processes.

[4] Monstrous mutations in animals and plants usually result in the death of the organism, but 'hope' emerges when strange new forms occasionally survive and give rise to new species. Steven Jay Gould suggests that 'new species arise abruptly by discontinuous variation, or macromutation' (1980: 188–9).

[5] The phrase 'multispecies mash-up' originates with Wallace Correy, a student in my Environmental Humanities Capstone course. Thanks are due to all the students in the course who toured the Royal Botanical Gardens with me and Dale Dixon in September 2013.

[6] For example, one *F. macrophylla* specimen used in this paper (identified as GA679) was collected from the gardens of the Auckland Museum in New Zealand, a place where figs are not native plants. The other *F. macrophylla* sequence was taken from GenBank (ITS accession number AY063571). This GenBank specimen was deposited by Emmanuelle Jousselin in association with a 2003 paper in *Evolution* that identifies the plant's origin simply as 'Australia' (Jousselin, Rasplus & Kjellberg 2003).

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Espèce: une étude praxiographique

Résumé

Les taxonomistes, qui décrivent et qualifient les nouvelles espèces, sont particulièrement conscients de la manière dont les forces politiques, économiques et écologiques engendrent de nouvelles formes de vies. En menant une recherche ethnographique parmis ces spécialistes en classification biologique – ces experts qui ordonnent les catégories d'animaux, de plantes, de fungi et de microbes – j'ai constaté qu'ils examinent minutieusement le va et vient de l'agentivité au sein des mondes multi-espèces. Les conclusions naissantes de la génomique et de l'informatique transforment les catégories existantes et en engendrent de nouvelles. Cet article soutient que le concept d'espèce reste un outil précieux, malgré les attaques culturelles récentes.

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