UNIVERSITY OF SOUTHAMPTON

FACULTY OF ENVIRONMENTAL AND LIFE SCIENCES

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Practicing Ecologies: Aquaponics and Intervention in the Anthropocene

by

James Gott

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ABSTRACT

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Reinventing a life of dignity for all humans in a finite and disrupted Earth has become the master issue of our time, the Anthropocene (Hamilton et al., 2015a), a 'bipolar' moment (Haraway et al., 2016), where the hope of scientific renewal through multidisciplinary collaboration glints on the doom-laden horizon of deepening ecological catastrophe. Against this backdrop, this thesis asks what the Anthropocene means for science and the scholarship of science, through the exploration of 'Aquaponics'. A food-system innovation that seeks to combine aquaculture and hydroponics in novel ecosystems, 'Aquaponics' is thought to hold potential for responding to the impending risks that mark late-industrial food systems in the Anthropocene. The thesis presents material from various ethnographic movements inside the field of Aquaponics, documenting what matters and what comes to matter for researchers and practitioners of this emergent field. The first movement is an engagement in the scientific labs of an agricultural research facility in the south of Belgium. Eschewing the usual terms of interdisciplinary activity, particularly the critical security of distanced observation, the researcher takes up a key role within an aquaponic experiment that seeks to test the possibilities of novel aquaponic ecologies for the agri-food sector. Experiencing the multispecies experiment as a space of both uncertainty and responsibility, political possibility becomes entangled within the aesthetic-material conditions and practices of science (Stengers, 2000). This ethnography discusses the potential and risks of affirming ontological proximity, more-than-human sensitivity, and a politics of care within technoscientific apparatuses. In a second line of ethnographic enquiry, the thesis documents my movements over 3 years within a European network of Aquaponic researchers, innovators and entrepreneurs. Following this 'field-in-the-making' (Swanson et al., 2015) the thesis develops an appreciation of knowledge politics involved in emergent fields, exploring the way urgent concerns become channelled down predictable disciplinary lines, complex issues like sustainability become side-lined for more attainable research targets, and technical problems get favoured over those of deliberation. In response to this, the thesis presents the outcome of a collaborative project in which the authors experiment with a shared aquaponic narrative and introduce the need for concepts that allow for types of *negotiation* that unsettle disciplinary boundaries. The thesis reclaims an idea of sustainability as a concept fitting for aquaponics in the Anthropocene. What follows is not a sparkling methodological blueprint that secures aquaponic solutions, but a collaborative experiment in the art of 'paying attention' (Stengers, 2016) that problematizes the experimental objectives of aquaponic research; a form of care for the academic milieu, one of many that increasingly sediment our troubled earth.

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DECLARATION OF AUTHORSHIP

I, James Gott ....

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

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....

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission

Signed: ....

Date: ....

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Rumana and Rabeyah were the biggest and most wonderful distraction of all. Every work needs a break.

Foreword

This thesis was not meant to be like this. Soon after starting this PhD, in an introductory training session held inside the National Oceanographic Centre (NOC), a very informative teacher relayed to a room of around twenty-five or so fresh and bright-eyed PhD students something that would become central to this project. "Why, given our difficult time of public sector cuts, do you think there are so many PhD students in this room all starting new projects?" the teacher asked. The room was quiet. "It's simple…" the teacher continued, "you are here, because it is expected that each PhD will give a return on investment of around 6 times the funding cost." After a great deal more advice on how to turn the PhD process in to a success, this helpful session came to a close. Leaving the NOC, I collected my bike, and out from the securitised dockland I cycled back, through persistent drizzle, to my new home. My head was filled with much information but the words that kept circling were those of the teacher. Of course there had been a dash of humour when the teacher defined our PhD's by way of a single, lucrative equation. Yet, there was something deeply unsettling in how the next four years of our lives could be cast with such cynicism and in such an openly, mundane way. Everybody knows that science is big business, but I must admit, even I was shocked by how the research process in these opening moments had been branded so explicitly with capitalist values, and in the absence of any others. This was the start of a four-year journey in learning how to 'reclaim' a PhD and a research process (Stengers, 2016).

This research project was funded by the UK's Natural Environment Research Council (NERC). The original title of this project was '*Valuing the cultural benefits that coastal ecosystems provide to people using Citizen Science'*. As I looked to extend my interest in how interdisciplinarity might be applied to environmental challenges, the potential of this project to bring together my background in Marine Biology and Anthropology was exciting. For four months, I studied the 'cultural ecosystem services' literature, a rapidly emerging although "arguably one of the least understood, and most controversial areas" (Fish, 2011, 674) of the then booming field of Ecosystem Services. Prominent scholars ambitiously called for the inclusion of diverse social science methods (Chan et al., 2012), but finding a way into this field, whose framework had already established its position as "an *a priori* way of knowing" (Leyshon, 2014; 722), proved a daunting task. In the breakneck 'multidisciplinary clamour' to identify, define, measure, evaluate, model and predict all matters of our earths pressured worlds, there was simply no scope within the Ecosystem Services framework to apply the critical and contextual methods of anthropology that are strongest when emphasising the mobility, motility and fluidity of people, ideas and objects (Leyshon, 2014).

What the Ecosystem Services framework was asking of this postgraduate research student, was to become what Pritchard Jr, et al. (2000; 39) call the '*economist/ecologist*': "a disinterested technician, adding energy flows or money flows to assess values that are ''out there;'' the analyst is neutral, the parameters are static, and the bottom line is the truth." This conflationary, albeit abstract, subject of the Ecosystem Services agenda promised to break down nature and culture, "but at the cost of turning everything into circuits of monetarization and accounting" (Haraway et al., 2016; 5). At the time, I didn't have the language to articulate well my unease with how issues normally falling outside the remit of natural science could nevertheless be overlain so inappropriately by the authority of science. Isabelle Stengers taught me a new language in this regard, and a great deal of this thesis would not be possible without her determined effort to defend the sciences against "an image of authority that is foreign to what makes for their fecundity and relative reliability" (Stengers, 2016; 69). It wasn't that the 'objects' of the Ecosystem Services agenda (the 'services') were unconvincing, or the style of diplomacy (technocratic) unsatisfactory, rather the framework fell into a much deeper and pervasive 'conceptual trap'; that of 'conceptualizing itself as being on the outside' (Palmesino et al., 2013; 16). The 'culture' of cultural ecosystem services was, like all the other services, just one more isolated node/set of parameters existing 'out there' to be looked down upon, and locked down, to be brought into the schema, economised.

Ecosystem Services: the 'view from nowhere' everywhere financialised. So I had to flee. I searched for a different intellectual frame. One where the relation between science and other disciplines might take a relationship other than the colonial movement of settling all experience by the same measure. For better or for worse, I quickly found myself in a different frame of intellectual inquiry entirely, this one also witnessing a rapid expansion. 'The Anthropocene' appeared on the horizon, and seemed to offer some possibility - however ambiguous, flawed, and dangerous - of pursuing different trajectories with science. This shift of frame precipitated an institutional shift in my PhD as I moved from Biological Sciences to Geography. As such, this thesis begins here, starting over, learning a different home.

Chapter 1: The Anthropocene

1.1 'Welcome to the Anthropocene'

At the turn of the millennium, the Nobel prize winning atmospheric chemists Paul Crutzen and Eugene Stoermer popularised the term 'Anthropocene' to name the present time interval, one in which many geologically significant conditions and processes had, for the first time, become profoundly altered by human activities (Crutzen and Stoermer, 2000b). There is increasing evidence that anthropogenic material flows stemming from fossil fuel combustion, agricultural production, and mineral extraction now rival in scale those natural flows supposedly occurring outside of human activity (Steffen et al., 2015a). As such, the term 'Anthropocene' has become congruent the idea that the technological deployment of modern science has reconfigured the biogeophysical makeup of our planet to a degree that marks the beginning of a new geological epoch, notably, one that is of humanity's own making. The benign era of the Holocene has passed, so the proposal claims; we have now entered a much more unpredictable and dangerous time where humanity recognises its devastating capacity to destabilise the planetary life support systems upon which it depends (Rockstrom et al., 2009, Steffen et al., 2015b). According to Professor Jan Zalasiewicz, chair of the Anthropocene Working Group of the International Commission on Stratigraphy, the 'Anthropocene' has become the ''most important question of our age—scientifically, socially and politically" (Zalasiewicz et al, 2011b; 838). In this chapter, the aim is to develop a sense of the Anthropocene as the 'master narrative' of our times (Davis and Turpin, 2015b), the nature, magnitude and urgency of which brings great consequences for our modes of knowing. By now, this era changing proposal has resonated across the academy and beyond, gaining increasing attention across the natural and social sciences (Zalasiewicz et al., 2010, Castree, 2015, Wark, 2015, Haraway et al., 2016). It thus becomes important to begin this chapter with a discussion of what the Anthropocene means for different communities of scholars currently engaged with the phenomenon.

1.2 Defining a new epoch

The debate about the Anthropocene - what it is, if, and when it happened – was initially held within the Earth System sciences and geology but has quickly spread becoming an embedded feature in wide number of disciplines. It is now apparent that the broad appeal of the concept to different academic circles has resulted in a diversification of what the Anthropocene means to different people in different contexts. It therefore becomes important to specify what this thesis refers to when it talks of the Anthropocene, and in this regard, the analysis of Hamilton et al. (2015) might offer some clarity.

Hamilton et al. (2015; 2) discern 'three definitional dimensions' that have precipitated from the diverse interests surrounding the Anthropocene debate. The first definition proposes a new interval in *geological* history. Debates around this definition fall solely within the remit of stratigraphers. This group of geologists who study the particulars of rock strata have a centuries-old epistemic culture (Hamilton et al., 2015b) that is built upon specific, narrow, yet highly stringent kinds of evidence used to delineate strictly geological intervals (Zalasiewicz et al., 2011). To date, according to this stratigraphic definition, the Anthropocene has not yet been officially validated[1] and until this point, the epoch remains just a proposal (Zalasiewicz et al., 2017).

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A second definition of the Anthropocene coalesces around matters of 'Earth system science', a topic that draws upon a much more diverse disciplinary ensemble than pure geology – e.g. Atmospheric chemistry, global ecology, geochemistry, oceanography, climatology etc. - around a shared 'complex systems' view of the Earth (Steffen et al., 2006). This definition of the Anthropocene grows from an interdisciplinary perspective that views the Earth as a total entity, driven by cycles of material and energy and characterised by a dynamic, and incessant state of flux, from core to stratosphere. This wider view of the Anthropocene includes evidence, for instance, of anticipated sea-level rise, large-scale shifts of sediment, rapid rates of species extinction and prevalence around the globe of artificial organic molecules (Zalasiewicz et al. 2012). These ideas of the Anthropocene have given rise to influential theories, such as the 'planetary boundaries' forwarded the Stockholm resilience centre (Rockstrom et al., 2009), as well as ideas of the approaching, or even surpassed, 'tipping points' in which the Earth system might, or has, shifted into a 'no-analogue state' (Crutzen and Steffen, 2003; 253). This second definition attempts to account for the shifting states in the earth system as a totality (not merely geological or ecological changes that had been recognised already in the previous century).

A third definition suggested by Hamilton et al. (2015) extends the idea of the Anthropocene to an even wider set of issues related to the human impact on the planet. An early paper by Crutzen (2002) does an excellent job of introducing these terrific perturbations:

[1] Proposals of the stratigraphic basis for the Anthropocene "must pass scrutiny by the 'Anthropocene Working Group', the 'Subcommission on Quaternary Stratigraphy' and the 'International Commission on Stratigraphy' before being ratified by the Executive Committee of the International Union of Geological Sciences." (Zalasiewicz et al., 2017; 289). As of December, 2018, the ratification process continues and thus a date remains to be decided definitively.

"About 30–50% of the planet's land surface is exploited by humans…More than half of all accessible fresh water is used by mankind. Fisheries remove more than 25% of the primary production in upwelling ocean regions and 35% in the temperate continental shelf… Energy use has grown 16-fold during the twentieth century, causing 160 million tonnes of atmospheric sulphur dioxide emissions per year, more than twice the sum of its natural emissions… More nitrogen fertilizer is applied in agriculture than is fixed naturally in all terrestrial ecosystems… Fossil-fuel burning and agriculture have caused substantial increases in the concentrations of 'greenhouse' gases — carbon dioxide by 30% and methane by more than 100% — reaching their highest levels over the past 400 millennia, with more to follow." (Crutzen, 2002; 23)

The third definition of the Anthropocene gathers up what James Syvitski (2012) refers to as 'the cumulative impact of civilisation', in a usage that comes to represent a threshold marking a 'step-change' in the relationship of humans to the natural world. Most often represented by the 'impossible' fact that humans become a 'force of nature', the situation becomes one where human action and earth dynamics can no longer be held apart. In this usage, the Anthropocene concept becomes able to capture a wide number of 'post-natural' intellectual energies and imaginations that do not fit with the modernist separation of man and nature. As Lorimer (2017) shows, the Anthropocene overflows the spaces of the geosciences from which it had originally emerged, the term becoming in some sense 'transcontextual' (King, 2016). The term Anthropocene becomes the marker of a wider 'intellectual *zeitgeist'* that emerges from 'a widespread recognition of the 'end of Nature'' (Lorimer, 2017; 123). In this understanding of the Anthropocene, *"social, cultural and political orders are woven into and co-evolve with techno-natural orders of specific matter and energy flow metabolism at a global level … Whatever the chosen date for this human hijacking of the Earth's trajectory, acknowledging the Anthropocene means that natural history and human history, largely taken as independent and incommensurable since the early nineteenth century, must now be thought as one"* (Hamilton et al., 2015b; 4). The profound realisation of this moment installs potentially far reaching consequences for concepts and methods across the social sciences, humanities (O'Brien, 2013, Latour, 2014b), as well as natural science (Malm and Hornborg, 2014). Already, social science and humanities projects, alongside artist and poetic interventions, are contributing towards what Noel Castree (2015) has termed the 'Anthropo(s)cene', offering an 'epistemic and ontological pluralism often absent from comparable academic zeitgeists' (Lorimer, 2017; 133). The claim from prominent voices is that the Anthropocene challenges us all to radically rethink what nature, humans as well as the political and historical relationship between them might be. Even if the Anthropocene Working Group fail to ratify a stratigraphically recognised Anthropocene, it looks unlikely that the term can be put back in the box; the Anthropocene looks like it's here to stay.

This thesis will hold a view of the Anthropocene that goes beyond strict stratigraphic accounts that seek to precisely define a new interval of geological history, as they do, through narrow and stringent evidence found solely within the earth's crust. In doing so, it will attempt to take the Anthropocene as a wider hypothesis about the troubled and troubling relation between humans and the earth. Further elaboration of the Anthropocene in this third definitional guise will be presented below. This is a time, we are led to believe, where a whole gamut of knowledge practices, the disturbed inheritance of a modernist *episteme*, are being challenged, a time that obliges urgent experimentation with the currently held domains of thought, action, and scholarly activity.

1.3 On damaged terrain

In the Anthropocene everyone is tarred with a troubled inheritance. Our *Oikos* - or rather, any guarantee we had in something we might call home - is irreparably mutilated. This is a dilemma that fundamentally challenges the most deeply rooted beliefs of the modernist project (epistemology, ontology, temporality, morality, aesthetics, politics). To suggest that this has far reaching consequences for our societies which have been organised around such modes of thinking and doing, is to understate the point somewhat. Claire Colebrook sums up the magnitude with aplomb:

> *"The earth – not the world but the earth (or the geological strata from which philosophy and various forms of humanity formed itself) – is poised at a singular point or threshold that would render all human life in its current mode untenable." (Colebrook, 2015; 21)*

What becomes apparent in the Anthropocene narrative, is that nature is no longer what conventional science imagined it to be. A profound intertwining of the fates of nature and humankind increasingly emerges from an accumulating evidence base (Zalasiewicz et al., 2010). The supposed Cartesian dualism between nature and society, so central to modern scientific thought, becomes challenged by the statistics of science itself, and with it, the idea of Nature, framed as the externally conditioning sphere of human existence, is exposed as illusory (Morton, 2007). The Anthropocene signals an awareness of our radically entangled position at the interface between human history and geological deep time. To live in the Anthropocene is to be ensnared in what Tom Cohen calls the 'double logic of *eco-eco* disaster', that is, to be sucked into a present that results from a monstrous relationship between an *economic* disaster and *ecological* disaster:

"The rapacious present places the hidden metaphoric levers of the eco or oikos in an unsustainable exponential curve, compounding megadebt upon itself, and consuming futures in what has been portrayed as a sort of psychotic trance" (Cohen, 2013; 16)

Cohen highlights an important point that others (Klein, 2015, Moore, 2015) have claimed, namely the inseparable relation between the two *eco*s. But something more can be found here. Cohen makes a link between the disastrous double logic and its present condition suggesting that what is playing out is some kind of 'trance'. There appears to be an unnerving contradiction in the way things are developing; a growing tension between apocalyptic environmental visions on the one hand, and an overbearing and wholly immovable, institutional status quo on the other. Cohen's trance might well allude to the 'contradictory' political moment that has been diagnosed as the 'post-political ontology of the Anthropocene' (Swyngedouw, 2014).

For Swyngedouw (2014) the 'post-political ontology of the Anthropocene' entails the simultaneous extension and foreclosure of politics. Michel Serres gets close to this when he proclaims: "the concrete world behaves as if we had made it; similarly, the money we mint and the projects we undertake act towards us as if we had not produced them" (Serres, 2013; 29). On one side, the 'becoming-geological of the man' is seen to undo aesthetic sensibilities and unground previous political commitments that were based on the perceived unbridgeable gap between human doings and brute nature (Latour, 2004a). An increasing politicisation of what was thought as nature is witnessed. The political is seen to extend into uncharted domains that were previously given over to immovable mechanics, or, to put differently, the Non-human world becomes increasingly 'enrolled' in a process of politicisation. This has become particularly relevant when we begin to discuss technoscience (Braun and Whatmore, 2010).

On the other side however, theorists of contemporary political subjectivity continue to elaborate upon the current political climate as 'post-politics' (Žižek, 2000, Rancière, 2014, Mouffe, 2005). According to these thinkers, within this 'post-political' horizon, the present and its future are structured around the perceived inevitability of capitalist relations, for which there is no alternative. It is a time defined by a lack of antagonism, where technocratic management and decision-making by consensus ensue. Experts become moderators of narrowly defined social concerns. Action is constricted within blinkered decision-making processes where the possibility space for solutions is reduced to what Stengers (2016) calls 'infernal alternatives'; choices between technologies, between managerial adjustments, and between timings for the implementation of such matters (Stengers, 2016). The space for major 'acts' that might reverse or present openness to the current situation are sutured (Žižek and Hanlon, 2001; 11). Cohen captures the sentiment of these times: 'the event of the twenty-first century is *that there will be no event, that no crisis will disturb the expansion of consumption beyond all supposed limits or peaks*.' (Cohen, 2013; 14).

It becomes important to appreciate the double sided and contradictory movement of politics identified by Swyngedouw that characterise the Anthropocene. Of particular importance for us here, is the way science is implicated within this 'post-political ontology'. The focus of the next section will be to discuss the peculiar perception of how science is at work both in the expansion and foreclosure of politics that mark the times of the Anthropocene.

1.4 Science and the Anthropocene

From the molecular to the global, humans are inadvertently reconfiguring the livability of our planet at ever increasing velocity (Scheffers et al., 2016, Steffen et al., 2015a), across scales that are barely comprehensible (Rockstrom et al., 2009), and in ways that challenge the very foundations of our most deep-seated beliefs (Schmidt et al., 2016). But how do we know this? We know this because science tells us so. The mind-boggling scales of the deeply concerning situation unfolding around us would scarcely be perceptible without the highly precise, elaborately interconnected technologies of contemporary technoscience (Wark, 2015). For some observers this situation of increasingly heightened visions of catastrophe becomes a point of exasperation. The Invisible Committee (2015; 32):

"At the apex of his insanity, Man has even proclaimed himself a "geological force" … But what's remarkable is that he continues relating in the same disastrous manner to the disaster produced by his own disastrous relationship with the world. He calculates the rate at which the ice pack is disappearing. He measures the extermination of the non-human forms of life. As to climate change, he doesn't talk about it based on his sensible experience-a bird that doesn't return in the same period of the year, an insect whose sounds aren't heard anymore, a plant that no longer flowers at the same time as some other one. He talks about it scientifically with numbers and averages."

Science in the Anthropocene contributes more than merely an escalating anxiety of numbers; it repeatedly confirms the damage caused by the prior execution of scientific thought in the world. The 'unsustainable exponential curve' - those ubiquitous scientific depictions of our present (and diminishing future) – are of course ongoing works of representation populated by the data of science. Donna Haraway (2016a), however, does right to remind us that these works stand for, and extend far beyond mere graph paper or flickering screens[2]. Science both *represents* and *works* on the Anthropocene. From this vantage point, we might do worse than revisit Horkheimer and Adorno's (2002) famous words afresh: "*Yet the wholly enlightened earth is radiant with triumphant calamity*" (Horkheimer and Adorno, 2002; 1).

Many prominent voices in the anthropo(scene) share more accommodating visions of science than those offered by the invisible committee (Latour, 2004a, Haraway, 2016b, Morton, 2016). Davis and Turpin (2015: 17) suggest a line of engagement with science that 'doesn't so easily dismiss science, its protocols, or numbers' since they might be taken as 'signs' of a mutual language, a mutual warning. Writing recently, Michel Serres (2013), the prolific, influential, yet seldom referenced thinker who has contributed considerably to ideas of science in our contemporary times, states: *"Here is the news. While the sciences, since the Greeks and Galileo, dealt with the things of the world in more and more sophisticated and specialised disciplines, recently they have spoken with one voice. More attentive to detail and relations, they now talk about the world as a global partner and no longer in terms of local things. They also say that the world is speaking. It is as if scholars are beginning to decipher what Biogea is telling us*" (Serres, 2013; 40). For Serres, it seems, science is an unavoidable part of our present condition, and more than this, might well be an indispensable asset for our overly critical[3] situation (see also: Latour, 2004b), one that may offer glimpses at a very different relation between humans and our earth, indeed a third relation that he calls 'Biogea'. This new relation(ship) has already come under many guises; Biogea (Serres, 2015), Gaia (Stengers, 2015a, Latour, 2017), '*Terra incognita'* (Castree, 2015), but what becomes consistent is that this relation is literally untenable *without* science.

To experience the current threshold is to be locked in a deep and uncertain relationship with science and its objects. In the Anthropocene "every cubic metre of air and water, and every hectare of land, now has a human imprint" (Hamilton, 2015; 34), and for Latour, all this muddying of modernist categories (culture/nature, social/science) is offered by science as a 'gift' that only itself can bring, albeit one that might turn out to be 'poisonous' if handled the wrong way (Latour, 2014b). The potential of the Anthropocene for Latour, and many others, is the demand it makes of us to radically rethink the object(ives) of our disciplines (What does 'natural' science mean

[2] Particularly regarding graphs, Donna Haraway (2016a; 43) astutely describes the multiple work carried out by the presentation of scientific data: "Part of the visual and ideological power of the j-curve is that it looks like a natural fact, as opposed to a really interesting constructed technological object that does some work better than others, and that does some work that would be better not done."
[3] Serres, like his student Latour (2004b), holds equal suspicion over the value of the contrary commitments pursued by the divided camps he calls the 'observant' natural sciences and the 'surveillant' social sciences that may only stand for critique: "Sciences that are not acquainted with objects can only rely on sleuthing and policing, they are caught up in myth. Objective knowledge creates present history whereas the human, ancient sciences lead to mythology. The observer weaves in the light of day what the surveillant undoes during the night. Which is more frightening?" (Serres, 2008; 17)

now? What happens to 'human' centred disciplines now the 'anthropos' can no longer be handled in its hermetic seal of the 'social'?). Continuing his long development in challenging orthodox interpretations of science, Latour (2014) has recently suggested *another* change in perspective towards science is required. Whereas previous understandings once necessitated the need to 'fight against the perceived "naturalization" and 'biopower' exerted by natural science', contemporary Anthropocene science, he suggests, breaks with this view: "How could you "naturalize" anything anyway when the very ingredients of what used to play the role of "natural forces" have been so transmogrified that they include humans in pieces and morsels at every junction? (Latour, 2014b; 139). Latour looks positively upon the science communities he engages with, hinting at a growing self-awareness within certain research circles of the possibly radical implications the Anthropocene might entail for scientific practice.

On the flip side, the 'poisonous' potential of the Anthropocene is that it may come to be seen by some as a signal either to dissolve the human altogether (for instance in some New materialist accounts (Anderson and Perrin, 2015)[4] or, perhaps even worse, fetishize it further. In terms of this latter point, the high-profile engagement with the Anthropocene coming from the self-described group of 'eco-modernists' is noteworthy (Hamilton, 2013). Associated with the Breakthrough Institute, this group welcomes the Anthropocene as an event to be *celebrated* rather than feared, a sign of our ability to transform and control rather than any final proof of a history of damaging, short-sighted and arrogant human relationships. From this view, humans, with their technoscientific innovations such as geoengineering, might well achieve the Enlightenment destiny as the 'God Species' (Lynas, 2011). A recent manifesto (Asafu-Adjaye et al., 2015) makes a stand for a 'good Anthropocene', one that will be achieved through better technology, efficient urbanism and the 'decoupling' of people from nature (Blomqvist et al., 2015).

Taking stock at this point, it becomes clear why Haraway et al. (2016; 1) claim the Anthropocene narrative has propagated a 'bipolar' message; one of environmental doom peppered with the promise of 'scientific renewal (and global survival) through trans-disciplinary collaboration'. As we have seen, just what kind of 'humanity' and 'science' fit into this narrative and our future is very much up for grabs. And here, considering again the thoughts of the invisible committee (above), we might ask, together with Heather Davis and Etienne Turpin (2015), what is the value of setting

[4] Anderson and Perrin (2015) argue convincingly against some views in new materialism and beyond that dismiss the 'human' entirely as a fantasy of the moderns: "The figure of the nature-transcendent human must, we have argued here, be understood not as an otherworldly fantasy, but as a worldly, and for this reason an always-contingent, always-unstable, production. A materialist engagement with—rather than disengagement from—the idea of human exceptionality is, therefore, vital for a humanities tuned to a planet under pressure".

up a scene with ‘Man’ and ‘Science’ as the all-too-abstract, all-too-dissociated protagonists of a caricatured and disastrous (or glorious) Anthropocene story? Chapter 2 will present voices from the field of Science and Technology Studies (STS) that refuse to accept science as a pure and detached realm where rational description is king. These studies will underline the need to apprehend science in its real-world configurations and obligate the development of down-to-earth, materially sensitive methodological approaches that offer more than simply critique.

1.5 Summary

The scientific proposal that the Earth has entered a new epoch as a result of human activities – ‘The Anthropocene’ – has become an evocative and contentious master narrative of our times. It's a proposal that suggests an urgent rethinking of our current practices and relationships with the earth is called for. Amidst the need to comprehend and respond to a fast-changing Earth departing from its previous Holocene boundaries, it seems “everything is now in play” (Hamilton, 2015; 34), where the boundaries of our disciplines and knowledge practices are stretched and challenged.

The fact that humans are a geological force fundamentally challenges the basic assumptions of modern thought. This includes the dualisms separating humans from nature, conceptions of unique human agency, the presumption of progressive norms, and that the planet is capacious enough for individual acts to be thought of as disconnected from the peoples, species and processes once rendered as ‘others’. The Anthropocene marks a point “where previous ethical norms require reassessment and novel problems arise in what are often metaphysical blind spots” (Schmidt et al., 2016; 9). In light of this, some suggest a reassessment of the orientations of, and boundaries, between the disciplines is needed, the historical development of which is built on a modernist episteme whose relevance is being challenged (Latour, 1993).

Contributing greatly to the Anthropocene narrative and the ‘becoming geological’ of humanity is contemporary science, which increasingly operates with a dazzling and terrifying reach - indeed, the Anthropocene itself might be viewed as “a collective assemblage of scientific enunciation” (Davis and Turpin, 2015a; 7). However, this chapter has shown that the terms of this enunciation are in no way guaranteed. Science is seen to become increasingly political, and yet at the same time is seen to contribute towards a deepening political impasse that has been termed the post-political. Within this frame, prominent voices across geography and beyond call for greater engagement with science and its productions. It becomes important then to assess more specifically where and what science is at work in the production of our *terra incognita,* and how Human Geography might engage such a task (Castree, 2015).

1.6 Introduction to the thesis (Finding orientation in the Anthropocene)

After fleeing the conceptual framework of Ecosystem Services, I went in search of a different framing through which to relate to science and the natural world. I quickly found myself in the 'Anthropo-scene' (Lorimer, 2017). **Chapter 1** introduces the way the Anthropocene emerges not only as a marker for geologic time, but also a scholarly one, as both master narrative and intellectual zeitgeist. The magnitude of the term carries with it high hopes, not only for long-overdue attention to proliferating global environmental problems, but also for a much-longed-for (by some) breakdown in the separation between the human and natural sciences. As Swanson et al. (2015; 150) point out, "the enthusiasm for the term Anthropocene (and a good part of the suspicion against it)" lies in its apparent promise to mark a "paradigm shift", one where the distinction between "nature" and "culture" collapses along with the academic partitions that maintained it. This thesis then, takes the Anthropocene as a provocation about scholarship. In the broadest sense, this thesis is interested in what the Anthropocene means for science and for scholarship.

Chapter 2 introduces 'aquaponics', a rapidly emerging field of science, as a case study for the thesis. Aquaponics is a food system innovation that combines aquaculture and hydroponics, an attempt to reorganise fish and plant production in response to widespread challenges of the contemporary food-system. Historically situating the field of aquaponics within the wider expansion of aquaculture (2.2), this chapter elaborates key concepts and motivations of aquaponic science. The chapter highlights the way recent aquaponic scholarship justifies research by grounding the field as a response to global concerns that are characteristic of the Anthropocene. With this ground work, the chapter positions Aquaponics as a point of focus for the thesis, an opportunity to explore the specific ways in which science becomes articulated within the Anthropocene problematic.

Chapter 3 looks for ways of approaching aquaponic science. I turn to the field of Science and Technology Studies (STS) looking to learn from those who have taken science as their object of study. The chapter retells a narrative of the development of the field of STS, paying particular attention to the shifting understandings of science and how these have impacted methodological approaches. It begins with the early studies from the field of Sociology of Scientific knowledge (SSK) which questioned the *representation* of science (its discourse, semiotics), through to the early Lab studies which ethnographically examined the *materiality* of science by following its workings in the laboratory (3.2). Next is a discussion of how ideas of *Social Construction* give way to those of *Coproduction,* involving a re-conceptualization and -contextualisation of 'Science' as 'Technoscience' (3.3). The theoretical and methodological implications of this reconceptualization of science fuel the proliferation of Actor Network Theory and material-semiotic treatments of science.

Through the sustained probing of modernist research practices, STS paved the way for critical geographers to develop the so-called 'more-than-human' geographies (MTH). Section 3.5 explores the ways scholars working in MTH geography, along with certain strands of contemporary STS have developed avenues of research that have a shared interest in 1) unpacking assemblages of bodies, knowledges and properties; 2) nonanthropocentric perspectives on whom (or what) should matter politically; 3) attending nonhuman agency; 4) exploring space and time relationally, not absolutely, with reference to the processes through which they emerge, and; 5) acknowledging the limited capacities of humans to represent the world coupled with the challenge to hone new sensitivities, skills and affectual capacities (Greenhough, 2014). These shared commitments become the building blocks of my approach to aquaponic science.

In section 3.6 I look to the burgeoning field of animal geographies in an attempt to hone the commitments of MTH geography. Animal geographies offers diverse theoretical and methodological attempts to attend more sensitively to creatures of all varieties. Following this line, and in anticipation of an engagement with aquaponic science, I look to geographers who are currently exploring the ways in which plants (3.6.1) and fish (3.6.2) co-produce lively multispecies worlds that consistently challenge the epistemological, ontological and ethical foundations of geographic research. At the end of Chapter 3 the argument is made that aquaponic science represents a clear and hitherto untapped opportunity for STS and MTH geographic scholarship. Research questions are formed around what might be seen as two interconnected poles of interest. 1) How does aquaponic science articulate and intervene in the Anthropocene problematic. 2) How can the research methods, sentiments, and commitments of STS and MTH geographies be brought in relation to aquaponic science? What can this tell us about scholarship in the Anthropocene?

Building on the discussion in Chapter 3 of the rich potential for bringing together aquaponic science with STS and MTH Geographies scholarship, **Chapter 4** plots their intersection. This chapter outlines my route into the world of aquaponics. In May 2015, I joined the EU aquaponic Hub (COST Action FA1305), a COST Action network that brings together researchers, practitioners and entrepreneurs from diverse European institutions to facilitate the expansion of the field of aquaponics. The details and specifics of my ethnographic movements within the 'Hub' are outlined, as I attend summer schools, conferences, working group meetings. A significant focus of this chapter concerns my ethnographic participation in an aquaponic experiment at the University of Liege's Agro-bio-tech facility, in Gembloux, Belgium. Drawn from the discussion of Chapter 3, this chapter details the ethnographic approach of my research, elaborating in detail the speculative nature of my study of aquaponics and foregrounding the multi-sited, embodied, performance-based methodology that I carried out. Details of data collection, analysis, and writing-up are presented. The aim of Chapter 4 is to give a foundation for what is presented in the following findings chapters (Chapter 5, 6, 7).

Chapter 5 is an ethnographic account of my participation as a scientist in an experiment conducted on a prototype aquaponic system known as the 'PAFF Box', at the University of Liege's Agro-bio-tech facility in Gembloux, Belgium. The chapter follows the temporal pattern of the ten-week experiment that I helped conduct. Working within a team of aquaponic scientists, this account attempts to relay the commitments, hopes and fears of everyday aquaponic science, as expressed by my fellow co-scientists. The account explores the complexities and challenges involved in getting these (eco)systems to 'work'. I discover that the team in Gembloux have developed rich multisensory relationships with the PAFF Box, which facilitate and enable this multispecies world to flourish and to perform experimentally. But this is also a first-hand account of my role in the experiment and the thickening concerns that come along with engaged practice. The account attempts to bring forth the sensations, textures, and emotions involved in an ongoing process of affective attunement with fishy subjects, material flows and metabolic processes that characterise aquaponic realities. Documenting my ongoing entanglement within the operations of the PAFF box, my account begins to circulate around the ethico-political dimensions of aquaponic research. My participation in this experiment raises questions about the nature of intervention that force me to let go of my intention of conducting a symmetrical discussion of aquaponic science. Rather, the ethnography focuses upon the possibilities and challenges involved in bringing forth more caring aquaponic realities and the ethico-political dimensions of being a (scientific/ethnographic) researcher invested heavily into technoscientific apparatuses that prefigure patterns of aquaponic life and death. As such, the ethnography opens up questions about the nature of intervention and the politics of care in technoscience. The chapter ends with discussion of the way my aquaponic experience feeds into wider concerns that confront science in the Anthropocene.

Chapter 6 is called 'Moving on'. The chapter covers two movements. The first movement is a taking stock of the (ethically, scholarly, and physically) challenging experience in the PAFF box. There is a discussion of my own shifting relationship to research, and the nature of politically engaged ethnographic work as intervention in technoscience. Secondly, the chapter charts my movement out of the aquaponic lab in Gembloux and into the wider field of researchers, practitioners, and entrepreneurs active across Europe and in the EU COST Action Aquaponic Hub. This short chapter condenses a two and half year process of following aquaponics out in the world, visiting farms, working with start-ups, presenting at conferences – becoming an 'aquaponicist'. Taking inspiration from Swanson et al. (2015) this chapter sketches an outline of the aquaponic 'field-in-the-making' as experienced in my participation in conferences and working group meetings of the Hub. Becoming attentive to these creative gatherings, I follow trends and connections articulating across research areas. In the journey through developments and failures, convictions and gossip, inspiration and frustration, I become enrolled in the knowledge politics of a field. The chapter follows the pressures on aquaponic participation, as promising start-ups fizzle out, shared academic concerns fragment into detached disciplinary pursuits, and the field faces up to daunting complexity and uncertainty. At the end of Chapter 6, an introduction is provided for Chapter 7 detailing the way the experiences of the field flow into a collaborative project.

Chapter 7 is a response to the developments detailed in chapter 6. Once again, I found myself becoming 'aquaponically activated' but this time in a different way to the formative experience of the PAFF box. Chapter 7 is a collaborative project completed by myself with other members of the aquaponic research community, that has subsequently been published as a chapter for an aquaponic book (Gott et al., 2019). Devised by the editors to be a manual to the state-of-the-art of the field, the book aimed to present the outcomes of the Hub's four years of activities. Chapter 7 was written as both a challenge and plea to our aquaponic field as we attempt to activate the need for what Isabelle Stengers (2016) calls 'paying attention'. The focus is on our academic milieu, the dangers of our field, and how we might care for it. As such, Chapter 7 becomes an experiment in crafting a shared aquaponic narrative. In the face of conservative and curtailed disciplinary pursuits we introduce the need for concepts that allow for the types of *negotiation* that unsettle disciplinary boundaries. In chapter 7 then, we offer to the aquaponic community not a neat blueprint for bringing about aquaponic solutions, but a way of problematizing as collective practice, a way of "crafting problems greater than their solutions." (Manning, 2014; 10) to keep an idea of aquaponics that is responsive to the insatiable challenges of our Anthropocene.

Chapter 8 offers a conclusion to the thesis.

Chapter 2: What is Aquaponics?

2.1 Introduction

Aquaponics. The word has a futuristic ring that can strike near instantaneous bemusement on the face of the uninitiated. Aquaponics the idea, is one that stakes a claim at a unique position within a nexus of scientific discourse on agriculture, a huge area of study that is increasingly aware of its role in the Anthropocene. This is a point that will be drawn out in the following chapter.

Aquaponics, according to Wikipedia[5], *"refers to any system that combines conventional aquaculture (raising aquatic animals such as snails, fish, crayfish or prawns in tanks) with hydroponics (cultivating plants in water) in a symbiotic environment".* Many recent publications suggest this definition requires revision. According to Konig et al. (2016; 26) "Aquaponics is an evolving closed-system food production technology that integrates recirculating aquaculture with hydroponics." For these authors, aquaponics is a form of 'controlled environment agriculture': whereby fully contained and climate-controlled aquaponic systems 'potentially operate under water conserving and contaminant-free conditions' (Konig et al., 2016; 26) allowing more 'effective management of the food-water-energy-nexus' (Kloas et al., 2015; 67). Because of this, proponents of this emerging field claim the technology might be an important innovation towards 'stable and sustainable food production' and the 'goals of a circular economy' (Junge et al., 2017; 1).

At its simplest, aquaponics is an innovation designed to recycle the waste products generated when rearing fish into useful forms that can be used to fertilize the growth of plants. Particular bacterial communities are encouraged within aquaponic systems to convert the fish waste into these more beneficial chemical forms (Wongkiew et al., 2017). Aquaponics, therefore, can be seen a form of 'integrated multi-trophic aquaculture' (Somerville, 2014), in that it aims to utilize the metabolic propensities of organisms from different trophic levels (fish, bacteria, and plants). By encouraging such 'agro-ecological intensification', aquaponics hopes to mitigate particular problems associated with conventional intensive aquaculture and hydroponic production techniques, with a view towards more productive, efficient, and sustainable fish and plant provision (Konig et al., 2016; 27).

[5] '*Aquaponics*'. Online: Wikipedia. Available: https://en.wikipedia.org/wiki/Aquaponics [Accessed 15/10/2015].

The agro-ecological principle of combined fish and plant production can operate effectively on a very low-tech basis (Gliessman, 1991, Trang and Brix, 2014) and can be traced back thousands of years in both the Americas and notably Asia (Beveridge, 2002). However, in the most recent technoscientific iteration of the idea, 'aquaponics' becomes a 'technology-intensive, capital-intensive and knowledge-intensive' method of food production (Konig et al., 2016), drawing the attention of multidisciplinary research teams (aquaculture, hydroponic horticulture, microbiology, biochemistry, engineering) and intergovernmental research funding streams. Although the first scientific research on aquaponics was pioneered in the 70's (Dalrymple, 1973, Sneed et al., 1975, Bohl, 1977) the vast majority of research on the subject has actually been carried out only since 2010 (Junge et al., 2017). The surge in research output is mirrored by a growing sector of commercial operations across America (Love et al., 2015) and Europe (Miličić et al., 2017). Some commentators have noted that in comparison to other emergent technologies, the field of aquaponics seems particularly influenced by 'hype' (Junge et al., 2017) – a high profile example being the European Union Parliament's recent proclamation that aquaponics is one of "ten technologies which could change our lives" (Van Woensel et al., 2015).

The potential of aquaponics resonates with the growing interest in sustainable agriculture, industrial ecology, food sovereignty and alternative-food-networks, and is increasingly gaining the attention of a diverse set of interest groups. More recently, an emergent industry of commercial producers (Love et al., 2015), as well as a growing community of domestic home users, referred to as ''back-yard' producers, have been noted (Malcolm, 2000). Further to this, aquaponics has been deployed in third sector humanitarian relief projects (Somerville, 2013), and non-profit community groups (Laidlaw and Magee, 2014).

This chapter will chart the development of the field that has now come to be recognised as Aquaponics. The first task will be to situate aquaponics within the wider historical developments that have characterised the global expansion of aquaculture (section 2.2). Next, a history of the field will be presented (section 2.3), outlining a trajectory in its philosophy, application, and form since its emergence in the 70-80's to its present-day form. This will lead to a discussion of how the objectives and aspirations of this field become characterised by an awareness of the issues that mark the Anthropocene (section 2.4).

2.2 The rise of aquaculture

Since the 1970's huge shifts have occurred in the way humans acquire fish to eat. The term 'blue revolution' (Coull, 1993a) aptly captures the spectacular global expansion of aquaculture over the last four decades, a process that "surpassed even the most optimistic predictions" (Belton and

Bush, 2014; 4). By around 1996, it became apparent that marine capture fisheries had reached their limits. Unable to keep up with an insatiable global demand, the official - and now questionable (Pauly and Zeller, 2016) - line was that the majority of global fish stocks had plateaued out. Capture fisheries globally were witnessing crisis. At the same time, aquacultural production was accelerating beyond everyone's expectations. Since the 1970's aquaculture has been the world's fastest growing agri-food sector. At its peak in the 1980's, growth in aquacultural production was hitting 11%per year. By many measures, aquaculture was plugging the deficit experienced by the crisis in capture fisheries. This trend continued and somewhere around 2015, for the first time in history, the amount of fish produced by aquaculture equalled that of capture fisheries. By 2025 aquaculture is expected to provide close to 60% of all the aquatic organisms consumed by humans (FAO, 2016).

This rapid transformation is in large part due to the growth of intensive aquaculture, the specific characteristics of which reflect particularly our contemporary historical circumstance. Global agri-food production networks have facilitated an accelerating dissemination of techno-scientific innovation in the sector, profoundly and heterogeneously reconfiguring the shape of fish husbandry through what might be called a 'mosaic of directionalities' (De Koninck et al., 2012). The scale and speed of these developments have been extraordinary. The domestication of fish species bred in hatcheries is occurring at evolutionary 'warp speed' (Christie et al., 2012). Aquatic species that were once experienced as exclusive wild-caught delicacies have been transformed into mass-produced global commodities available in supermarkets in most parts of the world. It should be taken in the deepest possible sense, when Marianne Lien states that intensive aquaculture is driving "what a farmed fish is and will become" (Lien, 2007; 170).

Genetic topologies of fish lives are not the only areas in transformation at the frontier of aquacultural expansion. Belton and Bush note that in addition to the 'extreme dynamism' and 'diversity' that marks the trajectories of contemporary aquaculture, the most distinctive characteristic is its capacity to 'rapidly transform social and physical landscapes' alike (Belton and Bush, 2014; 9). Pollution from Chinese farms degrading fresh and coastal waters (Cao et al., 2007); shrimp farms causing saltwater intrusion in Bangladesh and Thailand (Szuster and Flaherty, 2002, Azad et al., 2009); and disputes over freshwater access in Egypt where tilapia farmers have been denied use of irrigation water (Eltholth et al., 2015). These are a handful of local case studies emblematic of very real concerns that run throughout the entire industry. The use of fishmeal to feed more marketable carnivorous fish short-circuits the ambitions of preserving wild stocks, while the externalities of polluting nutrient wastes, uncontrolled chemical and antibiotic use, and genetic erosion of wild fish stocks from escapees, dissipate the detrimental signs of the industry across temporal and spatial scales that are only beginning to be recognised (Allsopp et al., 2013, Hu et al., 2013, Gephart et al., 2017). In summary, aquaculture bares many of the hallmarks of other intensive agro-industries; a technoscientific assemblage that works to potently redistribute material flows, genetic ecologies, and human relations at a global level, and increasingly so.

By now, the search for solutions to issues in aquacultural practices has been pursued for decades (Williams, 1997, Bert, 2007), and has expanded into many aspects of production (Klinger and Naylor, 2012). Within this wider picture of the hugely expanding aquacultural sector, aquaponics has come to be seen as one avenue of research that might contribute towards the continuing urgency of a 'blue revolution' in the sustainability of aquaculture (Costa-Pierce, 2002), or to be more precise, a 'blue-green' revolution (Ahmed et al., 2012) in that it promises to mitigate sustainability issues in both horticulture and aquaculture.

2.3 History of a field

2.3.1 Pre-History.

Search for the history of Aquaponics and you find reference to a diverse array of ancient agricultural societies from ancient central America and China, to Egypt and India (Goodman, 2011, Turcios and Papenbrock, 2014, Kőmíves and Ranka, 2015). What each of these societies had developed, according to varying levels of archaeological speculation, were systems of agriculture/aquaculture that combined growing crops with different forms of fish rearing. The potential of these practices to be deemed multitrophic, - that is, containing both plants and aquatic species - is enough for some to trace the credentials of aquaponics back through exotic histories.

The most often cited example are the *Chinampas,* the 'raised fields' or 'stationary islands' set up in the shallow lakes of central America between 1150–1350 BC by Native American farmers of the Basin of Mexico (Sanders et al., 1979). Archaeological evidence suggests that raised-field agriculture was conducted in a great range of environments across central America, from the highland plateaux of the Andes and inter-Andean valleys to the hot lowlands (Renard et al., 2012). Raised fields had virtually disappeared by the colonial period (Renard et al., 2012, Merlín-Uribe et al., 2013) with the notable exception of the *chinampas*, some of which have been in continuous use for over 1000 years (Gliessman, 1991). Similar links are made between aquaponics and the rich aquacultural tradition of China, SE Asia. The publication of *You Hou Bin* during the Han dynasty detailed the integration of fish with aquatic plant and vegetable production around 200BC (Beveridge, 2002).

2.3.2 New Alchemy.

The development of aquaponics was significantly influenced by the sustainable agriculture movement that arose in the late 1960's (Love et al., 2014). A group often seen as laying the 'basis' of aquaponic research is the New Alchemy Institute, who are often credited as the earliest developer of integrated fish and vegetable systems in contemporary aquaponic literature (Diver, 2000, Goddek et al., 2015). The key figureheads of the institute were John Todd and William McLarney, setting up their first project in 1969 around the Woods Hole area, Cape Cod. It was a small scale, low budget, research group whose ambition was to reorganise the concept of farming around ways that mimic natural systems. By the late 70's the New Alchemy Institute began pioneering ecological approaches to aquaculture (Zweig, 1976, Todd and Todd, 1980, Engstrom, 1981) that are now recognised as the precursors to present day aquaponics.

The New Alchemists were driven by a deep-seated fear of an impending ecological collapse. They shared an anxiety with the increasingly visible damage being caused to the earth's natural systems. Their slogan 'To Restore the Lands, Protect the Seas, and Inform the Earth's Stewards', amply captures the spirit of the project which operated through a back-to-the-land style mixture of environmentalism, political anarchism and anti-urbanism (Todd, 1977; vii). At the root of this, in their eyes, was a diabolical combination of population growth, industrialised food systems, and rotten capitalism. "There is the disquieting feeling that we are witnessing the agricultural equivalent of the launching of the Titanic, only this time there are several billion passengers" Todd explains in volume two of their in-house journal (Todd, 1975). "Collapse, maybe within the next 10 to 20 years" they claimed in an interview in *Science* (Wade, 1975; 727). But narratives of ecological catastrophe took place alongside redemptive conceptions of the future. The central agricultural design pioneered at Cape Cod was named the 'Ark'. It was a polycultural food system that shared more than just connotations with more biblical counterparts; the 'Ark' was seen as a kind of 'ecological lifeboat' that would be vital if and when the wider collapse of ecosystems set in (Todd, 1976a).

The New Alchemists were influenced by theories of permaculture, a practice first codified by researchers in the mid-1970s in Australia that looked to nature as the ultimate designer (Mollison and Holmgren, 1978). Using careful observation of natural cycles and processes as the template for creating sustainable food systems, the design features of the Ark mirrored the ecological principles that Todd and McLarney saw at work in the wider environment. The Ark was to be a 'self-contained microcosm' (Todd, 1976b). It consisted of three Buckminster Fuller greenhouse domes. Inside the greenhouses, an interconnected system of ponds was built, inspired by the fish farming of Maoist China. Installed one below the other on a slight incline, the two uppermost ponds were used for growing food for the fish that were housed in the lower pond. Water from the pond was pumped up by a windmill to the top pond, passing through a solar heater en route. Tropical edible fish species were chosen to suit the high temperatures within the domes. These were predominantly tilapia but also St. Peter's fish (Zweig, 1976).

The choice of name for this experiment in ecological farming, 'New Alchemy', carries significance regarding the wider philosophy of the project. As Wade (1975: 727) elaborates in an interview with Todd's group, 'New Alchemy' gives the impression of something pre-modern, something 'non-scientific'. However, this was by no means a 'rejection of modern science', but rather 'a harking back to a time when science, art, and philosophy did not have to be practiced as separate, mutually exclusive realms of knowledge' (Wade, 1975; 727). As Todd explains: "The purpose of new Alchemy is to bridge the gap between anti-science and the esoteric, inhuman, specialized kind of science which is going on almost everywhere" (Wade, 1975; 729). The New Alchemists were attempting an ecology not just of organisms and energetic flows, but also of knowledges. There is an impression in their writings that science in some way has been cut off from pre-modern ways of relating to the world, namely through the reciprocal relationship between the microcosm of human activity and macrocosm of the world at large.

The institute was supported by over a thousand associate members, each subscribing at least $25 a year, as well as by grants from the Rockefeller Brothers Fund and other foundations (Todd, 1977). In 1973, after a side project in Costa Rica, the New Alchemists were granted a contract worth several hundred thousand dollars from the Canadian government for the construction of a prototype agricultural "Ark" on Prince Edward's Island, N E Canada (Anker, 2005). The culmination of their efforts, the Ark was a solar-powered, self-sufficient, bio-shelter designed to accommodate the year-round needs of a family of four using holistic methods to provide fish, vegetables and shelter. As Anker (2005; 537) notes, if the ambitions of the New Alchemy Arks had been measured by numbers of visitors, by the mid-70's their project would have already been deemed a success: "the Ark at Cape Cod had become a 'New Age Mecca of sorts' with a larger turnout of visitors than the New Alchemists could handle" and attracted notable scholars engaged in ecological practice and design, including Lyn Margulis (Anker, 2005).

Following the New Alchemy Institute, a number of research programmes across the United States and Canada also became interested in the idea that small, closed system aquaculture represented a potentially valuable part of family-sized food production systems. These included: Foundation for Self-Sufficiency (Welsh, 1977); Amity Foundation (Head and Splane, 1980); Goddard College (Pierce, 1980); The Ark Project (MacKay, 1981); Rodale Research Center (Van Gorder, 1983).

2.3.3 Aquaponics science

During the 1970s the recirculating aquaculture research community in the USA pioneered the idea of using edible plants to remove waste products from recirculating aquaculture systems (Dalrymple, 1973, Sneed et al., 1975, Bohl, 1977). A major challenge for recirculating aquaculture was the accumulation of nitrogen compounds, a potentially toxic by-product of fish waste (Collins et al., 1975, Bohl, 1977). It was when investigators experimented with soilless plant systems as a means of treating this fish waste (Sneed et al., 1975, Naegel, 1977, Lewis et al., 1978, Sutton and Lewis, 1982) that supposedly marks the start of contemporary aquaponics. In the 1980's Mark McMurtry develops the first 'closed loop system' during his PhD with Professor Doug Sanders at North Carolina State University (McMurtry et al., 1990, McMurtry, 1992).

These earlier experiments cemented the key features of aquaponic technology. The crux is the way that by-products from fish production are recycled through the incorporation of a simple ecosystem within a closed-loop system. Nitrifying bacteria are used to convert ichthyotoxic ammonium in fish waste into nitrate, a readily absorbed fertilizer. Plants grown hydroponically in the system take up this nitrate as they grow, cleansing the water of fish waste as it recycles back to the fish. It is because of the way that nutrients contained in fish feed and fish faeces are re-used to grow crop plants in an ecological cycle, that aquaponic food production is considered highly efficient by its proponents (Love et al., 2015)

In 1980, Dr. James Rakocy begins experiments at the University of the Virgin Islands. Rakocy is considered a key figure in the scientific development of aquaponics having published around 100 papers, articles and books over 30 years. The emphasis of his research was on the conservation and reuse of water and nutrient recycling. After several production trials on small sized systems, the first commercial-scale system was built containing six hydroponic tanks with a total growing area of 214 m^2 and four fish rearing tanks, each with a water volume of 5.0 m^3. Rakocy (2012a): "By 1999, the UVI system had proven to be reliable, robust and productive. We therefore launched a training program and taught 566 students from 45 U.S states and territories and 56 other counties.". The UVI model is now approaching 30 years old and has provided possibly the largest body of data used in aquaponics. Rakocy was involved in the founding of a quarterly periodical - Aquaponics Journal - which since 1997 has published articles, conference announcements and product advertisements related to the field of aquaponics (Rakocy, 2012b). These early pioneers laid the foundations of what is now becoming an emergent commercial aquaponic sector (Love et al., 2015). Contemporary aquaponic production exists primarily in controlled environments, such as greenhouses or outdoor locations with favourable climates, using methods and equipment that draw from both the hydroponics and aquaculture industries (Love et al., 2015).

2.4 Aquaponics and the Anthropocene

The Food and Agriculture Organization of the United Nations (FAO) has highlighted aquaponics as a future sustainable food production practice, recently releasing recommendations on small scale aquaponic production systems (Somerville, 2014). Key drivers for aquaponic research are the global environmental, social and economic challenges identified by authorities like the FAO and United nations (UN) (DESA, 2015) whose calls for sustainable and stable food production advance the ‘need for new and improved solutions for food production and consumption’ (Junge et al., 2017; 1). Konig et al (2016; 26) give a precise summary:

“*Assuring food security in the twenty-first century within sustainable planetary boundaries requires a multi-faceted agro-ecological intensification of food production and the decoupling from unsustainable resource use*”.

As with the imperatives of supranational organisation like the FAO and UN, justifications of aquaponic research foreground the challenge of food security on a globe with an increasing human population and ever strained resource base. There is an open emphasis on “Our appetite’s strain on a farmed up the earth” (Ramsundar, 2015; 3) in aquaponic literature. Many research papers open with a variant of the following sentence taken from Kloas, et al (2015; 179): “The growth of the world’s population is expected to nearly stabilize at just above 10 billion people after 2062 and poses challenges concerning security of water, food, and energy for humans in the 21st century.” According to the UN, agriculture is the largest global user of water, accounting for 70% of total withdrawal, and food production and their supply chains consume around 30% of total global energy production (UN, 2014). Thus, water, food, and energy are inextricably linked by interacting with each other in what has come to be known as the ‘water−food−energy nexus’ (Bird et al., 2014).

On a pressured and depleted earth such interactions must be managed in a sustainable way and the holistic and enclosed systems approach of aquaponics technology appears to offer unique solutions for such interdependent issues (Kloas et al., 2015). For instance, recent demonstrations of fresh water budgets in conventional aquaculture have exposed the potential for extreme levels of fresh water consumption in conventional fish production[6], placing aquaponics in a favourable light (Gephart et al., 2017). The recirculating nature of aquaponics systems, added with an ecological cycle that cleanses system water of potential contaminants can result in high water efficiency[7] in plant and fish production (Rakocy et al., 2006, Timmons, 2009). Climate induced effects of drought globally are an increasing concern for food security (Lobell and Field, 2007), and the enclosed, water efficient systems of aquaponics are seen by some as opportunities for food production in arid zones that may not have previously had the capacity to do so (Kotzen and Appelbaum, 2010). Likewise, an increasingly urban world exerts pressures for food provision (Desa, 2012), and aquaponic practices are increasingly becoming associated with urban and peri-urban farming (Vermeulen and Kamstra, 2012, Thomaier et al., 2015, Laidlaw and Magee, 2016). These authors claim that the physical characteristics of aquaponics offer great potential for the challenges of urban environments; compact, intensive growing solutions, can make aquaponics 'most appropriate where land is expensive, water is scarce, and soil is poor' (Somerville, 2014; 26).

In a time of 'peak-everything' (Cohen, 2012), the perception that current agricultural modes of production cause wasteful overconsumption of environmental resources, rely on increasingly scarce and expensive fossil fuel, exacerbate environmental contamination, and ultimately contribute to climate change (Pearson, 2007), has given rise to diagnosis that 'continuous innovation' is needed 'in an attempt to achieve the goals of a circular economy', a view in which aquaponics technology occupies a favourable position (Junge et al., 2017; 1, Nemethy and Kőmíves, 2016). In this call for a shift from conventional 'open' or 'leaky systems' to more closed, regenerative ones, conceptions of agricultural practices have become viewed through a 'material budgets' lens (Pearson, 2007; 409). Aquaponics research increasingly draws from and speaks to this discourse. Aquaponics shows potential for more efficient use of resources through the tightening of nutrient cycles and the reduction of waste. Much aquaponic research aligns itself to the challenge proposed by research on planetary boundaries (Steffen et al., 2015b), particularly

[6] Calculations of the freshwater consumption of China's aquaculture indicate a footprint ranging between 2,000–57,000 litres per kilo of fish. In comparison, a kilo of beef requires around 15,000 litres to be produced whereas a kilo of chicken meat has a water footprint of around 4,000 litres.
[7] According to Timmons (2009), aquaponic systems often have between 0.5-5% water loss per day, saving between 90-95% of fresh water consumption compared to conventional aquaculture. Likewise, in lettuce production, aquaponic systems have claimed to use half the water needed to raise conventional hydroponically grown lettuce.

regarding the critical thresholds of Nitrogen (Delaide et al., 2017, Wongkiew et al., 2017) and limits to Phosphorous (Cerozi and Fitzsimmons, 2017) cycles. Within closed loop aquaponic systems intense and dynamic Nitrogen transformations occur that become particularly relevant to discussions about the ongoing anthropogenic shifts across the globe (Wongkiew et al., 2017). Nitrogen transformations in intensive aquaculture systems have been shown to have globally significant implications to climate change through their emissions of nitrous oxide (Hu et al., 2013). N2O is a potent greenhouse gas with global warming potential as high as 310 times of CO_2 over 100-year lifespan and has also been reported to destroy the stratospheric ozone layers (Chipperfield, 2009). Branches of aquaponic research have become linked to this literature, experimenting with system configurations and the management of microbial populations within aquaponic systems to reduce such emissions (Zou et al., 2016, Hu et al., 2014, Fang et al., 2017).

This section has demonstrated how contemporary aquaponic research is increasingly situated within discussions of global food security, planetary boundaries discourse, and anthropogenic climate alterations. By doing so, aquaponics as a field becomes explicitly linked to numerous global concerns that are characteristic of the Anthropocene.

2.5 Summary

Aquaponics is a form of 'integrated multi-trophic aquaculture' (Somerville, 2014) that aims to harness the metabolic propensities of organisms from different trophic levels (fish, bacteria, and plants) in a way that mitigates particular problems associated with intensive aquaculture and Hydroponics. Aquaponics research promotes and tests a particular form of agro-ecological intensification through the creation of technologically mediated artificial ecosystems. Early aquaponic science grew from the need to redirect the environmentally destructive wastes generated by a fast-growing aquaculture industry, but contemporary justifications for research have taken more global perspectives. The objectives of aquaponic research are now located in its potential to confront serious global issues - greatly distorted planetary nitrogen and phosphorus cycles, efficiently feeding an increasingly crowded and urban planet, water scarcity and desertification, the collapse of global fisheries and global demand of aquaculture, climate change inducing anthropogenic emissions. As such, from within the metanarratives of sustainability, productivity, and circular economies, contemporary aquaponics is seen by proponents to offer unique potential within the 'water−food−energy nexus' discourse of global food production on a finite planet and by doing so Aquaponics as a field becomes explicitly linked to global concerns that are characteristic of the Anthropocene.

Chapter 3: **Theorising the study of science in the Anthropocene**

3.1 Introduction

This chapter will provide a review of approaches, both theoretical and methodological, to the study of science. Section 3.2 charts a development from early studies from the field of Sociology of Scientific knowledge (SSK) which questioned the *representation* of science (its discourse, semiotics), through to the early lab studies which ethnographically examined the *materiality* of science by following its workings in the laboratory. Section 3.3 discusses the way ideas of *Social Construction* give way to those of *Coproduction.* This involved a reconceptualization and contextualisation of 'Science' as 'Technoscience', particularly via influential views of science developed by Actor Network Theorists. Section 3.4 follows the implications of these scholarly shifts into the field of 'more-than-human' geographies elaborating theoretical and methodological commitments that become essential to the thesis. Section 3.5 tunes this study further towards an upcoming engagement with Aquaponics looking to the burgeoning field of Animal Geographies with particular focus on contemporary work in Plant- (3.5.1) and Fish-geographies (3.5.2). A summary (3.6) points out the potential of aquaponics as a field rich with possibility for the exploration and elaboration of MTH and STS research. The culmination of this chapter allows the research questions of this thesis to be organised and detailed in section 3.7.

3.2 Early approaches to Science

3.2.1 From social studies to early ethnographies of science

In 1988 Sharon Traweek published a study of a scientific community working at the Stanford Linear Accelerator (Traweek, 1988). As an ethnographer, Traweek sought to contextualize the science of high-energy physics in relation to the ways in which this group of physicists organized themselves socially. She lived her "days and weeks and months within the patterns of the community's life, moving in spaces shaped by the community and taking part in its activities on its terms" (Traweek, 1988; 10). The result was a rich depiction of the complex social reality that lay behind the work of natural science. In the final pages of the book, Traweek concludes:

“I have presented an account of how high energy physicists construct their world and represent it to themselves as free of their own agency, a description, as thick as I could make it, of an extreme culture of objectivity: a culture of no culture, which longs passionately for a world without loose ends… a world outside human space and time.” (Traweek, 1988; 162)

Traweek’s study described a community that was defined by the shared cultural conviction that its shared convictions were not in the least bit cultural, but, rather, timeless truths – they were, in Traweek’s terms, a self-proclaimed “culture of no culture”. This observation serves to mark an epistemological position against which the early ethnographies of science attempted to define themselves - the supposed ‘naïve’ view of scientific work. The naïve position viewed the work of science as a purely rational process of representing a nature that revealed itself in transparent observations. The ‘rational process’ of the naïve view refers to the idea that universalistic and technical decision criteria, for instance concerning evidence or reliability, are the determining factors in the outcomes of decisions regarding methods, knowledge claims, and theories in science. Traweek’s account of the physicist community was important in that it described the way fundamental presuppositions about time, space, and matter, gave meaning to the world of the high-energy physicists. However, when Traweek arrived back from a comparative study of physics labs in Japan (Traweek, 1992) she demonstrated important differences between the fundamental presuppositions of the US scientists and those in Japan, an emphatic demonstration of their historically contingent nature. By doing so Traweek joined a number of early STS scholars whose research contributed towards the “debunking of an image of ‘The Scientist’” (Lynch, 1985; xiv).

Traweek was not the first to question the idea of science as the very paradigm of rationality. Famously, the work of Thomas Kuhn (Kuhn, 2012 [1962]), but also Ludwik Fleck (Fleck, 2012 [1935]) and Paul Feyerabend (Feyerabend, 1993 [1975]), had made important interventions regarding the less than rational historical and philosophical relationships between scientific institutions and scientific knowledge. But, as Knorr-Cetina (1995; 140) pointed out, for the early STS scholars in the 1970’s a simply ‘less naïve’ survey of the historic functioning of scientific institutions was not enough; “One also needed to gain access to the technical content of science through channels other than those of accepted scientific 'facts" and theories—for once knowledge has "set" (once it is accepted as true), it is as hard to unravel as concrete.” If the ‘hard core’ of science are its facts (the epistemological currency taken up by the Philosophy of Science), the early STS scholars of the 1970’s in various ways sought to catch a view of science before the ‘fact’. They focused their attention on two empirical openings; ‘scientific controversies’ and ‘unfinished knowledge’ (Knorr Cetina, 1995).

‘Controversies’ in science offered some methodological purchase for a current of STS known as the sociology of scientific knowledge (SSK). The SSK researchers emphasized the interpretive flexibility of evidence and the way in which knowledge claims were influenced by the social context, for instance, in localised decision-making processes and negotiations among core sets of actors in a controversy (Collins, 1981). In doing so, they also highlighted the contingency in what comes to be constituted as the accepted methods of a field (Hess, 1995). By the 1980’s the result of this research was no less than a comprehensive sociological contextualization of science (see, Bloor, 1976). Since these studies revolved around the interpretation of events by scientists in relation to their findings, methodological focus was placed on informant interviewing and textual analysis, with relatively less emphasis on the laboratory as a site of investigation (Knorr Cetina, 1995). The SSK scholars explored the processes, choices and negotiations that were needed for science to arrive at its claims. They found these mechanisms could not be explained either by a particularly distinctive form of rationality nor by an especially ‘scientific’ procedure or logic – these processes were, so to speak, quite ordinary, local and social. The conclusion was that science is a result of specifically *social* negotiations, it was therefore *socially constructed*.

The idea of social construction forwarded by the SSKers did not sit easily with the early lab studies. Rather than solely focusing on what the scientist said, through contested speech acts/consensus building etc., their approach to science was more anthropological in its outlook and methods in that it viewed scientists as the producers of *material culture.* Many of the early lab studies focused on the ‘unfinished knowledge’ in science, and this opened up a set of rather different questions to those being asked by the SSK scholars. Knowledge that is yet in the process of being constituted, hence ‘unfinished’, obviated the need to look at what previous philosophers of science had dubbed as (and largely marginalised) ‘the context of discovery’. Here, emphasis was placed on the circumstances that form the *setting* in which scientific work occurred. In this way, ‘unfinished knowledge’ entailed a need to get at “the on-line, real-time process” (Zenzen and Restivo, 1982; 447) through which scientists “arrive at the goods that continuously change and enhance [society]” (Knorr Cetina, 1995; 141). The classic laboratory studies[8] aimed to get at this ‘science-in-action’ by turning away from “armchair and anecdotal reconstructions” of scientific work towards an ethnographic approach that took participant observation to the scientific lab (Zenzen and Restivo, 1982; 447).

The scientific context of these early ethnographies was diverse, covering a number of fields: the brain's endocrine system (Latour and Woolgar, 1986 [1979]), the biochemistry, microbiology and

[8] The often quoted classic laboratory studies are: Latour & Woolgar (1986 [1979]); Knorr-Cetina (2013); Law & Williams (1982); Zenzen & Restivo (1982); Collins (1992 [1985]); Lynch (1985); and Traweek (1988). For a review of these studies see Knorr-Cetina (1983).

technology of plant proteins (Knorr-Cetina, 2013), cell biology (Law and Williams, 1982), the colloid chemistry of immiscible liquids (Zenzen and Restivo, 1982), neurotransmitters (Lynch, 1985) and, as previously mentioned, high-energy physics (Traweek, 1988). If diverse in discipline, geographically the studies had a more unified flavour; all but the Law and Williams study were ethnographies of American Laboratories. Attempting to collapse the contextual diversity of these studies would run counter to their unified goal of exploring the situationally specific experience of scientific work, nevertheless, it is worth pointing out two important areas of convergence in both method and theory for our purposes here. Firstly, how a laboratory was to be defined and the way it differed from scientific 'methods' or 'experiments', and secondly, the way scientific knowledge was arrived at, were areas of these lab studies that coalesced enough for them to be grouped into what is now known as the 'constructivist' interpretation of science. It is important to take a closer look at these two aspects in more detail.

3.2.2 Experiments, Methodologies, and the Laboratory

The experiment, at least since Robert Boyle, as has been accepted as the central feature of scientific method (Shapin and Schaffer, 1985). When considering explanations of the validity of scientific work and its rational basis the phenomenon we call the 'experiment' has historically carried much epistemological gravitas. It is the framework within which "the scientific method" is deployed, and it has been thought of as the unit through which science proceeds, since empirical verification comes from carefully demonstrating that the repetition of the experiment yields the same results. The experiment crucially lends itself to the Cartesian practice of breaking a problem down into discrete components, analysing the separate parts in isolation, and then reconstructing the system from the interpretations of the parts. In this way, the experiment is the guarantor of a number of acclaimed benefits of the scientific method including: the ability to untangle variables and test each separately; the possibility of a control group to compare results; avoidance of experimenter bias and subjective expectations; and results that can be justified through replications that "anyone" can check or perform.

The last point is important. Experiments are defined *methodologically* so that they can be repeated and validated. Experimental design is inscribed as a step-by-step description of the essential procedure undertaken to reach a specific conclusion. It is a technical list that can be read and repeated to test the claims of the science reported. Materials, equipment, and protocols are detailed. Notions like blind and double-blind procedures, control groups, factor isolation, and replication are all contained in the scientific method report. Ultimately, scientific claims to objective validity are assessed on the merit of the experimental methodology. But a shared conviction of the laboratory ethnographies of the 1980s was exactly to break with this idea that the content of the experiment is exclusively contained in the scientists' methods report. As Lynch (1985; 3) puts it:

"Methods reports supply step-by-step maxims of conduct for the already competent practitioner to assimilate within an indefinite mix of common sense and unformulated, but specifically scientific, practices of inquiry. These unformulated practices are necessarily omitted from the domain of study when science studies rely upon the literary residues of laboratory inquiry as the observable and analysable presence of scientific work."

When Lynch speaks here of 'unformulated practices' he is saying at least two things. First, the experiment proceeds in excess of the formalised methods. Secondly, to some point this excess is located in the observable practices within the laboratory. The proposition here is that the technical activities of science should be considered within their wider context. The early lab ethnographies hoped to extend the intellectual terrain of the experiment to take account of the material and symbolic practices in which it is embedded. In this way, the notion of the laboratory shifted the focus of investigation beyond the epistemologically entrenched bounds of methodological description toward the study of the cultural activity of science (Knorr Cetina, 1995, Hess, 2001). In the words of Lynch: "Lab studies have raised to a new level the discussion of such traditional topics as rationality, consensus formation, discovery, and scientific controversy. Sociologists can now treat these topics as matters to be *observed and described in the present*, and not as the exclusive property of historians and philosophers of science." (Lynch, 1985; xiv italics added). The lab studies explored and developed a more intimate temporal and spatial dimensions to the study of science. What these studies were doing was challenging the long held - modern - ideas about what was 'internal' and 'external' to science. They showed how interests or 'the macro', were pulled into the supposed interior aspects of science and technology. This challenge to the bounds of science was a highly provocative move since, for the moderns, the boundaries of science must be strictly patrolled.

Shapin and Schaffer's (1985) by now canonical work, *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Life,* becomes extremely important in these discussions. In it, Shapin and Schaffer elegantly chart the development of the experimental scientific method pioneered by Robert Boyle. Aimed at settling a scientific controversy at the end of the 1600's regarding whether or not a vacuum can exist, and how this might be reliably evidenced, Boyle and his experimental method were pulled into a debate that questioned how nature could best be studied and how truth about nature could be attained. The controversy embodied a deeper question regarding the very foundation of how knowledge, power and authority could and should be organised in modern society. Boyle's programme, the experimental method, was designed to establish incontrovertible 'matters of fact' by setting up the conditions through which a consensus of impassionate rational witnesses might be reached. Boyle's success, according to Shapin and Schaffer, revolved around innovating three new foundational 'technologies': one material (the air-pump); one literary (the unbiased form of writing necessary to transfer the pump experiment to those who did not directly witness it); and one social (the way in which experimental practitioners should relate to each other's knowledge claims).

The laboratory in particular held a crucial position for modern science. The invention of the laboratory was an attempt to create a place where locally produced knowledge could make a 'self-evident' claim of universal validity (Shapin, 1984). The aim was to regulate the conditions within the walls of the laboratory to remove all influences of location - the lab was to become a 'placeless place' (Kohler, 2002). It involved controlling what (and who) was allowed to enter the experimental procedure (Shapin and Schaffer, 1985). The spatial division between a controlled environment and the knowledge object it purported to describe, meant that laboratory research could be viewed as 'inconsequential' to the world it investigated, the world it described (Guggenheim, 2012). However, Boyle's method was not just a way to alter constructions of nature in the form of facts and theories. Shapin and Schaffer's point went further than this. They documented the process through which the constructions of science, (through social institutions, practices, norms and rules etc,) worked to create an altogether new scientific form of life, one that we might now take for granted as experimental natural science. Boyle's programme and the methods of experimental science renegotiated the boundaries and distribution of labour, knowledge and power between different social bodies, in a process that contributed towards generating a specifically modern social order premised on particular divisions between nature, society, politics and religion. It is precisely these demarcations of reality that come under scrutiny in the troubling times of the Anthropocene.

3.2.3 Constructing difficulties

The methodological innovation of taking the study of science to the inner workings of the laboratory allowed a different view of science. The scientific practices being observed in laboratories could not be reduced to the application of their methodological rules. In this way, the products of scientific activity were not solely technical achievements, nor stood by reason alone. But there was another set of challenging observations. The practices of the laboratory that the ethnographers described seemed at odds with the commonly held view of scientific work as a descriptive process that sought to uncover facts about a universal reality. Under the descriptive conception of science the problem of facticity is located in the relation between the products of science and an external nature. But peering into the labs the ethnographers failed to find any part of the laboratory that lay ‘outside’ the culturally infused process of experimentation. Where was the external reality through which the claims of facticity were secured? Latour and Woolgar (1986 [1979]; 49) meticulously describe the materials of the experiment they witness; “animals… ether, cotton, pipettes, syringes, and tubes … a rotary evaporator, a centrifuge, a shaker, and a grinder” noting that the laboratory is a complex configuration of historically imbued equipment. Even the ‘raw’ materials of the lab, the distilled water for instance, are carefully selected and prepared beforehand; they are, so to speak, socially prefabricated[9]. Knorr-Cetina puts it boldly: “Nowhere in the laboratory do we find the 'nature' or 'reality' which is so crucial to the descriptivist interpretation of inquiry. To the observer from the outside world, the laboratory displays itself as a site of action from which 'nature' is as much as possible excluded rather than included.” (Knorr-Cetina, 1983; 119).

In the early ethnographic accounts of laboratories never are scientists described accessing a brute reality through their use of specialist tools and rationalised methods. Rather, as Zenzen and Restivo (1982; 470) observe: “the laboratory studies suggest that scientific objects are *produced* and *reproduced* at the sites of scientific action.” To be clear, instead of a process of description the ethnographers depict scientific practice as a process of construction. The laboratory is a place that specialises in the manipulation of its objects. Latour and Woolgar: “Construction refers to the slow, practical craftwork by which inscriptions are superimposed and accounts backed up or dismissed” (1986, 236). Research involves a sustained, diligent yet mundane, indeed laborious, process of ‘*bricolage’* (Latour and Woolgar, 1986 [1979]) or ‘*tinkering’* (Knorr-Cetina, 2013) in order to make unruly material do what it is supposed to. The laboratory studies suggested that natural objects were to some degree ‘malleable’. In fact, the technical innovation of the laboratory as the site of the scientific experiment seemed to rest upon the phenomenon that objects are not entirely fixed entities. Substances are purified, just as organisms are ‘standardised’ for laboratory procedures. Entities are extracted from their environments and tested under the ‘artificial’ conditions of the lab. The laboratory exists as site that actively facilitates the ‘improving’ of natural objects in a way that renders them more amenable to the purposes of science (Knorr Cetina, 1995). In this way the laboratory becomes a site of theoretical importance in the study of

[9] Consider also Knorr-Cetina’s (1995; 164) description of the emblematic of laboratory materials, the lab mouse: “The "wild type" mouse is as much a product of special breeding laboratories that supply mice to scientists as other laboratory animals; not only could it not survive in the wild, but the lab could not use real mice captured in the woods because of the "nonstandardized" biological variations and diseases these animals carry.” Haraway (1997), famously chooses the lab mouse as her charismatic, yet selfless companion in her discussions of Technoscience.

science. Knorr-Cetina (1995) interprets this process through a phenomenological stance, leaning on the work of Merleau-Ponty. She claims the laboratory as a site that allows a “reconfiguration of the system of ‘self-others-things’ in the phenomenal field in which science is made” (Knorr-Cetina 1995; 145). In these reconfigurations the structure of symmetrical relations that holds between “the social order and the natural order, between actors and environments” is altered, even if only temporarily, in such a way that yields “epistemic profit for science” (Knorr-Cetina 1995; 145).

This leads to another important theoretical outcome of the early lab studies. With their focus on the process of fact production, the early ethnographers had placed much emphasis on the *objects* of science. They described the laboratory as a place through which the objects are altered and reworked for the epistemic benefit of science, however, this also implied a reciprocal effect on the configuration of the social. Hacking (1983) described this process as one of ‘*intervention*’. For him scientific practice intervenes not only into the material reality of the lab, but also its social reality (Hacking, 1983). Knorr-Cetina: “If we see laboratory processes as processes that "align" the natural order with the social order by creating reconfigured, "workable" objects in relation to agents of a given time and place, we also have to see how laboratories install “reconfigured" scientists who become "workable" (feasible) in relation to these objects.” (Knorr Cetina, 1995; 147). Under this impression, the power of the laboratory stems from its role as a place where the boundaries of such a reality are encouraged to become permeable.

The early ethnographers of science did not view the uncertainty of the lab as detrimental to the work of science, rather it was the opposite. For Zenzen and Restivo, for instance, the contingencies of the lab are “constitutive of the research” (Zenzen and Restivo, 1982: 24). Knorr-Cetina (1983) considered it the very principle of scientific change. Uncertainty at the heart of the scientific process then, was seen as integral to the function of science. Latour and Woolgar (1986) go to length documenting the ways through which scientists created information out of noise and organization out of chance events. They describe the process of scientific work as essentially the creation of 'order out of disorder': “order is *created* and this order in no way preexists the [scientists] manipulations” (Latour and Woolgar (1986; 246). These observations lead Latour and Woolgar (1986; 180) to a bold position that still holds much influence contemporary research of science: “’reality’ cannot be used to explain why a statement becomes a fact, since it is only after it has become a fact that the effect of reality is obtained.”

Contingency and disorder, then, are key features of an ethnographic understanding of science. But contingency causes problems for any plan of the social scientist to pin down the scientific fact. Knorr-Cetina: “Thus we are confronted with the somewhat annoying picture of an indeterminacy inherent in social action. The indexicality and the idiosyncrasies of scientific work jeopardize the hope of the philosopher of science to find once and for all the set of criteria which rule scientific selections." (Knorr-Cetina, 1983; 134). The dissatisfaction expressed here is of the inability of the sociologist to completely explain the function of science. The inability to explain entirely why science arrives at its product. The constructive process of scientific work is shot through with two different sources of irreducibility. On the one hand, scientific practice was shown to be *underdetermined* in that methodologies only became meaningful when interpreted within their specific context. Scientific practice could not be defined by methodological rules prior to its enactment - the enactment was 'when', 'where', and 'who' dependent. On the other hand, scientific practice was also *overdetermined* in that any given result or methodological problem was open to many 'interpreted constraints', for instance technical preference or personal goals, which meant that the pathway to fact production was dependent on the unpredictable dynamics of negotiation (Knorr-Cetina, 1983).

In the above discussion I have given a brief account of the ways various strands of STS research contributed to the understanding that scientific knowledge is something that is constituted by social practices that function both discursively and materially in the course of scientific labour. The early ethnographic accounts of the lab showed that scientific objects were seen not only as "socially situated, contingent, discursive accomplishments" (Zenzen and Restivo, 1982; 470) but equally, that they involved reconfigurations of material and social realities. They contributed to a view that saw scientific objects not merely as "technically" manufactured in laboratories, but also highlighted the way they were inextricably *symbolically* and *politically* construed. Most could agree that to some extent science might be understood as '*socially constructed*', but this term carried some deeply problematic connotations (Jasanoff, 2004a). Firstly, the term seemed to suggest a causal primacy might be found within the "social" (a point that was carefully and consistently denied by many (Knorr-Cetina, 2013, Pickering, 1995, Woolgar, 1988, Latour and Woolgar, 1986 [1979]). As Hacking points out, the adherents of constructivist readings of science did not argue social reality was ontologically prior to natural reality, nor that social factors alone determine the workings of nature; yet the rubric "social construction" carried exactly such connotations (Hacking, 1999). The second was that concerns of social construction tended to hinder the analytic aspirations of symmetry – a point most forcefully taken up by the adherents of ANT (Pickering, 1992). For Latour and co. any dimension of 'the social' – be it "interests", "capital", "the state", "gender" etc– risks becoming 'black-boxed', that is, treated as fundamental, granted agency, and so exempted from further analysis ultimately obscuring the process through which society and science are constituted.

3.3 Coproduction - Contextualising Technoscience

Science studies as a field worked to rid itself of problematic conceptions of social construction, moving instead to show that "what counts as "social" about science is itself a subject of unsuspected depth and complexity" (Jasanoff, 2004a; 20). In this way, understandings of science move towards what was termed *coproduction.* As we saw with Shapin and Schaffer's (1985) elaboration of Boyle's experimental method, scientific knowledge and its material embodiments are at once products of social work *and* constitutive of forms of life. This view, dubbed 'coproduction', has become a dominant idiom through which to approach science (Jasanoff, 2004b). In the coproductionist frame, science is understood as neither a simple reflection of the truth about nature nor an epiphenomenon of social and political interests. Indeed, science, technology and society become viewed as emergent phenomena, imbricated and implicated in each other's becoming.

Viewing science as a process that articulates rather than 'discovers' the boundaries of what we call reality, coproductionist analysis of science comes to be distinguished from conventional metaphysical or epistemological inquiry through its consistent rejection of *a priori* demarcations. Indeed, it is through a commitment to presenting the way knowledge of things in particular situations relate to earlier choices about how we wish to know things in the first place, that coproductionist accounts might be seen as attempts to suspend the very distinction between metaphysics and epistemology itself. Coproduction, thus, develops as a critique of a certain realist ideology that uncompromisingly separates the domains of nature, objectivity, facts, reason, and policy on the one hand, from those of culture, subjectivity, values, emotion and politics on the other (Jasanoff, 2004b).

In the attempt to attend at once to the 'social dimensions of cognitive commitments and understandings, while at the same time underscoring the epistemic and material correlates of social formations' co-production takes on a *symmetrical* character (Jasanoff, 2004b; 18). Symmetry, as we shall see, becomes a point of contention for those studying science. The Bloorian principle of symmetry[10] had been popularised as a key concept in SSK approaches to science (Bloor, 1976). It required that all knowledge claims be treated equally and to be explained sociologically. It was an attempt to resist, methodologically, the assumption that an

[10] The 'symmetry' principle held that the same types of causes would explain both true and false beliefs. The use of methodological symmetry attempted to counter asymmetric patterns of explanation, for instance when internal and rationalist explanations are used for true beliefs, whereas external or 'social' explanations are used for false beliefs.

unproblematic, rational process lay between the material world on the one hand, and correct beliefs about that world on the other. But just how far methodological symmetry should be taken becomes a key debate in STS. As we will see, some strands within STS took the idea of symmetry a step further in demanding that the social sciences, and social science concepts and constructions also be subjected to the same form of critical investigation as the constructions of natural science. These debates catalyse important new conceptions of the nature of science and the role of the researcher of science.

3.3.1 Symmetry, Networks, and ANT

Towards the end of the 80's Latour and Woolgar released the second edition of their seminal study *Laboratory Life: the social construction of scientific facts* (Latour and Woolgar, 1986 [1979]). The original text was left almost completely unaltered by the authors, bar one striking omission - the word 'social' from the subtitle. In the postscript to the second edition the authors explain why:

"But how useful is it once we accept that all interactions are social? What does the term "social" convey when it refers equally to a pen's inscription on graph paper, to the construction of a text and to the gradual elaboration of an amino-acid chain? Not a lot. By demonstrating its pervasive applicability, the social study of science has rendered "social" devoid of any meaning." (Latour and Woolgar, 1986 [1979]; 281)

Lab studies had shown that science both embeds and is embedded in social practices, techniques, norms, technologies, discourses, and institutions – all the constituents of what might be deemed as social. These views of science – which later came to be known as 'co-production' (see below) - suggested that scientific knowledge could no longer be viewed as the transcendent mirror of reality so hoped for by the moderns. But likewise, they necessarily raised fundamental questions about particular commitments, whether active or passive to what was known as 'the social'. Indeed, Latour and Woolgar's omission of the word 'social' was *not* simply because everything constructed (including scientific objects) held traces of the social; such an assumption was precisely what they warned against. Rather, they wanted to shake free from the idea that the social provided the causal primacy of events in the lab. They forwarded a view of science that challenged both *descriptivist* ideas of modern science (that held to the idea of a brute nature 'out there' that lay distinct from humanity waiting to be discovered), and *social constructivist* ideas (that viewed natural science as a social construct ultimately derived and relative to its social context.)

In *Laboratory Life* Latour and Woolgar depart from their initial objective (anthropologically documenting the way in which facts are socially constructed), because what they find is that society and nature are simultaneously coproduced. They quickly realise that in order to understand this process science must be followed out beyond the realms of the lab (Latour and Woolgar, 1986 [1979]), a point Latour soon elaborates with his plan for following 'science in action' along the networks mobilised in its production (Latour, 1987). This methodology becomes further refined towards a version of Actor Network Theory when Latour is dragged into the now (in)famous debate among prominent practitioners of STS, the so-called game of 'Epistemological Chicken'[11].

For Callon and Latour (1992) and also Woolgar (1992), the principle of symmetry deployed by the SSKers was analytically conservative, since it left 'the sociological' untouched as the foundation of explanation. They rejected the 'residual asymmetry' found in SSK accounts of science that keep the human and the non-human categorically separate. In distinction to this, Callon and Latour argued that human and nonhuman actors should be treated as being in some way on par with one another. The remedy, in their opinion, was to 'extend' methodological symmetry so that the social sciences, its concepts and constructions, also be studied with the same radically open method as one studied nature, science and technology. To this extent ANT is seen as an extension - or possibly 'completion' (Pels, 1996) - of the Bloorian tenet of symmetry found in SSK. For some, such as Collins and Yearly, the radical symmetry of ANT represented a backward step for explanations in STS since, they argued, such a 'misconceived extension of symmetry' misplaced 'humans out of their pivotal role' (Collins, 1992; 322). The proponents of ANT, however, claimed that the even-handedness of 'following the actors' along hybrid networks of 'culture-natures' represented a step towards a more rigorously empirical and descriptivist strategy (Woolgar, 1992, Callon and Latour, 1992).

Latour and Woolgar: "We do not wish to say that facts do not exist nor that there is no such thing as reality. In this simple sense our position is not relativist. Our point is that "out-there-ness" is the *consequence* of scientific work rather than its *cause*" (Latour and Woolgar, 1986 [1979]; 180). The Actor-network approach sought to capture the nature of scientific practice in the metaphor of the making and breaking of associations between actors (both human and nonhuman), whilst at the same time refusing to assign different properties to either category. Proponents of ANT stressed they had no theory of what either the 'human' or 'the social' might be (Callon, 1984, Pickering, 1992, Law, 2008). There was no essence or nature of either of these categories, since

[11] See: Pickering (1992). The 'Epistemological Chicken' debate plays out between Harry Collins and Steven Yearley (1992a, 1992b), on one side, and Bruno Latour and Michel Callon (1992), and Steve Woolgar (1992), on the other. The debate centres on exactly how far the principle of symmetry in SSK can be methodologically generalized.

these entities must be seen as the *effect* of ascription and distribution of status within relational networks of heterogeneous affects. The positions and characteristics of 'humans' or 'the social' emerge in the process of scientific production. People are not always subjects, they suggested, and things are not always objects; such categories must be understood as the result of effects and cannot (or should not) be defined a priori. The relationism - or associationism - proposed by ANT worked on an expanded version of semiotics that sought to include the material within processes of meaning making[12]. For instance, Callon (1984) suggests the term 'actor' be used in the same way that semiotics uses the term 'actant'. For him, fishermen, scientists, and scallops were equally considered as elements of a 'sociology of translation' (Callon, 1984).

Their position therefore contributes greatly to an 'ontologisation' of science, or better, an ontogenesis of things, where the objects of science come into existence as a result of the patterns of relations of which they are part. Knowledge, in in the coproductive frame, comes to be is seen as something 'crystallizing' in certain ontological states, whether organizational, material or embodied (Jasanoff, 2004b). These states become objects of study in their own right, and thus the study of science becomes inflected with the need to apprehend *ontological* configurations of bodies and materials and the way these emerge in a process of transformation and translation. An awareness of the conditions of coproduction and an openness to novel configurations of entities become some essential terms of an engaged ethnographic practice that seeks to assess what science is, and does, in the Anthropocene. The next section will carry this argument further by looking at the way Donna Haraway's take on coproduction and the consequences this has for an engaged study of science.

3.3.2 Haraway

Donna Haraway offers a powerful point of comparison to STS approaches such as ANT. In *Modest-Witness@Second-Millennium.FemaleMan-Meets-OncoMouse : feminism and technoscience* (Haraway, 1997; 52) she invites STS scholars towards what she terms a 'cyborg anthropology'. This section will introduce Haraway's formulation of technoscience, and what is at stake in a cyborg anthropology.

Haraway (1997; 12) depicts a scientific practice that has become entwined with wider processes of globalisation. Scientific work is less concerned with 'the universal' now than it is caught up in processes of 'the global'. In fact, technoscience is the 'story of Globalisation', the "travelogue of distributed, heterogeneous, linked, sociotechnical circulations that craft the world as a net called

[12] In semiotics an 'actant' can be described as any entity that: 1) has a position in a discourse; 2) is ascribed agency, and; 3) is described as the cause or origin of an occurrence.

the global". But for Haraway (1997; 3) there is more to technoscience than merely a distributed and far reaching network: Technoscience "extravagantly exceeds the distinction between science and technology as well as those between nature and society, subjects and objects, and the natural and the artefactual that structured the imaginary time called modernity"(3). The functioning of technoscience, she argues, is "vastly different from the constitutional arrangements that established the separations of nature and society proper to "modernity" (Haraway 1997; 42). Technology and science were once regarded as separate. Technology was by definition 'material', and science 'semiotic'. Science proper dealt with knowledge claims, it was concerned with statements of truth. Technology was a material entity, it could be described by its physical effects. Haraway is claiming that technoscience, as its compounded name suggests, signals the collapse of science into technology. This is not a simple additive function (technology + science), rather, Haraway stresses that technoscience is a qualitatively different thing (Haraway 1997; 43). The regime of technoscience is 'material-semiotic'. Although she appears far from content with such a term[13], Haraway is essentially describing technoscience as a sort of postmodern condition.

According to this reading, science no longer deals with neatly separated subjects and objects. The "*cordon sanitaire* erected between subjects and objects by Boyle and reinforced by Kant" is no longer the concern of Technoscience (Haraway 1997; 43). Rather, technoscience deals with hybrid entities. Haraway develops her hybrid figure of the cyborg by adopting the FemaleMan and the trademarked OncoMouse to explore the construction of boundaries in science between technology and culture, nature and humanity. The hybrid figure has been an evocative concept throughout the social sciences for a long time, where it most forcefully stands in as a critique of pure form. A hybrid can be endlessly complicated with further mixing, and to this extent it shares a similar fractal logic to that we found with Latourian networks (Strathern, 1996). However, the *capacity* of technoscience to multiply these cyborg figures is not Haraway's main concern. "It is not just that objects, and nature, have been shown to be full of labour" claims Haraway (1997; 43), suggesting we pay attention to Marx before turning to the constructivist readings of science produced by STS scholarship. More importantly, the predicament that Haraway (1997; 43) stresses is that the chimeras of technoscience, its humans and nonhumans, the machines and organisms, subjects and objects "are *the obligatory passage points*, the embodiments and articulations, *through which travellers must pass to get much of anywhere in the world*." What she

[13] Rather than 'postmodern', Haraway suggests Rabinow's (1992) term 'metamodern' is more appropriate (42-3), although in her opinion it still implies a greater continuity than she perceives between 'modernity' and the time of technoscience. What does she propose instead? A solution that runs the length of the book, that is, a call to action: "Instead of naming this difference--postmodern, metamodern, amodern, late modern, hypermodern, or just plain generic Wonder Bread modern- I give the reader an e-mail address, if not a password, to situate things in the net." (43).

is saying is that nothing is beyond the reach of technoscience. There is no 'outside' of technoscience. This has some rather serious implications for the STS researcher.

Generally, Haraway seems eager to shift the terms of discussion in STS away from questions of 'what science is' (recall the in-house debates over what constitutes scientific fact or just where the border lies in radical symmetries) toward more normative questions regarding 'what science does'. In her view, to show that society and nature are co-constituted in the process we call science is not where the story ends. The question is which society? Which nature? Haraway has sights on a more critical STS practice. She highlights the work of a number of feminist scholars such as Sandra Harding (1993) and Susan Leigh Star (1991). Social injustices of all kinds are borne "through the constitutive practices of technoscience production themselves" (Haraway, 1997; 35), and STS scholarship has been unable to confront this in its failure to properly integrate important insights from feminist standpoint theory. In one breath Haraway applauds 'Latour and others' who "masterfully unveiled the self-invisible modest man" of science (Haraway, 1997; 33), but then in the next moment turns critical attention back onto the prominent STS scholars themselves, and particularly towards the rising methodological prominence of actor network theory.

Haraway (1997; 34) offers a critical reading of Latour's *Science in Action* (1987). For her, the 'creative abstraction' found in Latour's network metaphysics of is both "breathtaking and numbingly conventional". Technoscience appears with infinite connective possibilities, yet the science-in-the-making that Latour wants to follow is seen by Haraway (1997; 35) as a macho performance more suitable to a colosseum than a laboratory: "all trials and feats of strength, amassing of allies, forging of worlds in the strength and numbers of forced allies. All action is agonistic". The powerful tropic system that ANT represents is described by Haraway (1997; 35) as 'quicksand', because it works by 'relentless, recursive mimesis': "The story told is told by the same story. The object studied and the method of study mime each other. The analyst and the analysed all do the same thing, and the reader is sucked into the game". Haraway's point becomes a rather incisive critique. Through all this exceptional and abstract wizardry, Latour and others actually magnify the very thing they claim to overcome - the modernist process installed by Boyle: "nature is a materialized fantasy, a projection whose solidity is guaranteed by the self-invisible representor" (Haraway 1997; 34). The workings of science-in-action precipitate out as actors translate effect along diverse networked trails, yes, but who, Haraway invites us to question, is the one giving witness to this? The ethnographer (Latour) in this account of scientific practice is entirely extracted. Networks are presented but the presenter evades being caught in his subject's conceptualization. The ethnographic encounter never happens. In watching the laboratory and reporting the science-in-action *without effect* the ANT scholar ironically reproduces another version of the infamous 'view from nowhere'. It is true that Latour (1987) had importantly argued that within the context of scientific research nothing is ever strictly transparent (the process depends on an apparatus of representation and intervention that come with their own ambiguous codes of visibility and intelligibility), but Haraway's charge is that by shrouding the STS scholar's role in the research process, Latour had, if anything, extended this ambiguity further. If technoscience is the "demiurge that makes and unmakes worlds" (Haraway 1997; 34) then in these accounts the ANT theorist becomes its invisible, agnostic accomplice.

3.3.3 Modest witness

To remedy the detached scholarship of the 'self-invisible modest man', Haraway offers up in its place the 'Modest witness'. There is no hidden vantage point for the researcher, she argues, since both the 'facts and the witnesses' are constituted in the encounters of technoscientific practice: "the subjects and objects of technoscience are forged and branded in the crucible of specific, located practices, some of which are global in their location" (Haraway 1997; 35). The modest witness is unavoidably caught up in the 'material-semiotic' workings of science. Central to this argument is Haraway's earlier work on 'situated knowledges' (Haraway, 1988) in which she elaborates the way objectivity is achieved as a function of partiality[14]. In light of this, "innocence and transparency are not available to [the] feminist modest witness"; accounts of science no longer have recourse to the kinds of partiality that allow the representor to pull the 'God-trick' with an advantaged 'view from nowhere' (Haraway 1997; 38). Science, Haraway tells us, is the result of "located practices at all levels". Her Modest Witness has a view from *somewhere,* and with it, a responsibility towards making clear just where this somewhere is. Since the researcher actively 'crafts' and 'inhabits' this location, the ways of doing so "must be made relentlessly visible and open to critical intervention" (Haraway 1997; 36)[15].

It may seem that Haraway is simply calling for greater reflexivity in STS practice. Importantly, however, the impact of Haraway's critical interpretation of technoscience and those who study it does not fall solely on the not-so-invisible, transcendence aspiring researcher. The stakes have been raised also for the objects of science. To understand this, we must consider what these objects are. Haraway (1997; 12) tells us the objects of technoscience are hybrid figures, cyborgs exemplified by the 'seed, chip, gene, database, bomb, foetus, race, brain, and ecosystem'. They

[14] "Objectivity is not about disengagement but about mutual *and* usually unequal structuring, about taking risks in a world where *"we"* are permanently mortal, that is, not in "final" control." (Haraway, 1988; 596).

[15] It is worth pointing out that responsibility towards those involved is neither a radical nor novel point for those practicing ethnography beyond the confines of STS, where such points are a prerequisite for an accountable ethnographic practice.

are ‘implosions’ of subjects and objects, natural and artificial and because of this they are “simultaneously literal and figurative” (Haraway 1997; 11). This is no minor point. What Haraway is claiming is that the once separately held domains that populated modern ways of understanding reality, for instance epistemology and materiality, or knowledge and power, are now fused. Science and technology have collapsed into one another, and whilst doing that, have imploded all the things that once kept them separate. ‘*Technobiopower*‘ is the unwieldy name she gives for the “mutated space-time regime” of technoscience’s cyborg figures (Haraway 1997; 12). Now, the seed, chip, gene, ecosystem etc become important sites of investigation, not only to make sense of this historical predicament, but because these cyborg figures demand a reassessment of the coordinates of knowledge and power so influentially laid out by Foucault. The traditional boundaries that qualified the ways one could assess scientific practice (epistemology) have been broken, and this leaves the door wide open for ethical, aesthetic and other engagements. No subject nor object of science, Haraway tells us, is exempt from the “permanent finitude of engaged interpretation” (Haraway 1997; 36).

So given all this heady positioning, what does engagement look like for the spatio-temporally warped STS researcher of Haraway’s technoscience? She insists that we are part of technoscience, that we “inhabit and are inhabited by [the] figures that map universes of knowledge, practice and power”. We cannot escape. The familiar and comfortable places that had traditionally been used for reflection and critique (distance, representation) have all but evaporated. This is a position for which reflexivity is ill equipped to respond, since it pits “self-vision as the cure for self-invisibility” (Haraway 1997; 33). In response to this problem, Haraway offers up the concept of ‘diffraction’ as a replacement for reflexivity. And here is the crux of the argument. Diffraction, “the production of difference patterns” (Haraway 1997; 34) is Haraway’s metaphor of choice to describe her methodological approach. There is no longer the ontological separation that affords the critical engagement with the knowledge of science. The researcher is just one more relation in the networked webs of technoscience. In light of our thoroughly entangled position, commitments towards representing technoscience (“as if such an epistemological copying practice were possible” (Haraway 1997; 63) become relatively less important. Unavoidably caught within the processes of science, what is now key is “*articulating* clusters of processes, subjects, objects, meanings, and commitments” (Haraway 1997; 63). The course of action for Haraway’s ‘Cyborg anthropology’, is a call to “*refigure provocatively* the border relations among specific humans, other organisms, and machines” (Haraway 1997; 52). Haraway’s situated ethico-political practice seeks to “bring the technical and the political back into realignment so that questions about possible liveable worlds lie visibly at the heart of our best science” (Haraway, 1997; 39), and in doing so, she points towards a more engaged relationship to the study of science. The next section will explore the way Geographers have taken on and developed key themes and sentiments found in STS scholarship.

3.4 More-Than-Human Geographies

In the more-or-less sustained probing of modernist research practices, and the contradictory binaries they ratify, STS and other critical research through the 80's and 90's opened up an inviting space for critical geographers. Writing already in 2006, Sarah Whatmore draws lines between these literatures and contemporary human geography scholarship. Some strands of geographic scholarship had begun to gravitate towards the increasingly pervasive phenomenon that had long been of interest to STS - namely the "intensification of the interface between 'life' and 'informatic' sciences and politics" (Whatmore, 2006; 601). She is left with little doubt that cultural geographers have become 'bound up' with the proliferation of what Latour had called 'matters of concern' (Latour, 2004a). It is these 'interfaces' between non-human life and the human that have become fertile ground for the now burgeoning field of more-than-human geographies (MTH), marking a departure with the conventional disciplinary boundaries that had traditionally defined human geography.

Broadly put, 'more-than-human' research has sought to approach nonhuman life more earnestly, attempting to step beyond the modernist dismissal of nonhumans as a 'nature' worth only plundering. Typically, this has proceeded through a commitment to pay close attention to the entanglements of the human/nonhuman. There has been an underlying concern with the 'symmetrical' challenge of, on the one hand, decentring the human within research practice, and on the other, of attending to the agencies, perspectives and experiences of non-humans. The result of this tends towards modes of research that are situated, embodied and non-homogenising in their nature (Buller, 2015b, Hodgetts and Lorimer, 2015). In this regard, more-than-human geographies have paid more than a passing glance to the principles of feminist scholarship, particularly stemming from STS corners, which sought to put traditional methods under a more critical spotlight (Harding, 1987, Haraway, 1988).

According to Whatmore, more-than-human modes of enquiry neither presume that socio-material change is an exclusively human achievement, nor do they exclude the 'human' from the stuff of fabrication (Whatmore, 2006). This is an important point that Whatmore makes very clear. The 'more-than' label stands in distinction to classically 'human', and 'post-human' approaches:

"It is what exceeds, rather than what comes after the human, however configured in particular times and places, that is the more promising and pressing project. It is for this reason I… continue to work with a different signature – preferring the 'more-than-human' to the 'posthuman'; a signature that conjures-up a very different historicity" (Whatmore, 2004; 1361).

The category human for her is too dynamic, disunified, and unbounded to produce a convincing rendition of the posthuman. The 'posthuman' is inappropriately bound to the remnants of an essential 'human' original that never was. Whatmore sees more-than-human research ambitions, as a 'convergence' between ongoing conversations in geography and science studies (see (Whatmore, 2002; 4). In this sense, the more-than-human project shows affiliations with the 'we have *never* been human/modern' corpus developed by Latour a decade earlier (Latour, 1993). Consider Whatmore's statement above. Firstly, notice how the emphasis is on what exceeds. The additive nature of the '*more-than*-human' harbours the same characteristic '*and… and… and'* function displayed by Latour's expanding actor networks. Secondly, notice how the frame of reference is the present. The 'promise' of the project lies in *particular* times and places. Think back again to Latour's insistence on following 'science in action' as it happens or indeed on Haraway's dedication to situated practices that resist placeless universalisation. Whatmore's more-than-human geographies are resolutely '*hybrid-geographies'* (Whatmore, 2002); they aspire to account for entities that exceed the categories of traditional knowledge practices. She borrows vocabularies of hybridity that have been keenly honed through STS devices like the 'cyborg' (Haraway, 1985), the 'hybrid collectif' (Callon and Law, 1995), and the 'quasi-object' (Serres and Latour, 1995), towards a project that is ambitiously dynamic, fluid, and overtly Deleuzian:

"In place of the geometric habits that reiterate the world as a single grid-like surface open to the inscription of theoretical claims or uni-versal designs, hybrid mappings are necessarily topological, emphasizing the multiplicity of spacetimes generated in/by the movements and rhythms of heterogeneous association" (Whatmore, 2002; 6).

This is an important point. There is a shared conviction in the more-than-human literature that space and time should be understood, not absolutely, but relationally. Time and space only make sense with reference to the processes through which they emerge. The fluid topologies of more-than-human approaches, according to Whatmore (2002; 6), 'unsettle the coordinates' of the classic geographic questions of 'distance and proximity', 'local and global', 'inside and outside' appearing remarkably congruent with the imperatives of following the situated, hybrid becomings of technoscience pursued by STS scholars.

Beth Greenhough (2014) identifies five key areas of consistency that run through more-than-human literatures: 1) there is an interest in unpacking assemblages of bodies, knowledges and properties; 2) a nonanthropocentric perspective on whom (or what) should matter politically; 3) a recognition of non-human agency; 4) a conviction that space and time should be defined relationally, not absolutely, and with reference to the processes through which they emerge, and; 5) a recognition of humans' limited capacities to represent the world coupled with an imperative to hone new sensitivities, skills and affectual capacities (Greenhough, 2014). These five commitments will become important touch stones for an engagement with Aquaponics that is sensitive to the ontological, epistemological, and ethical challenges of the Anthropocene. At this point it becomes important to point out how an engagement with aquaponic science in particular can be of interest for MTH research commitments. In what way can aquaponic science be applied to key concerns and debates of the MTH? The following chapter will follow animal geographers who are dealing with contemporary fish- and plant-geographies.

3.5 Animal Geographies

In attempting to look beyond the confines of a human centred practice in geography, More-than-human approaches have, with particular verve, been taken up towards the study of that most conventionally 'non-human' of entities - the animal (Buller, 2014, Buller, 2015b, Buller, 2015a). As Buller points out, growing recognition that our relations with non-human animals are of importance to human (geographic) understanding, has led to an outburst of scholarship into the spaces and places of human-animal interaction (Buller, 2014). Key points of contact include: Pets and their owners (Fox, 2006, Bernstein, 2007, Power, 2008, Kemp et al., 2016), farmers (Vanhonacker et al., 2008), the zoo (Anderson, 1995, Braverman, 2011), and importantly for this study, laboratories (Birke et al., 2007, Shyan-Norwalt, 2009). Again, what we find in these studies is the recognition that our relations with non-human animals are not only of importance to human understanding, but that they are indeed constitutive of the very actors themselves, both human and non-human, caught up in those relations. As Lestel and colleagues put it: "we still need work that attempts to account for the *shared lives* that grow up between humans and animals. Simply studying the effect of the one on the other is not enough" (Lestel et al., 2006; 57)

Buller points to three methodological challenges faced by Animal geographers wishing to extend the reach of scholarship to account for animal presences (Buller, 2015a). First, a genuine methodology for animal geography must reach beyond the all-too-easy collective and abstract categorizations of the non-human (such as orderings by species, function or location, common to both natural and social science approaches to the animal) to focus rather upon animals as 'embodied individuals living their lives entangled with humans and their own wider environment' (Taylor, 2012; 40). Second, what is required are approaches to understanding animals that do not rely upon wholly human representative accounts – 'the animal as it is seen' (Derrida, 2008; 82) – but find other ways of letting animals 'speak' – 'the animal that sees'. Third, Buller underlines the need to move away from the traditional separation of social and natural science to establish a set of concepts and methodologies that addresses what matters for both human and non-human animal subjects in their various relational combinations and spaces.

The novel ecologies being generated in the aquaponic science labs across Europe offer some clear points of contact with problems and discussions arising in the field Animal Geographies. Aquaponics offers an opportunity to study the shared lives of fish and plants and humans in aquaponic systems, to explore the way these multispecies environments might speak to the challenges of Animal Geography scholarship. Below is a discussion of the expanding domains of Fish and Plant Geographies.

3.5.1 Plants

That plants are implicated in many of contemporary society's controversies (think: GMOs; deforestation; intellectual property rights; biofuels; the war on drugs; seed banks etc.) can be justified by considering their consistent and pervasive relation to human society. Quite simply, plants are everywhere: sources of food and fibre, material for tools and structures, the substance of medicine, objects of ornamentation, sites of memory, symbols of emotion, and reminders of worlds beyond our own (Goody, 1993). Of the diverse ways in which plants facilitate human existence possibly the most foundational is their ability to photosynthesise, a process that trophically underpins the majority of life on earth - including our own - whilst simultaneously providing the atmosphere for life (Morton, 2008). The process of photosynthesis, we are told, is one of the 'distinctive capacities' of plant life (Head et al., 2015), that are used to explain both our connection to plants (through an unpayable energetic 'debt'), as well our separation from them (we cannot 'eat the sun' to use Morton's rather blunt term (Morton, 2008)). The line that cleaves these ideas of similarity and difference in human-plant relations is traceable deep into our intellectual heritage (Hall, 2011), and one that plays a significant role in the way we apprehend vegetative life. Ryan (2012; 111) points out that "by and large, utilitarianism is one of the dominant social values associated with plants: as food, fodder, fibre, and medicine". Indeed, plants as 'things to be acted upon' has effectively been the position rehearsed through the history of the social sciences, wherby, traditionally, plants have broadly fallen into three passive forms; as part of landscapes; as food; or as symbols (Kopnina, 2013, Kirksey and Helmreich, 2010).

There are, however, moves across the academy to reassess the confines of this ontology, touching fields as wide as the scientific (Trewavas, 2002), philosophic (Marder, 2011), and legal (Pouteau, 2013). Geographic scholarship attempting to get beyond organising principles that render plant life passive have recently picked up pace. Head and Atchison (2008) - who could be seen as the forerunners of a MTH plant geography - spell it out: “we are not interested in assuming an ontological and unproblematic separation between ‘cultures’ and ‘their [vegetative] environment’ as the basis on which straightforward ‘interactions’ or ‘adaptations’ can be analysed” (Head and Atchison, 2008; 1). Noticing the paucity of plant related studies, find it “puzzling… that human-plant geographies have been less commented on than human-animal geographies” (Head and Atchison. 2008; 3), suggesting a number of reasons: “First, animal geographies have been spurred on by questions of ethics. Between plants and humans, there is arguably a greater ethical distance, and the unit of ethical standing (individual, species, biome?) is more in question. Second, the fact that plants or their constituent parts can be transformed in so many ways contributes to their mobility, malleability and invisibility. Plants are easy to take for granted. Third, [related material is bracketed under] food or commodity geographies.”

Specifically, plants have “distinctive capacities” (Head et al., 2015) that make them conceptually and methodologically resistant to the approaches which have been so fruitful when applied to animals. Faced with this challenge, Ryan has proposed a novel interdisciplinary framework for researching flora, under the name of human-plant studies (Ryan, 2012). For Ryan (2012; 106) “the role plants in society are best articulated through interdisciplinary art, literature, philosophy, Indigenous knowledges, and science”. This is an ambtious scheme, that stresses the need to differentiate between botanical intelligence (“plants acting upon people to co-orchestrate cultural beliefs and practices in the umwelt of living organisms”) and the intelligent use of plants (“people acting upon plants in utilitarian and potentially exploitative ways that posit intelligent animals against —passive plants”) (Ryan, 2012; 116). This emphasis on being attentive to the active role vegetative life plays in the co-creation of human-plant worlds is a commitment that is echoed in much recent geographhic work on human-plant relations, that moves toward a position of plants as “important designers of our outer and inner landscape” (Pouteau, 2013).

3.5.1.1 More-than-human plant geographies

The approach of traditional cultural geography wherein plants were bundled together in anthropocentric categories as part of cultural landscapes has by now been well contested (Hitchings and Jones, 2004). Important avenues of research, however, continue to rest on traditional interest in public space, for instance, Baker’s assessment of the contested spaces of Toronto’s community gardens (Baker, 2004). Gardens in particular have a strong focus in the geographic literature. For Hitchings (2003; 99), the private gardens of Londoners become a site to examine the criticisms and possibilities of ANT approaches. Hitchings describes a “shifting locus of power and performance" at work in the private garden where "the status of the garden and the gardener [are] constantly shifting between the enroller and the enrolled, the performer and the stagehand." The garden becomes a site where "struggle between lively materiality and its symbolic denial is played out not just in academic manoeuvres, but also in routine everyday interactions".

Head and Pat (2006; 507) seek to describe human-garden relationships from 265 Australian backyards in a process that focuses on how 'boundary-making' and narratives of 'native', fit into "the urgent environmental challenges of a humanly transformed earth". Here, gardens are described as a site around which the binaries of nature/society, country/city, wild/domestic, and indigenous/non-indigenous coalesce. This said, Head and Pat (2006; 511) are eager to point out that gardens become sites where boundaries and binaries rupture, opening possibilities for "attitudes and practices to change". Along similar lines, Longhurst (2006; 5) finds gardens as spaces where people can create and enact a range of embodied subjectivities, and thus as places of potentiality: "where it is possible to reinforce hegemonic geographies and/or create alternative ones."

Shillington (2008) also attempts to recognise the co-constitutive role humans and plants have in creating spaces and realities in her study of the patios of homes in marginalized barrios of Managua, Nicaragua. Shillington uses feminist geographic understandings of 'home' to feed insights into human-plant relations that exist in these slums, allowing her to elaborate on three different sets of socio-ecological relations: corporeal, aesthetic and economic. An unavoidable aesthetic stems from the fact that slums are literally built into the trees, but it is the productive materialities of food, fuel, fodder and medicine, nourishing the bodies of the poor, which exemplify the corporeal 'intimacies' of patio human-plant relations. A vast, yet intimate, coproduced city emerges where human-plant relations (particularly the cutting of shade trees for other purposes such as growing food) are linked even to a coproduced microclimate. The rich ecologies of multi-layered interactions described here have a complexity far surpassing those found above in the gardens of the global north. A strong argument is outlined that there are natures of the global south that are not fully captured by theories of commodification, so pervasive in the study of gardens in the north.

Corporeal intimacies involved in human-plant relations have not escaped all studies in the global north. Hitchings and collaborator Verity Jones, use both private garden and public botanical garden to explore different techniques for documenting the ways in which such agencies are encountered (Hitchings and Jones, 2004). They question how contemporary living landscapes, together with people's movements (as both researchers and societies) through these, can foster certain attitudes towards botanical life. Seeking to "enliven geographic approaches to the botanic" Hitchings and Jones, (2004; 4) deploy a wide range of different ethnographic methodologies (walking, interview, pictures, discussion groups about pictures, 'bodily observation' of people's interaction with plants). Their theoretical focus, leaning on Ingold's ideas of dwelling (Ingold, 2000), concerns the possibilities of attending a 'situated' ethics that emerges through the everyday encounter with plants. A compelling aspect of this methodology is the way Hitchings and Jones (2004; 16) are able to describe human relations to plants in their "immediacy as individual life forms, rather than as components to larger, and sometimes unwieldy, categories of nature, environment or landscape", whist also recognising that these relations and attitudes are "co-constituted" through the particular methods utilised to document them. The focus on the immediate and affective relations in Hitchings and Jone's account offers a fine-grained temporal dimension to human-plant relations that shows promising synergies with Shillington's (2008) sensitivity to the way human-plant relations sediment over varied and often extended temporalities.

Personal encounters with vegetal life are given a strong role in Doody et al's (2014) in depth study of weeds in domestic gardens of Christchurch, New Zealand. The singular and context-specific nature of 'Human-weed' relations is uncovered wherein the realities of seedlings performed in the garden is always "momentary, unpredictable, improvisatory and multiple" (Doody et al., 2014; 134). The recognition of multiplicity in human-plant relations is not, however, what sets this scheme apart from previous studies of the garden [e.g. (Hitchings, 2003, Power, 2005, Head and Pat, 2006, Longhurst, 2006)], rather, this happens when Doody et al (2014; 144) reference Annamarie Mol's *body multiple* (Mol, 2003) stating that in "recognising this multiplicity we have a responsibility to consider which types of realities we want to enact" - an acknowledgement of an inherent responsibility found in the production of MTH plant relations.

A project of reformulating the politics of human-nonhuman relations is no simple task. Pitt (2015; 48) is eager to point to some ethnographic methodologies that can help engage 'more directly with plants and what they do'. Again, turning to the insightful, and ecologically compatible, ideas of Ingold, Pitt draws on notions of learning between 'novice' and 'expert'. Less markers of legitimacy or hierarchy in knowledge as discussed in debates of scientific expertise, Ingold's categories of 'novice' and 'expert' appear more closely aligned to a communication of perceptual experience: "placed in specific situations, novices are instructed to feel this, taste that, or watch out for the other thing. Through this fine-tuning of perceptual skills, meanings immanent in the environment – that is the relational contexts of the perceiver's involvement in the world – are not so much constructed as discovered" (Ingold, 2000; 78). In order to aid the novice human-geographer, Pitt (2015; 51) offers three areas of ethnographic inquiry: 'Learning through moving and attending to motion'; 'Learning through working with gardeners'; and 'Visual methods focused on plants'. These techniques offer ways to intimately attend to plant existence and are appealing when Pitt suggests researchers work more closely with human experts of plants (Pitt, 2015).

Brice (2014) finds that the experiential expertise of viticultural labourers is under pressure as he follows them in vineyards of Australia. Attentive to the particular human-plant relations at work in the assemblage associated with the wine industry, Brice describes the many ways in which the humans of the wine industry exert increasing attention to the vines as they approach the crucial moment of harvest (Brice, 2014). Brice accompanies the workers in the field (tasting, feeling, and watching); follows others in the lab conducting sugar analysis on the grapes; and joins in guessing on the unpredictable weather patterns, which allows him to describe how human energies are tied to the metabolic processes of the vines. Scientific processes of sugar analysis, used to predict harvest times, clash with in-the-field, subjective and affective assessments of the vines readiness. It is not only the excellent grape juice that is coproduced in this account; Brice also explains that the very experience of temporality shifts as the different methods of attending to the vines seasonality are enacted differently. The claim Brice (2014; 960) makes here, is that these multiple temporalities are the manifestation of a vine agency that works to dispute the work of narratives that fix plants, animals and landscapes to a "clock-time regime concerned with maintaining social coordination among humans".

3.5.2 Fish

One of the earliest depictions of aquaculture is thought to be a 4,000-year-old bas relief figure that was discovered in the Egyptian tomb of Thebaine, apparently depicting a nobleman fishing what is thought to be an artificial, drainable pond (Beveridge, 2002). Despite these ancient origins, however, it is only recently that aquacultural matters have been taken up by the geographic community (Barton and Stanifordt, 1998). Before the 1980's, geographic literature on fish farming was limited to Japanese studies with a national focus (Barton and Stanifordt, 1998). It wasn't until 1986 that global aquaculture issues first appeared on geography's agenda, with Francois Doumenge's paper 'La revolution aquacole' (Doumenge, 1986).

Through the 90's only a trickle of geographic studies of aquaculture registered (Coull, 1993a, Lloyd and Livingstone, 1991, Wood et al., 1990, Nowell, 1990, Coull, 1988, Coull, 1993b). The appearance of Barton and Staniford's (1998) paper "*Net deficits and the case for aquacultural geography*" can be seen as a milestone for geographic work on aquaculture. Their intent on confronting the sustainability of aquaculture alone was seminal for the times (Belton and Bush, 2014). In this review the authors are concerned not just with the unavoidable realisation of the 90’s that global capture fisheries were reaching crisis point - a deficit in landings relative to demand – but also that the global aquaculture industry began to accelerate with scarce attention from geographers. For Barton and Staniford, this scholarly blind spot constituted a second deficit, this time one concerned with geographic knowledge. Barton and Staniford (1998; 145): "*The crisis in capture fisheries has placed an increased onus on aquaculture to supply the world fish demand. The advancing role of culture relative to capture fisheries has precipitated environmental and socio-economic transformations. Geographers have paid scant attention to these developments.*" And further, in their view, if aquaculture was not to “arrive at the ’crisis’ stage itself", there needed to be a critical study of the complex relationships between production and the environment, the economic, the political, and the ‘social milieu’ (Barton and Staniford 1998; 148).

To this issue Belton and Bush (2014; 12) propose the setting of a new agenda to bring the field up to date with recent developments. In their view, the past studies oriented towards the export-market require a reconsideration as they have undergone "enormous changes since Barton and Staniford". They take the shifting conceptual developments of Vandergeest and colleagues as exemplary of the situation; shifting from "critiques of the worst excesses of the early boom in coastal aquaculture”, towards "concerns around new forms of regulatory control and governance” (Vandergeest and Unno, 2012; 9).

Turning their attention towards trends appearing in western economies, Belton and Bush (2014; 4) predict that aquacultural geographies will be increasingly influenced by wider movements within geographic scholarship that have "detailed the emergence of ‘alternative’ food networks founded on ‘post-productivist’ values such as organic, ‘local’, ‘sustainable’ and ‘fair’, which run counter to, or alongside, the prioritisation of profit, standardisation and efficiency". They predict support to organic or ‘local’ aquaculture production systems, may stem from the growing attention to “carbon footprints, life cycle assessment and energy intensity”. Belton and Bush suggest that research in aquaculture should try to contend what De Konick et al. (2012) label as a ‘mosaic of directionalities’ in agrarian transformation across heterogenous globalised networks. Ultimately, Belton and Bush (2014) find that geographers have the greatest opportunity if they focus their attention on the global South, towards what Rigg (2007) calls the geography of the ‘everyday’. The task, in their eyes, is to “build theory around the locale-specific processes and material realities that are revealed” (Belton and Bush, 2014; 12) quoting Rigg’s ambition to reconcile: ‘contradictions between the emergence of a world worn flat by the indefatigable forces of globalisation, and a world where localities and localism are gaining in significance and where difference and complexity are becoming ever more pronounced and powerful’ (Rigg, 2007; 11).

An excellent example of recent geographic research that has concerned itself with ‘specificities of locale’ and ‘the material realities’ this entails is Probyn’s (2011) study of an emerging tuna farming industry in Boston Bay, South Australia. Probyn uses ethnographic as well as historical data to show how this fledgling industry becomes a lens through which to explore "ways of thinking intimacy, emotions and globalisation in a different voice” (Probyn, 2011). The paper forms part of a larger project on how the relationships between taste (consumption) and place (production) are being rearranged in the globalised food system (Probyn, 2011). What follows - amongst a description of the experience of swimming with tuna during feeding - is a detailed account that moves across scales and registers (from tuna, to fishermen, to global markets, history) to build a picture of tuna industry in a process of continued change - from the early days of the 60's, spawned from Japanese tastes and freezing technologies, to the crash of stocks to 2.5% of their original size, to the new 'farming' style approaches that are appearing. As she paints the picture of a global assemblage of technology, she also attends to the changing affectivities and emotional geographies implicated in the tuna industry. Japan is the 'taste broker' of tuna, and even now, tastes are shifting from wild to their fattier farmed cousins. Even with the diverse spatial and temporal scales that Probyn puts to work in building a ‘conception of the field of taste’ within this human-ocean entanglement, her account attempts to maintain a grasp on materiality (eg. Law, 2013). As she says, the focus is on “the emotional and affective forms of embodiment that are formed and re-formed within the materiality of hybrid forums”. This is a very textural account in which Probyn seems most determined in describing the assemblage of human- non-human that contributes to the tuna industry. She sidesteps any discussion of more visceral human-fish relations with the rather hasty concluding remark of: "We do not know what tuna feel, and to speculate on that risks drawing us into the false security of sentimental comfort”. This sentiment echoes a reoccurring theme in the literature - that apprehending what is ‘fish’ often contains a dangerous aspect speculation or mystery.

In various ways the recent geographic literature has highlighted fish as, to paraphrase Law and Mol (2001; 611), ‘fluid objects, in distinctly fluid spaces.’ An excellent example of this ‘fluidity’ would be Bear and Eden’s (2008) investigation of the 'multiple spatialities involved in production of Marine Stewardship Council (MSC) certifications’. The MSC uses its Eco-labelling scheme to promote sustainable fisheries management, and through examining this certification, Bear and Eden explore how fisheries are 'defined'. They show how the fluid and relational behaviours of the fish themselves strain the managerialist "network and regional spaces of the MSC", finding that "to operate its scheme successfully, the MSC has to recognise this spatial fluidity, acknowledging the rupture of boundaries and the movement of actors" (Bear and Eden, 2008; 492).

The above example of the spatial fluidity of fish is, of course, related to the fact that fish exist in environments that defy the territorial boundary producing forces applicable to the land (Collet, 2007), remaining largely inaccessible to us land loving humans (Bear and Eden, 2011). In his paper "Notes on Fish, Ponds and Theory" John Law (2012), extends these ideas to the realm of concepts claiming fish offer up a certain conceptual fluidity. Drawing on ethnographic work in Salmon Farms in Norway, Law offers up four conceptual specificities that contribute towards the mystery contained in working with fish: 1) *Slipperiness* - "So yes, this is still an animal. And this is the hypothesis. It's an animal, in part precisely because it is slippery. Or because and more precisely, when it meets with humans, it exceeds the grasp and becomes slippery." (Law, 2012; 8) 2) *Invisibility* - "all that you can see is a few dozen salmon out of 50,000. This is the paradox. Even though they are being controlled, the salmon are also dissolving themselves into invisibility." (Law, 2012; 9) 3) *Anomaly* - there are always 'loser' salmon that do not make it, that don't fit the system they are forced into. 4) *Marginality* - there are always salmon that literally escape from the farm. These observations are intended to inform wider debates in the conceptual development of ANT and relational ontologies literature, but they also stand as important ideas when approaching fish difference more generally. As Law states: *"Salmon have their specificities, held at a distance by the fact the people prefer to breathe air rather than water. But there they are, even so, marginal and excessive. A part of human practice, but Other too. Because they are slippery, invisible, anomalous, and marginal. Because they slip in and out of the edges of human practices in their particular salmon-like, ways"* (Law, 2012; 10).

Bear and Eden (2011) investigate recreational anglers' engagements with fish in the rivers of Yorkshire, UK. Their account describes the varied ways that anglers make sense of fish behaviour over space and time, categorising and differentiating fish through their fishing practices. In describing the difficulties that anglers have in their pursuits (fish are often unseen), Bear and Eden (2011; 341) find that anglers often attempt to "'think like a fish' when deciding on their tactics" – a phenomenon that reappears in many of the studies below. However, Bear and Eden (2011; 348) also find that the category 'fish' is ambiguously used by the anglers in relation to species, size, and rhythm: "These various engagements might be understood as different, and frequently overlapping, scales of relationality, where anglers engage with: (1) individual fish; (2) different species of fish; and (3) generic `fish'."

Bear and Eden describe interesting moments where anglers can become attentive to the specificities of individual fish, often when watching their feeding habits. However, the most common register is that of the species (useful in describing patterns of feeding behaviour etc). There are times, also, when the anglers shift to the generic use of 'fish', often when describing the perceived general attributes common to all fish. Turning to Deleuze and Guattari's 'becoming animal', Bear and Eden make clear that these categories are not rigid boundaries: "Understood through this rhizomatic ontology, the fish that anglers become is never only an individual, nor a species or genus - these categories are overlapping and fluid" (Bear and Eden 2011; 347). With this view Bear and Eden (2011; 348) stress that "becoming-fish is not merely the relationship between two individuals", suggesting a need to extend Haraway’s 'companion species' approach that favours "actual animals" (Haraway, 2008; 27) over Deleuzian abstractions.

The call to focus on ‘actual animals’ is taken in an acute way in Bear’s (2011) study of Angelica, a Pacific octopus kept an aquarium in Kingston-upon-Hull, UK. Bear (2011; 298) opens up questions of individuality in the study of non-humans, aiming to "highlight the types of observations that might help develop a less anthropocentric animal geography." Pointing to Derrida's (2002) work, Bear (2011; 301) underscores the fact that in the face of cultural geography's interest in individual difference, the category ‘animal’ appears 'increasingly untenable'. In this sense his observations of Angelica also act as a critique of previous animal geographers’ studies that have only considered collectives – for instance ‘species’ of ‘herd’ - whilst ignoring individual creatures. On top of his observations of the octopus, Bear's (2011; 302) methodology uses observation of people and artefacts, stating his wish to "move an individual animal from the margins, looking not only at how this is represented, but at how it presents itself, lives a life outside of these (re)presentations and at how humans have responded." Counter to the way Angelica is framed by the 'species talk' on information boards in the aquarium, Bear describes the variety of ways the octopus expresses her own subjectivity, for example, through demands for food and the disciplined exploration of her surroundings. Through these observations and interactions Angelica’s existence "begins (indeed, only begins) to give a sense of the wholeness of this individual’s life".

With his study of Angelica, Bear extends animal geographies towards the body forms and habits of the individual. Common sense would suggest such work also presents new empirical challenges for the field, challenges, Bear (2011; 303) points out, that have "implications for the ways such animals are ‘made visible’". One such implication, he offers, would be to overly anthropomorphise the interpretation of individual animals.

The ways in which animals are made visible appears to be a prominent feature of Country et al’s (2015) collaborative paper. One immediately discovers the authorship of the paper itself - written as an experimental collective ‘we’ which includes 4 indigenous, 3 non-indigenous academics and Bawaka Country itself as the lead author - appears to push ‘flattened’ methodologies to their extreme limits (Country et al., 2015). Their work attempts to consider what attending to the ontology of the indigenous Yolŋu in Bawaka in North East Arnhem Land, Australia might mean for the way academics do research. In their words: "Ultimately, we propose that practising relational research requires researchers to open themselves up to the reality of their connections with the world, and consider what it means to live as part of the world, rather than distinct from it. We do this by calling for a methodology of attending and consider how this is necessarily informed by an ethics of caring" (Country et al., 2015; 220).

Human-fish relations are considered when the authors describe a group fishing trip, directed at a particular fish called wäkun, as a process of co-becoming. The way that Country et. al, (2005; 224) attempt to describe the fishing through the relational Yolŋu ontology, shows their ambitions of opening up the research process and methodologies to co-production with those they study with – be it non-western peoples or fish. It's an endeavour that appears fuelled by honourable ambitions of mutual respect and learning, even though the authors admit that putting the insights of relational ontologies and more-than- human research into practice "remains difficult, particularly in the context of a still non-Indigenous dominated academy" (Country et al, 2015; 275).

3.6 Summary

Animal geographies has aimed to 'reveal what matters to animals as subjective selves' (Buller, 2014; 7), or in the words of Hodgetts and Lorimer (2014; 8): Animals 'as subjects *and* ecological agents'. It's a move that draws on, and challenges, a rich anthropological inheritance of grappling with how one might know, and indeed represent, the 'other'. The rise of 'multispecies ethnography' has been an emblematic point of reference (Kirksey and Helmreich 2010). Where some commentators, mostly from a more strict anthropological canon (Smart, 2014, Watson, 2016), have found the 'multispecies' scene overly radical, many animal geographers, have preferred to view 'the animal' as an unsettling imperative that unavoidably challenges disciplinary boundaries and obliges an openness to both theoretical and methodological experimentation. In the end, this may be most important contribution from Animal Geographers.

As Latimer and Miele (2013; 7) point out, the value of charting 'naturecultures', as the animal geographers have done, is not located in a vain attempt to add 'others' back into a common denominator by denying human characteristics, nor indeed in the flipside of this move - dispelling a general misguided anthropocentrism concerning non-human others. As they suggest 'attempts to make animals stand up … appear doomed to failure unless we also rethink the nature of science, social or physical, as itself a domain of culture'. By doing so, Animal geographies lay down a challenge to certain influential approaches to science such as ANT, for it is "not simply a matter of stripping away meaning as all too human, in favour of heterogeneity and the symmetry of Latour's double contingency, by giving nonhumans the status of actants with the capacity to act differently from how they are already known. *It is more that the very basis of our anthropology appears to limit the horizons of science to a particular (and, dare one say, peculiar) set of relations.*" (Latimer and Miele, 2013; 7). The animal and plant geographies literature discussed above have been nourished by *situated* and *affective*, encounters between humans and their non-human others. It is in this way that animal geographies might be seen to extend the sensibilities of a Harawayian exploration of science. To inhabit the encounter (Johnson, 2015) with our non-human others becomes a way of challenging dominant knowledge practices (whether they be natural or social science) by provocatively existing in their blind spots.

The goal of this chapter was to describe the relevance and potential that a study of aquaponic science might have for the research imperatives of MTH Geographies. An attempt to align key features of Aquaponic science with key ideas, commitments, and debates in MTH geographies literature was made, particularly through avenues of Animal geographies literature that has taken up the challenge of studying geographic engagements with plants and fish. Animal and plant geographies often coevolve alongside the growth and dynamism of natural science research and its multifarious concepts and products. In this regard, this chapter has highlighted not only how MTH commitments offer essential foundations for study of ecological sciences in the Anthropocene, but also how the experimental and laboratory settings of aquaponic research offers a unique, timely, and hitherto unexplored opportunity to encounter and experiment with, novel, more-than-human ecologies and assemblages.

Commented [EJR2]: Good.

3.7 Research questions.

In Chapter 1, discussions of science were framed within the contemporary moment that is called the Anthropocene. Locating an urgent need to consider the current trajectories of science in the ongoing elaboration of the Anthropocene problematic, Chapter 2 identifies Aquaponics as an emergent field of science that is increasingly focussed upon key challenges related to the Anthropocene. In chapter 3, previous scholarly approaches to science were reviewed to learn of the different ways in which science might be theoretically approached. Following the historic developments in STS, shifts towards conceptions of technoscience, and the affect this had on method were elaborated. Amidst worries of the institutionalisation of social science/science collaboration on the one hand, and the trend towards depoliticised descriptivist analytic accounts of science on the other, potential was located in ethnographic material-semiotic approaches towards a speculative practice for reimagining new modes of science (studies) scholarship. Building on this, and in response to prominent calls for Human Geographers to engage more with science in the Anthropocene, this chapter then asked how MTH geographic scholarship could enrich, theoretically and methodologically, an 'engaged' ethnography of science in the

Anthropocene. Links were drawn between the aquaponic science presented in Chapter 2, and the commitments and questions of human geographies scholarship that has been grouped under the name 'more-than-human Geographies' (MTH) with particular attention to the growing fields of plant- and fish-geographies.

At this point, it is possible to elaborate more clearly the key questions guiding this thesis that I will take with me into the field of Aquaponics. Questions can be organised into three interrelated groups of questioning and concern.

The **first** relate to a general interest in what the Anthropocene means for science. In particular, how does aquaponic science engage in the on-going elaboration of the Anthropocene problematic? What is at stake in the aquaponic science? What are the commitments, challenges and opportunities facing aquaponic science? What does this tell us about the function of science more generally in the Anthropocene?

A **second** group of concerns ask how MTH geography might enrich our understanding of aquaponics. More particularly, how might the questions and sentiments of MTH approaches help to unpack the assemblages of bodies, knowledges and properties of aquaponic science? What forms of non-human agency are present in aquaponics systems? How might relational approaches reference those processes through which aquaponics emerges?

A **third** group ask what might happen when the methods and practices of engaged ethnographic STS and MTH scholarship are used to *do* aquaponic science. How can active ethnographic engagement be brought to aquaponic science? How might an engaged ethnographic practice strengthen the imperative to hone new sensitivities, skills and affectual capacities? What is to be experienced and learned in situated and affective encounters between the humans and the non-humans of aquaponic science? Ultimately, how might engaged ethnographic practice challenge both science and MTH scholarship?

Chapter 4: **Methods**

4.1 Sketching an ethnography of science in the Anthropocene

What is at stake in aquaponic science? What are the commitments, challenges and opportunities facing aquaponic science? How does aquaponic science engage in the on-going elaboration of the Anthropocene problematic? What does this tell us about the function of science more generally in the Anthropocene? How can MTH geographies contribute to these questions? Chapter 3 ended by identifying three interconnected concerns that this thesis will explore through an engaged ethnographic practice in the field of aquaponic science. In this chapter I outline the methods I adopted to get at these questions regarding aquaponic systems, and the wider gatherings of people, resources and materials that aquaponic interests set in motion.

The statements this thesis makes about aquaponics are made possible through doing, or performing, the work of aquaponics, that is, by integrating myself autoethnographically within aquaponic research processes. I suggest that by taking participatory auto-ethnographic methods to aquaponic research spaces a deep engagement with what matters in the field was made possible. This point applies both in terms of the human practitioners involved as well and the more-than-human constituents that make aquaponics happen. Participating in the practices of aquaponic research, I argue, allowed me to learn from researchers, innovators and workers in the field about what mattered to them in their work, whether materially, emotionally, or epistemologically. Further to this, through my integration I developed my own relationship with the complex and numerous 'things' that are gathered together to produce aquaponic realities. Developing these 'intimate entanglements' within aquaponic worlds (Latimer and López Gómez, 2019), I was able to grasp a sense of the convoluted processes of power, discourse and materiality in aquaponic research spaces, including the consequences that emerge in sites of aquaponic production, often in relation to my own bodily invested aquaponic research practices.

Extending an autoethnographic approach to the study of aquaponics in the Anthropocene, this thesis develops a multisited, embodied and performance centred approach to research. This qualitative engagement carries into aquaponic worlds the speculative commitments of a posthuman ethics of care. The ambition of this thesis then, is not to study Aquaponics with the positivist impulse of extracting (Mackenzie and Murphie, 2008) aquaponic knowledge for the benefit of MTH Geographic scholarship, but rather to bring the two together and let the concerns of each feed into one another. What is to be learned by letting the research process and MTH scholarship become aquaponically *activated (*Papadopoulos, 2018). An ambition of this thesis is to explore what it means to live the multiple membership of academically concerned communities and thus an important aspect of the method was to take up scientific roles within the field of aquaponics. This engaged style of autoethnographic practice, I hoped, would bring greater opportunity for me to actively explore the heterogeneous socio-material ecologies of aquaponics. To this extent, along with Papadopoulos (2018: 68), I hoped for an approach "as experimental as the worldings it engages with require it to be". This chapter details my route into the world of aquaponics and offers some specificities regarding the autoethnographic style and focus, materials and methods, providing a foundation for the findings chapters 5, 6, and 7.

4.2 Autoethnography for the Anthropocene

Living in our times is to experience the redistribution of human agency. The Anthropocene, Bruno Latour (2014b) points out, is a moment where the link between sediments and sentiments can no longer be attributed to myth; it is literal. But just how might methodology begin to account for the inextricable insertion of researcher inside the territory of the researched? This thesis turns to autoethnography as a method that can offer much to this impending question.

As a qualitative method of research, writing, and story, autoethnography has, for some decades, been concerned with this question, producing detailed, creatively written, local, first person accounts of the relationship between the autobiographical or personal and the cultural, social and political. Autoethnographic forms feature concrete action, emotion, embodiment, self-consciousness, and introspection, whilst often claiming conventions of literary writing (Ellis, 2004; xix). Autoethnographic work of the past has tried to acknowledge that people, through their daily interaction and activity, become inscribed within dialogic, socially shared, representational practices (Bakhtin, 2010), a situation that calls for a sensitivity towards the complex and changing subject position of the researcher in relation to others.

Although all ethnographic method might to some degree be considered autoethnographic (Atkinson, 2001), it was not until scholarly ruptures ushered in by the so called 'triple crisis' - of representation, legitimation, and authority – that autoethnography became a recognised mode of scholarship. As the triple crisis accelerated the dissolution of the modernist ethnographic subject-object divide an opportunity - or imperative – arose to break with what some considered elitist, institutionalised anthropology, especially those schools of entrenched research epistemologies that ratified a distanced analysis of 'cultural wholes' in the received canon of a disengaged master discourse (Rosaldo, 1993). Postcolonial and feminist ethnographers called for a shift in knowledge ways towards a 'politics of location', demanding the recognition, and production, of necessarily situated, multiple and partial knowledge making practices. Over the years, autoethnographers sought to shift the ethnographic enterprise from nouns to verbs, from mimesis to kinesis, from textualized space to co-experienced time (Hayano, 1979, Church, 1995, Jackson and Mazzei, 2008).

The autoethnographic movement was predicated on a set of imperatives which sought to respond to the intuition that culture flows through self and vice versa (Ellis and Bochner, 2006). Rather than deny or separate the researcher from the research object, including as well the personal from the cultural and political, autoethnographers often claim to embrace methods that identify and develop personal-cultural entanglements (Adams et al., 2014). As such, autoethnography as method is seen as especially well placed to creatively recognise the 'locally and temporally situated nature of identity, fieldwork and cultural interpretation and analysis' (Short et al., 2013; 95). One strength - or indeed purpose - of autoethnography has been it's potential to deconstruct and expose as constructed rather than as foundational or essential, the binaries of self/other, individual/society, researcher/researched etc (Sparkes, 2002). In this thesis I take the binary disrupting potential of engaged, located, and personal autoethnographic work to explore lived experience of aquaponic research spaces, a method I argue that contributes a critical practice that helps contextualize the formation of aquaponic knowledge in relation to power relations, open up scientific production to multiple perspectives, and hereby foster reflection upon whose knowledge it is that defines, shapes, and names aquaponic worlds. And yet, I also want to push autoethnography, to sharpen its relevance for our contemporary moment. In the time of the Anthropocene we experience the very notion of the 'human' and 'culture' shifting beyond the typical purview of autoethnographic concern as they expand unpredictably across nature-culture divides (Braidotti, 2013, Latour, 2014a). What I pursue here is an autoethnographic practice that can function 'in the thick of' posthuman debates surrounding the complexity and interconnection of life (Franklin, 2006). As such, this thesis attempts to gather the critical intensity of an autoethnographic method and reconfigure it with a sensitivity towards a posthuman subjectivity, one that seeks to explore and do justice to the boundary shifting dimensions and heterogenous action within the Anthropocene.

4.3 The Self: exploring posthuman subjectivities and positionality

If what is at stake in autoethnographic is the 'critical interrogation of the situated nature of self along with others in cultural milieus' (Spry, 2001; 46) it follows that 'the self' often carries foundational status to the practice. Indeed, since Hayano first advocated the name 'auto-ethnography' (Hayano, 1979), a raft of related terms have been used to refer to the method "of writing and research that displays multiple layers of consciousness, connecting the personal to the cultural" (Ellis and Bochner, 2000; 733). Whether in 'narratives of the self' (Richardson, 1994), ‘self-stories’ (Denzin, 1989), ‘first-person accounts’ (Ellis, 1998a), ‘personal ethnography’ (Crawford, 1996), ‘reflexive ethnography’ (Ellis & Bochner, 1996), or ‘ethnographic memoir’ (Tedlock, 1991) subjectivist orientations to research are often celebrated by autoethnographers as an important and unique resource for their analysis (McLeod, 2011, Ellis and Adams, 2014).

Locating the ‘self’, a category so deeply prefigured in humanist discourse, overtly at the centre of research processes has meant that autoethnographic work plays dangerously close to the pitfalls of arrogant individualist research patterns (Holman Jones, 2005, Anderson, 2006). In response, autoethnographic researchers have, over some decades, pursued an image of the self that challenges humanist assumptions, arguing that subjectivism should neither be taken as a form of isolated solipsism, nor a slide into self-indulgence, rather, that subjectivist stances challenge those invisiblised movements that nourish a deeply seated research ethic the work of which situates authority within a portrayal of distanced objectivity (Short et. al. 2013). When the ‘self’ becomes the turbulent locus of political action and reflection within its cultural milieu, it is exactly the presuppositions of continuity, coherence, pattern, and unity - characteristics of classic realist ethnography, and its underlying commitment to western ideas of humanist individualism - that come under fire. Already in the 1990’s Renato Rosaldo spoke of “using the plural to speak of an observer's identities”, a position in which the researcher is “more a busy intersection through which multiple identities crisscross than a unified coherent self” (Rosaldo, 1993; 194). In this situation, the idea of a fixed, autonomous self gives way to one in which the person becomes a “polysemic site of articulation for multiple identities and voices” (Conquergood, 1991; 185). These postmodern selves become experienced as multiple and fractured rather than unitary, mobile rather than stable, porous rather than enclosed, externally constituted rather than internal or "inner" natural essences (Keller, 2007). Postmodern autoethnographers worked hard to show that “the borders bleed, as much as they contain” Conquergood (1991; 184).

The above reads as a portfolio of powerful critique of modernist ethnographic research relations, that influence my approach to ethnography and my experience of positionality within the field. However, I nevertheless perceive a certain anxiety in a subject position that dissipates too freely into a postmodern flux of dislocation and discourse. I learn from growing contributions to posthuman thought (Barad, 2003, Braidotti, 2006, Coyle, 2006, Panelli, 2010) that have found lacking the postmodern attachment to dis-enchantment, ironical patterns, and anti-foundationalist assumptions. Yes, the humanist ‘self’ of classical ethnography falls short of the current situation, however, yet I share Braidotti’s (2013; 102) point that “one needs at least *some* subject position” and that this need not be either unitary or exclusively anthropocentric, but it must be the site for political and ethical accountability, for collective imaginaries and shared aspirations. As Biehl et al. (2007b; 8) put it, with words that chime relevance in the time of the

Anthropocene: “in a ‘world in pieces’, older notions of the subject who was cultural ‘all the way down’ seem inadequate.” In this thesis I therefore anchor my ethnographic practice to a materialist and vitalist foundation. Embodied and embedded, firmly located somewhere, and according to a feminist ‘politics of location’, this thesis extends a posthuman subjectivity at the centre of an autoethnographic exploration of aquaponics in the Anthropocene.

Hayles (1999) views the posthuman as identifying our embeddedness in a complex world, one in which humans never really were in control. Sensing also, especially in these times, the value in emulating a grasp of limits and limitation, my autoethnographic practice strives to make sense of the ethical relationships articulated within the expanded field of political action. A posthuman ethics for a non-unitary subject proposes an enlarged sense of inter-connection between self and others, including non-human others, by aiming at removing the obstacle of self-centred individualism. Braun (2004: 273) suggests three sets of scholarly function become discernible in posthuman scholarship: (1) those that inquire ‘after the *figure* of the human, its fixing and bounding. It is thus another name for vigilance, for a “deconstructive responsibility”’; (2) those that name ‘the *emergence* of the human, the human as project and practice, the body as an outcome of the “infolding” of the world’; and (3) those that signal ‘*non-anthropocentrism*, for recognizing a “vital topology” that extends far beyond us, and that is not of our making alone, it is focused on displacing the hubris of humanism so as to admit others into the calculus of the world’.

A posthuman theory of the subject emerges, therefore, as an empirical project to learn of an expanded, relational self that functions within a nature-culture continuum, the expression of which can never be predetermined. Exploring a posthuman approach to autoethnographic practice this thesis attempts to acknowledge the accumulating works across human geographic research that have shown how everyday sociality amasses from a set of more-than-human encounters that are imbued with meaning, danger and ethical quality (Whatmore, 2006, Willey, 2016, Gandy and Jasper, 2017). Along with these authors I consider the need to treat ‘social life’ in the Anthropocene as an impending, unfolding and compelling question mark (Braidotti, 2013, Latour, 2014b) that requires reinvigorated research patterns and an experimentation with what counts as both self and collective in a world populated with rich more-than-human agency. Ethnographically speaking, this means confronting to some extent a material-semiotic experiment in what contemporary, bio-technologically mediated bodies are capable of doing (Fortun, 2003, Kopnina, 2017). This thesis attempts to reinscribe posthuman bodies into radical ethnographic relationality that incorporates webs of power relations at the social, psychic, ecological and micro-biological/cellular/chemo levels. Diverse, interlinked concerns such as these, operating as they do across various spatial and temporal registers, requires some key areas of ethnographic practice to be considered in detail. Below I discuss the multisited, embodied, performance centred nature of my ethnographic approach.

4.4 Multi-sited ethnography

Following Tsing (1993), Law (1994), Latour (1996) and others, and in contrast with the more traditional ethnographic accounts, this thesis starts from an ontological position which sees structures and cultures as produced in practices (see chapter 3). Establishing particular connections between practices and sites, this thesis produces a multiply-situated account of aquaponic production. Taking a multi-sited ethnographic approach allows me to explore the world(s) of aquaponics from within specific nodes in the network(s) of aquaponic research. Starting with the embodied, affective and ethical world of practice, I have followed aquaponics with an eagerness to explore where the lines of tension and the sites of power lie. As such, this thesis does not attempt an exhaustive examination of aquaponics in Europe; rather, it offers a particularly situated account that attempts to stay with the trouble of what it means to research across different spatial limits within a dynamic, often conflicted, and variously contested field of aquaponic interest.

In 2015, when this study began, aquaponics research was in a nascent stage, being on the periphery of agronomic and aquacultural research departments in a handful of institutes scattered across Europe. On a purely practical level of access, the recently founded 'COST Action FA1305: *Realising Sustainable Integrated Fish and Vegetable Production for the EU' presented as an excellent opportunity for me to get engaged with an emerging aquaponic field.* COST is an EU-funded programme that enables researchers to set up interdisciplinary research networks within Europe and beyond at targeted research aims. First introduced in 1971, COST is based on a European intergovernmental framework for cooperation in science and technology. Its mission is in 'closing the gap between science, policy makers and society throughout Europe'. COST provides funds for organising conferences, meetings, training schools, short scientific exchanges or other networking activities across a spectrum of scientific fields.

On 14th May 2015 I joined the COST Action FA1305. A heterogeneous network of scientists, researchers and SMEs from across the EU and around the globe, the mission of COST Action FA1305 was 'to better understand the state of knowledge in aquaponics in Europe and to facilitate innovation and education in this field of sustainable fish and vegetal food production'. COST Action FA1305 was my gateway into a pan-European aquaponic research community. My participation in the COST Action FA1305 extended to 1 summer school, 3 annual conferences, 6 working group meetings, but beyond this, the networking potential alone meant the COST FA1305 became a central contact point between myself and the worlds of aquaponics. A week-long summer school at the University of Ljubljana became an important first step in building knowledge of aquaponics, gaining hands on experience, and networking with researchers within the COST Action. From here I snowballed as many contacts a possible and got myself into the aquaponic network.

Following aquaponics across Europe I visited research facilities, lab spaces, start-up enterprises, and community projects. There are 6 principle sites for this research. Three of these sites had aquaponic systems: an aquaponic research facility [PAFF box, Agrobiogtech facility, Gembloux Belgium], a commercial aquaponic farm (Grow Bristol, Bristol UK) and a community supported aquaponic project (Bristol fish project, Bristol UK). The other three principle sites were conference spaces that held aquaponic research conferences: Ljubljana (University of Ljubljana, Slovenia), Dubrovnik (Valamar Lacroma and President Hotels, Dubrovnik, Croatia) and Murcia (University of Murcia, Spain). Additionally, there were 13 subsidiary sites that included 6 research spaces (University of Ljubljana, Slovenia; Experimental Aquaponic Unit, Biotechnical centre Naklo, Slovenia; Murcia Oceanographic Centre; Tilamur INAPRO Project demonstration aquaponics facility, Spain; Provincial Centre for Applied Research on Vegetables East Vlaanderen, Belgium; ZHAW [Zürich University of Applied Sciences], Switzerland) and a further 7 commercial aquaponic farms (Grow up rooftop farm, UK; Grow up aquaponic farm, UK; Bioaquafarm, UK; Aqua4C fish farm, Ghent, Belgium; Ponod aquaponic farm, Slovenia; Ponika, Slovenia; and Urban Farmers, The Hague).

The sites of my research differed in important ways in terms of access, duration of stay, and exact research methods employed. The three principle research sites with aquaponic systems (PAFF Box, Grow Bristol, and Bristol fish project) involved extended periods of contact and involvement in-situ that lasted months, whereas the three conferences each lasted four days. The 13 subsidiary sites were often one-day or half-day visits to aquaponic facilities. A key difference between sites was whether or not I was paid to be there. My work at the PAFF box site was conducted whilst formally being contracted to do work there. My engagement at the other principle sites (Grow Bristol, Bristol fish project and three conferences), and all of the subsidiary sites was on an entirely voluntary basis.

4.4.1 PAFF Box STSM

A central concern of every COST Action is the facilitation of productive networks of researchers, institutions, and businesses. One way of achieving this for researchers is to fund ‘Short term scientific missions’ (STSM). STSMs facilitate the exchange of scientists between institutions or laboratories from different countries in the EU. They are designed to allow scientists to 'foster collaboration, learn a new technique, or to take measurements using instruments and/or methods not available in their own institution/laboratory'. In May 2015 an aquaponic research team at Gembloux Agro-Bio Tech, headed by Prof. Haissam Jijakli, advertised a funded 'Short term scientific mission' (STSM) through the COST Action FA1305 'EU Aquaponics Hub', titled: 'Plant production capacity and nutrient mass balance in the PAFF Box, an urban aquaponic module' My application for the advertised position was shortlisted, and I was selected for interview on Friday 22nd May 2015 via skype. News of my successful application was received by 2 June 2015, and preparation began for the STSM with the start date set to 24th July 2015. For a ten week period (24th July – 2nd Oct) I worked in collaboration with a team of researchers in the Gembloux Agro-Bio Tech running an experiment on their aquaponic prototype. Importantly, I was hired as a scientist to help run the experiment - I discuss the ethnographic dynamics of being 'hired in' (Downy and Dumit, 1997) in greater detail in chapter 5 (see 5.3 'Experimental positioning'). Under the guidance of Prof. Haissam Jijakli and Dr Boris Delaide, an in-depth experiment was conducted focussing on the management of plant production and nutrient levels in the PAFF Box aquaponic system. The PAFF box STSM was an intensive 10-week experience of aquaponic research, the result of this work is an ethnography that can be found in chapter 5.

4.4.2 Bristol projects

I began meeting with the *Bristol fish project* in late October 2015 after I had returned from the STSM in Gembloux. Over four months I went to fortnightly meetings helping with the planning of the project wherever I could. Much of my work at the Bristol Fish Project was voluntary labour – I travelled to Bristol each week helping to bang nails and rip walls from their newly acquired premises in preparation for the instalment of their aquaponic system. I was also a volunteer at the aquaponic start-up, *Bristol Grow*, though my engagement was far more focused around the aquaponic system. I helped them install their aquaponic system and travelled to Bristol once a week for 5 months to help with the running of their enterprise – I offered technical advice regarding system health and function, tilapia rearing, microgreen germination, but also organised and ran public talks, met with clients, attended outreach events. Through my engagement with these two aquaponic enterprises in Bristol, I travelled with them through the difficulties of trying to get an aquaponic systems funded and off the ground. This gave me crucial insight into the trials of aquaponic enterprises outside the funded research circuits. A discussion of the Bristol projects can be found in chapter 6.

4.4.3 COST Conferences and Working Group Meetings

COST Action FA1305 organised an annual conference each year. These provided a unique opportunity to embed myself within networks of researchers, practitioners, business owners, and other stakeholders of the field, hear the cutting edge of aquaponic research across Europe, and also present selections of my work. FA1305 Conferences were open to the public, NGOs, and other sectors, though audiences were dominated by scientific researchers most of which were based in Universities.

In addition to providing and facilitating a space for the traditional delivery and presentation of aquaponic work being conducted around Europe that was of particular research interest, the conferences of FA1305 were structured around four working groups (WG). COST Actions are required to achieve particular outcomes. These are related to research, publications, interfacing with SME's, public outreach etc. To these ends, the WGs allowed groups of researchers' time to collaborate on focussed topics that had been identified as important for aquaponic science in the EU. The WG's were informal spaces for sharing ideas, striking collaboration, determining research goals, and reporting back to colleagues about achievements, opportunities, and challenges. I participated in WG's 1 and 2. The remit of WG1 was 'to review EU policies, legislation and certification relating to aquaculture and hydroponics, with particular reference to topics such as environmental standards, food safety, water quality, food ethics and standards, and the sustainability credentials of combined fish and vegetal production'. The remit of WG2 was 'to review the science behind aquaponics in order to define best practice and to promote new developments'. Output areas included: systems design; water quality; fish feed; ammonia/nitrate conversion; and elucidating best veg and fish products for the EU and developing countries. A discussion of my participation in the conferences can be found in chapter 6, as described there, my engagement within the WG facilitated in large part an extended collaboration that resulted my final findings chapter 7.

4.4.4 Data collection

At three of the principle sites with aquaponic systems (PAFF Box; Grow Bristol; Bristol fish project) I conducted interviews with all the principal and most temporary workers of the systems, experiments, and projects. I placed focus upon the practical and ethical roots and consequences of their aquaponic activities, giving time for their thoughts on what attracted them to aquaponics, what aquaponics was capable of, and what the future held for their budding field. I employed semi-structured interviews where I felt they were most appropriate (often with high ranking staff members). These more formal encounters were often conducted in office spaces separate from the systems, but always informed by the discourses gleaned during the performance of everyday activities at aquaponic research sites. I tried to get at the reasoning behind the aquaponic worlds they were spearheading - the philosophy, the assumptions, and expectations. Further to this, with those personnel who worked on the systems often, and following the ideas of Hitchings (2003), I conducted 'walk through' interviews within the confines of the aquaponic systems, hoping that this could capture some of the vital relationship between scientist/researcher/technician and system, or at the very least spark some inspiration that an interview in the office couldn't. As such, much of the data informing this thesis was collected as vocalised statements. I used a compact voice recorder for the semi structured interviews, but also on a daily basis for everyday conversation with my informants. There were some moments where electrical devices were not appropriate. Aquaponic systems are semi aquatic environments - fish can be splashing, water can be leaking, solid waste can contaminate. In the heat of the moment, I would often prefer to leave the voice recorder behind, and write notes after the incident, or when things were calmer.

I wrote an ethnographic diary each day for the duration of time spent at my principle field sites. I found Evernote a useful tool to take notes, photographs, and capture my own moments of insight on the go. Often, I would flesh these out at the end of the day, writing longer diary pieces usually on the train home from the sites. Latour has suggested how a symmetrical engagement with human and non-human objects necessitates particular types of note taking. During my own research I tried to utilise his 'list of notebooks' metaphor as guidance for my data collection (Latour, 2005), which entailed three particular styles: 1) A 'log' of the duration of the ethnography that chronologically sets points of reference of things that happen in the field. Times of meetings, surprises, events etc; 2) A documentation of my thoughts *about* the experiences I encounter - A 'notebook' for "Ideas, paragraphs, metaphors, and tropes that might come haphazardly during the course of the study"; 3) A way to rearrange notes into categories that do not run chronologically, so that trends can be assessed (Latour, 2005; 134).

While the bulk of my time was spent at the 6 principle sites, I also visited 13 additional subsidiary sites. Many of the subsidiary sites were suggested to me as sites of potential interest by those research participants at the principle sites. Most were typically pre-arranged one-day visits during which I interviewed researchers and company owners, aquaponic technicians as well as students, volunteers and office staff, depending on availability. A handful of sites (Grow up aquaponic farm, UK; Aqua4C fish farm Ghent, Belgium; Urban Farmers, The Hague) declined interviews and didn't want me taking notes or pictures on the premises due to worries about the sensitivity of their industry innovations that they claimed were difficult to patent though easy to adopt. While my in-situ positioning at the principle sites offered an opportunity to work with the materials, creatures and people of aquaponics (see below), during the day visits to subsidiary sites this embodied engagement was not really possible. However, embodied engagement is just one way of ‘getting close’ to non-human action. By focusing in my interviews on the points of contestation, difficulty, or frustration that research teams and start-ups were facing from the non-humans they worked with, I was able to collect rich stories of how aquaponics might be seen as a more contested site of action than might be given in official publications, presentations and other outputs of aquaponic enterprises. By asking questions such as: have you had any system crashes? What problems are you facing at the moment? What is the future of aquaponics? How do your practices differ from other farms/research institutes? I was able to gain information about the practical and ethical dimensions of doing aquaponic work, as well as the aspirations and desires of different communities. Insights like these, gained at subsidiary sites where I had relatively shallow or no integration embodied integration, nevertheless contributed to my becoming aquaponic by continuously relating back to ideas, methods, practices at the principle sites. Logistically, multiplying locations facilitated serendipitous engagement on the one hand, while on the other allowed me insights into the differences and similarities in the mundane practices between locations. While not all subsidiary sites make it to the final text of the thesis, they all contributed to a deep understanding of the workings of aquaponic research and enterprise across Europe.

Working with the technicians, scientists, researchers, entrepreneurs, community activists in the spaces of aquaponics allowed me to collect a wealth of stories. These stories did not just provide a depth of intersecting aquaponic meaning, but conveyed a lot about the embodied realities of practitioners learning to ‘deal with’ the unruly agency of aquaponic ecologies on a daily basis. Working on aquaponic systems, contributing to research practices and community projects allowed me to learn from my participants, who, it seemed, were constantly engaged in processes of questioning regarding their actions, whether this was in reference to the ‘power’ of the emergent material phenomena, the anxieties and stress of high energy start-up work, the frustration of legislative red-tape for community projects, or the plethora of other factors that might contribute to the success or failure of aquaponic realities. In tracing these networks I was guided somewhat by my participants as they told me hot underground aquaponic gossip of what was happening where (or not), their latest theory filling the black boxes of our understanding of microbacterial action, or the whereabouts and systems that were making big strides (or big money) in the field. By telling me stories of particular materials/experiences/desires/fears my participants directed my attention in particular ways. As such, employing participants as ethnographers of events that make up their own lives (Mol 2002) facilitated my contact with the ‘heterogeneous action’ of aquaponics across Europe. To some degree then, my participants became co-producers of this multi-sited ethnography.

4.5 Praxiography, the body and intimacy

In auto ethnographic practice, as the "many facets of self and other engage, interrogate, and embrace", the effect of this process is often described as a 'blurring' - of distinctions between personal and social, self and other (Spry, 2001; 708). Within these boundary blurring moments, the starting point for generalizations and theorizations about the cultural, the social, and the political becomes the 'autoreflective perceptions of the world' (Lancaster, 2010; 29). It is here, that 'the body' surfaces in ethnographic analysis as an important heuristic to (more-than-) social processes. The body - my body - becomes a methodological cornerstone in this thesis, a nexus through which ontological and epistemological questions flow. Opening up my body to the situations, atmospheres, demands of aquaponic systems and research spaces became a way to develop a 'sense' of the aquaponic worlds in which I became invested. Along these lines, methodological approaches explored by non-representational theory (Anderson and Harrison, 2010, Vannini, 2015) have developed explicit ways of employing the researcher's own body as a tool for the acquisition of situated understanding. Yet, in spite of a host of embodied approaches appearing in the literature, there is still a lack of work that considers the role of embodiment in the work environment, and, further, which employ the mindbody of the researcher as a self-reflexive apprentice-in-training.

Understanding aquaponic practices as the locale of meaningful gatherings of human and nonhuman bodies required an active engagement on my behalf with the practice: 'Participation in a practice allows learning the implicit knowledge that underpins a practice' (Bueger, 2014; 36). In this thesis, such a task meant learning alongside aquaponic practitioners, often 'on the job' or by shadowing. A whole plethora of information ways – laboratory protocol, safety, and standards; aquaponic terminology and theory; mechanical 'systems thinking'; water chemistry analysis; fish husbandry; microbiological care; horticultural practices - intersect in the organisation of aquaponic research. Learning and putting to task these knowledges in functioning, professional research environments meant learning how the mindbody of a human practitioner must respond to, engage with, and work with the entities operating in aquaponic systems. This embodied engagement with aquaponic systems was crucial in forming my understanding of the practices of aquaponic research, especially when it allowed, or obliged, comparison with my colleagues. Hayles (1999; 196), for instance, stresses that embodiment should not be seen as an employment of a 'generic' human body, but as a 'specific instantiation generated from the noise of difference'. As such, I was able to view my own experiences of aquaponic work as situated and particular, while also comparing them to those of others and drawing theoretical conclusions about the importance of 'a' body's capacities and limitations in practice-acquisition and performance.

Documenting my body's movements and investments became a way to learn how more-than-human practice played out in the performance of experimental aquaponic ecosystems. As bodies become grounded in actual worlds, or "deeply sited' (Mascia-Lees, 2011; 2), it becomes impossible to theorize or generalize about embodiment without mining rich ethnographic details and writing vivid descriptions about everyday realities. A central purpose of my ethnographic diary was to document the dynamic and shifting terrain of embodied integration within the aquaponic systems I worked with. Documenting how human and non-human actants combine to make aquaponic systems work, my research became a study of *practice*. Bueger (2014; 27) states that methods which describe practices involve following combinations of "(1) forms of bodily and mental activities, (2) artefacts or 'things' and their use, and (3) a background, implicit or tacit knowledge which organizes the practice and gives meaning to it." An ethnography of practice, or 'praxiography' (Mol, 2003), would aim at reconstructing the meaning of these elements and their interplay (Bueger, 2014). The foundation of my study of practice was performance centred research activity. As opposed to top-down (theory-driven) methods, attention was given to emergent capabilities, practical skills, and other kinds of research resources (e.g. identity positions, theoretical sensitivities, data, materials, senses) – all of which become inflected and enhanced with autoethnographic recourse to reflexivity, a necessity for this style of analytical and investigative work (Henwood et al., 2019).

During this process I became all too aware of the difficulties in textual representation of the senses, as well as slippery non-human others (Serres, 2008, Anderson and Harrison, 2010, Law and Lien, 2013). A mixed-methods approach helped to promote understanding of the multi-dimensionality of aquaponic worlds as simultaneously visual, sensual, material and intangible (Mason, 2006). I therefore expanded Latour's 'notebooks' methodology so that it encompassed a number of data collection avenues beyond writing alone. I took photographs, videos, and sound recordings of anything I felt could document particularities about how the aquaponic systems were 'done', including bodies, movements, artefacts, and processes. This 'Multimodal' approach to research more readily recognises the range of ways in which more-than-human relations are made and unmade in non-verbal ways, encompassing embodied, tactile and object-focused modes of interaction (Henwood et al., 2019). The Evernote app proved a useful software to store and organise this mixed media ethnographic diary ready for analysis.

In my own practice I took the process of embodying research as a call to attend in the most deep and abiding way to an ethnographic encounter with aquaponic Otherness that demanded my entire body, where bodily attending meant living a shared time and space in the feeling and sensing contact of flesh to flesh, molecule to sensor, cotemporality of my aquaponic research spaces (Conquergood, 2002). Put bluntly, I got soaked on a daily basis, I reconfigured oxygen pumps, cleaned solids filters, backwashed biofilters. I left work at the end of the day smelling of fish. More than simply heavy labour, however, Evelyn Fox Keller (1984; 57) has shown how doing scientific research is partly about establishing an absorptive, sensitive attachment to the materials of enquiry, what Barbara McClintock called 'a feeling for an organism'. As such, I trained my eye for the traces left by caterpillars; for just how pink an ammonia test can be before your blood pressure rises in emergency; and the difference between 'hungry splashes' and 'bad splashes' when watching the movements and expressions of Tilapia. I even learned to fear the smell of hydrogen sulphide - my own body sensing the changing complexion of microbiological bodies in the aquaponic systems I worked on. The unpredictability of aquaponic ecologies poses a constant challenge to the researcher anxious to be part of the action, and a far greater part of the research process than I originally expected required an intuition of unfolding events of which I was part.

These somatic, living-breathing, encounters of entanglement within the everyday processes of technoscience describe a knowledge-making *intimacy* (Latimer and López Gómez, 2019). As Candea (2013) has shown, along with others (Despret, 2013, Haraway, 2016), intimacy in scientific settings involves more-than-human actors becoming attached, but most importantly mutually transformed. Indeed, at some point in the research process after working intensely with PAFF Box aquaponic system, I realised that my own experience of my senses, affect, and desire, had altered, as too had my approach to aquaponic research in general. For Raffles (2019), paying attention to the intimate is a way to make visible what is rendered invisible in science and technology – the work of the delegates of science, technicians, lab animals, and all sorts of 'domesticated' inscriptions whose labour is so often attributed to the central figure of the scientist/author/thinker. As such, by placing affect and intimacy at the centre of methodological devices, the 'neutrality' of science is challenged. For López Gómez, (2019), when the violence that these enrolments imply becomes perceptible, the researcher becomes impelled to respond – something I confronted as my research process integrated me within the logics of aquaponic realities and I became attuned to the ethicopolitical contours of the field. Where proliferating relations of trust and co-becoming in my experimental settings became stretched and heightened, the possibility of intervention (Gjefsen and Fisher, 2014, Martin, 2016, Zuiderent-Jerak, 2016) arose within the research process. As these instances play out (chapter 5) this experience becomes that of an autoethnographic ethic that does seek to artificially separate politics from research.

In that methods participate in a question of the possible, the production of methods becomes something of a speculative endeavour. For Maria Puig de la Bellacassa (2016; 17), the 'speculative' in research refers to "a mode of thought committed to foster visions of other worlds possible". Her work shows clearly how speculative commitments can connect scholarly activity to a feminist tradition, one that looked to spaces of possibility within research processes as an opportunity and imperative about “provoking political and ethical imagination in the present” (Puig de la Bellacassa (2016; 7). Speculative practice becomes as much about apprehending difference as it is about making a difference (Asdal et al., 2007, Zuiderent-Jerak, 2016), or, as Puig de la Bellacasa (2016; 110) would put it, “speculative thinking as involved intervention” becomes the format for material-semiotic method in my own work. There is an ethics of knowing which is fragile but crucial for ensuring that questions are made relevant not only to scientists but also to the objects of aquaponic enquiry, be they Tilapia, microbes, or aqueous forms of Ammonia. I discuss these moments in depth in chapter 5. As such, rather than see my affective investment as a source of bias or error, I attempt to present it as integral methodological move towards honing a political (posthuman) subjectivity, one that I needed to carry into later aquaponic projects and the developing questions of this thesis.

4.6 Analysis and writing

Aquaponic research is a domain dominated by science. The technical language of aquaponics is English, and the vast majority of publications follow suit. To some extent this mitigated the difficulties of translation work, as in all cases, my informants were comfortable and confident to carry out interviews in English. With the exception of some late in the day conference interviews conducted on the fly, I transcribed all of the verbal interview material myself while still in the field. I did not transcribe personal verbal notes made by myself, but rather extracted the most important things and adding quotes and summaries to the diary entries of the appropriate day. Transcription ‘in the field’ inevitably brought with it analytical reflection, which I included as part of my research diary.

The ethnographic work of primary aquaponic sites (PAFF Box; Bristol fish project; Grow Bristol) as well as those taken at the three international aquaponic conferences produced a considerable mass of mixed notes, pictures, videos, sound clips and interviews. I initially re-read, re-watched, and re-listened to all the data I had gathered inputting the textual data into Nvivo software and adding descriptive codes regarding the typical ‘who, what, where, when, how’ format (Cope, 2010). During a second-round of re-reading, I grouped the data using Nvivo into large meta-documents organised by analytic codes according to what was being discussed, worked with, or experienced. This process produced collections of digital folders that focussed on: technical dimensions (controversies, contestation and competing theories; scientific limits; technological potential); aquaponic horizons (ambitions; desires; fears); More-than-human ethnography (Human-plant, human-Fish, human-bacteria relations; chemo-ethnography); ethico-political dimensions (intervention; care; flourishing; exclusion); Anthropocene (materiality; circular economies; limits to growth). Having grouped my ethnographic material in this way, I then read 'across' these documents, coding patterns and identifying common themes that spoke to the theoretical concerns of my project (Crang, 2005).

Rather than imagining that analysis of my ethnographic data was something that would begin after the coding had finished, I followed Cope (2010), in recognizing that the coding *was* the analysis. Coding in this project was for me a recursive process of back-and-forth movement, of starting with initial codes that came from research questions, background literature and categories inherent to the project and then progressing through codes that are more interpretive as patterns, relationships, and differences arose. After lengthy cycles of reading and discovering ever more relations in my data I realised that the coding would probably never truly be 'finished'. One thing was certain however, after the depth of my experience with the PAFF Box and the richness of the data that flowed from it, I knew that I needed to write a longer text that could get at the textures of Gembloux and the aquaponic research being carried out in the PAFF box, particularly with respect to my place within the experiment. And so, the process of writing began.

Holman Jones, (2005; 764) get to the point when they state that autoethnography writes "a world in a state of flux and movement between story and context, writer and reader, crisis and denouncement, it creates charged moments of clarity, connection, and change" (Holman Jones, 2005). This exciting image is exactly what I strived for in Chapter 5. Regardless of the result, the actual process was one characterised by slow anguish, impossible frustration, and the odd moment of crystal-clear eureka. The task: to "confront the impossibility of representing lived experience by troubling the link between life and text" appeared to me, on the most part, a hugely daunting task that sucked in, in one way or the other, the entire research project (Holman Jones, 2005; 766). Clifford Geertz (2000: 221) once wrote that "In a splintered world, we must address the splinters", and my own writing process began to mirror, acknowledge, even accelerate a posthuman, dispersed, none linear style of inquiry into aquaponics. In my writing sessions, I learned to follow the advice of Adams et al. (2014; 71), exploring how to "create textual structures that purposefully delay the possibility of creating a storyline or a clear conclusion." Looking over my notes, I learned to feel out which experience/entity/discussion called me to write. I would then focus my writing sessions on generating the beginnings of multiple stories and storylines, avoiding attachment to any one idea or character or scene so that I could "let the story that wants to be told unfold throughout the writing process." (Adams et al., 2014; 71). Autoethnographic texts "are not just subjective accounts of experience," writes Spry (2001; 727), "they attempt to reflexively map multiple discourses that occur in a given social space". In Chapter 5 I attempt to weave together the contrasting discourses, scales, temporalities, and textures of the aquaponic world in Gembloux, striving for a style of storytelling inspired by

Hannah Arendt's insight: that storytelling might be seen as an activity which "'reveals' meaning without committing the error of defining it" (Arendt 1973, 107).

Chapter 7 presents a second style of writing. Borne out of a collaboration with aquaponic researchers later in my PhD journey, this chapter is a piece written for a aquaponic book that stands as one of the main outputs of COST Action FA1305 (see chapter 6.3 for a thorough introduction). The piece follows the editor's expectations, as well as formatting guidelines provided by Springer's publishing brief, to create a chapter for a book 'written by world experts' that 'provides an authoritative and comprehensive overview' of aquaponics. Although deploying a style of scientific prose, the chapter nevertheless builds upon the autoethnographic development of this thesis. By foregrounding personal experience in research and writing; illustrating sense-making processes; using and explicating reflexivity; illustrating insider knowledge of cultural phenomenon/experiences; describing and critiquing cultural norms, experiences, and practices; and seeking response from (mostly aquaponic) audiences, Chapter 7 of this thesis deploys six key features that Adams et al (2014) have shown to be the characteristics of autoethnographic writing. By smuggling in key features of autoethnographic writing into a scientific format, and in doing so, refitting reflexive and emotive argumentation for a scientific readership, the piece is an experiment in narrative form that attempts to address - and challenge - both aquaponic scholarship and MTH geographic scholarship as well as contribute to the increasing questions being asked with the advent of the Anthropocene regarding the possibility of an epistemic shift in the sciences towards "alternate world-making devices, such as narration and storytelling" (Davis and Turpin, 2015; 43).

4.7 Conclusion

This chapter has outlined the methodological tools I employed in this research project, highlighting the importance of long-term and embodied approaches in gathering data about heterogeneous action within the field of aquaponic research. Taking the ontological position that views aquaponic knowledge making practices as more-than-human achievements, led me as a researcher to focus on using participant observation and interview methods, together with an autoethnographic commitment to learning through embodied performance about the way aquaponic research is done, and the kinds of more-than-human relations it entails. Such a methodology enabled me to identify key 'things' that come to matter on a practical, ethico-political and material-semiotic level, within the worlds of aquaponics, and compelled me as a researcher to speculate, within situated and collaboratory practice, on the potential aquaponics has for intervention within the Anthropocene.

Chapter 5: **The PAFF Box: an ethnography of aquaponics and intervention in Gembloux, Belgium**

5.1 Gembloux and TERRA

University of Liege's integrated and urban plant pathology laboratory is located in their Agro-bio-tech facility in the small provincial town of Gembloux, 50km south of Brussels. It's a place with a rich history of agricultural innovation, being the site of the original State Agricultural Institute set up by the Belgian government in 1860 (Diser, 2012). Historic orchards of gnarly apple and pear trees sit beside plantations of banana tree clad in shining glass – amongst many other things, the plant pathology laboratory is the official virus diagnostic laboratory for the largest germplasm collection of banana held by Bioversity International. Once a small laboratory outpost on the edges of Belgium's agricultural heartland, the place now facilitates 585 agronomic and biotechnological research projects spanning five continents (Delvigne, 2018), connecting Gembloux to the dynamic and endangered ecologies of our quickly changing Earth.

During my time in Gembloux, the narrow main road of this quiet town was backed-up with slow moving trucks carrying huge steel girders. Underway was the construction of the Agro-bio-tech's new €21million development: TERRA. TERRA is set to be one of Europe's premier bioengineering research facilities, its 7,400 m^2 of research space will host over 200 researchers and contain some of most advanced food-system experimentation equipment available (Moreau, 2018). According to the developers, all themes in TERRA will be 'cross-cutting and interdisciplinary' having a focus on stimulating 'interfaculty collective knowledge' (Jacques, 2018). To this extent, research will be organised not around 'faculties', but rather '*CAREs*'[16]. The four CAREs in TERRA are named 'Agriculture is life'; 'Environment is life'; 'Food is life'; 'Forest is life', evoking the way in which life, our lives, are dependent upon and deeply interlinked with the various ecologies of the earth.

The centrepiece of the TERRA development will be the unique next generation laboratory called the 'Ecotron', which for the first time will make it possible to model the effects of climate change on room-sized snippets of living agro-ecosystems. Professor Philippe Jacques, manager of the TERRA Project states: "we'll be able to study an ecosystem in its entirety, that is, a growing plant,

[16] The CARE acronym is pulled from the French: "Cellules d'Appui à la Recherche et à l'Enseignement" or 'Research and Teaching Support Units' in English.

in connection with the ground, the roots, the microorganisms in the ground and maybe even insects, in perfectly controlled conditions in terms of temperature and pluviometry" (Jacques, 2016). The microcosm experiments of the Ecotron will be combined both with *in situ* field data generated from intermediate test plots, and with 'ICOS', a network of terrestrial atmospheric observatories that span Europe. This nested data collecting apparatus forms an ambitious multiscalar approach to agroecosystems that according to the developers will allow researchers to "simulate and anticipate the impact of climate change on crops over the next 20 to 30 years" (Jacques, 2016). For Prof. Jacques TERRA represents no less than "a collection of tools enabling the development of the agriculture of tomorrow" (Moreau, 2018). Reading these blueprints (marketing), TERRA might be seen as an institutional response to the less than certain landscapes of agro-scientific knowledge production in the Anthropocene.

I introduce TERRA at the beginning of this ethnography to give a sense of the atmosphere at the Agro-bio-tech in Gembloux. A place where questions of ecology and future ecologies are put to the test. Where multispecies experiments register as accomplishments or failures. A nexus of activity, fuelled as much by promise as by peril (Paxson and Helmreich, 2014), in which diverse biological collectives and processes are folded into networks of institutional, infrastructural, economic, and discursive circuits. What follows is an ethnography of my incorporation into this Agro-bio-tech, into a very particular ecology, the aquaponic system known as the PAFF box.

5.2 The start.

Somewhere between the grinding construction site of 'TERRA' and the mature experimental orchards of Gembloux's historic agricultural research post is the Agrobiotech's prototype aquaponic system called the 'PAFF Box' (short for 'Plant and Fish Food'). Viewed from the outside, the PAFF Box is a curious structure that consists of an insulated steel shipping container with a greenhouse integrated on top. Fish and bacteria live in the container. Plants grow up top. "The idea was to have a system able to produce food for an urban community… you could produce fish and vegetables for families and at the same time create a link between them as they take care of the system" Explains Prof. Haissam Jijakli, head of the urban an integrated plant pathology laboratory. Formally trained in microbiology and plant pathology at the University of Liege, Prof Jijakli was working for a private company in Rotterdam developing Biopesticides when he became inspired by urban agriculture projects popping up in the Dutch city. He returned to the University of Liege with a passion to work on urban agriculture, spearheading the aquaponics projects in Gembloux.

The Agribiotech is a place with its finger on the pulse of urban and peri-urban agriculture initiatives that are growing across Europe. Prof. Jijakli and his team believe that Aquaponics could be part of this movement that increasingly recognises urban agriculture as a means by which cities might move away from current inequitable and resource-dependent food systems, reduce their ecological footprint and increase their liveability. As Prof. Jijakli explains, inspiration for the PAFF Box flowed from the growing awareness of the need to find pragmatic growing solutions for our increasingly pressured urban environments. “[The PAFF Box] takes the space of two parked cars… it can be located in a small place, production can be intensive, and as it is an ecosystem you might be able to produce food with less negative impact on the environment.”

“We used a shipping container because we wanted to recycle it” explains Prof. Haissam Jijakli. Indeed, a good proportion of the prototype was built from reclaimed and recycled materials. But the shrewd application of resources in this aquaponic system are not solely down to an elegant eye that finds potential in what others deem waste. The reality is that a down-to-earth attitude towards reuse is necessitated by restricted flows of that most powerful resource: money. Without clear access into more generously funded areas of bioscience research, the whole aquaponic enterprise in Gembloux runs off a collection of humble research budgets brought together to support four aquaponic researchers. “With the money that we have, how can we make a difference?” Prof. Jijakli rhetorically asks me.

The whole occupies a total space of 71.21 m^3. Despite sharing a site entrance and an institutional ancestor - the Agro-bio-tech of the University of Liege – the PAFF box and TERRA, it seems, are worlds apart. Spatially, economically, and discursively, the PAFF Box, like Aquaponics, is on the periphery of ‘big science’, dwarfed by the sociomaterial assemblages that propagate mainstream agricultural research. To some degree, this is what brought me to Gembloux.

Science studies is a discipline whose field, both intellectual and locational, is defined by its scientific object of study (Biagioli, 1999). Whatever authority science studies may wish to claim is usually contingent upon a historically predefined subject matter that is rooted in financially and influentially powerful scientific institutions (Greenhough, 2006). Geographers, no less than any other, run the risk of (re)producing spatial narratives that ‘are constitutive of (and constituted by) the scientific facts they are about’ (Biagioli, 1996; 190). The state of current research programs and funding climates, which pull attention and envelope research in headline innovations and ‘high technology’ have at least some seasoned scholars of science questioning[17] the ‘institutional

[17] Downy and Dummit (1997; 10) ask: “Why have we granted disproportionate interest to the "High Technology," high-profile areas of biotechnology, genetics, physics, information technologies, and specialized medicine over and against such less visible areas as routine health care, water supply, agriculture, electrical power, and engineering?”. By doing so, they revisit Edwards Said’s (1989) question of

conditions of possibility for STS'. As we *follow* science so closely (financially, institutionally, spatially) some are asking just where are we following it to? (Winner, 1993, Arboleda, 2016, Bijker, 2017). Are we "so absorbed that there is no critical space left?" (Moser, 2007; 344); "would it also make sense for STS scholars to analyse roads not considered, projects not begun, methods ignored or dismissed out of hand, and technologies not explored systematically?" (Zuiderent-Jerak, 2016).

Greenhouses and shipping containers might be some of the most mundane features of the Northern Belgian landscape but bring them together in the unlikely composition of the PAFF box and it surprises the eye. But beyond the surface of appearances, Prof. Jijakli and his team are asking what other surprises might this prototype be capable of. How might food systems be rethought – reconfigured – towards the pressing urgency of food sustainability, sovereignty and waste? The PAFF box is an experiment in how the power of *ecosystems* might offer answers to these questions. There is no denying this is a speculative endeavour when Prof. Jijakli states that since the Paff box "is an ecosystem you might be able to produce food with less negative impact on the environment". There is a big unknown contained in that '*might be able to',* and getting to the bottom of this question, as we'll find, was the crux behind the experimental set up of the PAFF box system.

I followed aquaponics to Gembloux, to the edge of mainstream agriscience, because these questions motivated me. But I also brought my own questions to the lab, asking, what potential is there for new spaces of alternative social and ecological action and for material experimentation? (Papadopoulos, 2015). Following aquaponics to the PAFF Box in Gembloux then, I hoped might lead me to worlds of science less studied, to sociomaterial milieus less experienced, to questions less asked. To give ethico-political significance to ecologies of scientific practice on the periphery; I follow here Maria de la Bellacasa's (2011) inspiration of 'assembling neglected things', a commitment to care for marginalized or neglected issues. What is to be learned from the engagements of aquaponics in Gembloux? What is to be experienced, risked, achieved, inhabiting and co-constituting novel aquaponic ecologies? And to follow Goldstein and Johnson's (2014; 17) questioning: "What can (re)productive, technologically mediated metabolisms of life look like? How can we imagine a form of production that can both reproduce desirable lives and unmake the infrastructure of our ecologically catastrophic social formation? What forms of knowing – both embodied and immaterial – do we want to mobilize in our ongoing processes of world-making?" (Goldstein and Johnson, 2014).

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how, and in which ways, do our own directions of study participate in the reproduction of concentrated centres of cultural and capitalist authority at the expense of alternate subject areas and modes of inquiry.

5.3 Experimental positioning.

Getting off the commuter train from Brussels I arrived at Gembloux's Agribiotech with warm handshakes as a researcher for Prof. Haissam Jijakli. Together with his small team of researchers, Prof. Jijakli has been working on the PAFF Box since 2013. I was the newest addition to the team. A successful interview had secured me a place in the aquaponic research in Gembloux. I had been 'hired in' to use Downy and Dumit's (1997) phrase. Institutional arrangements, facilitated through COST action FA1305, had tied me formally to the experimental procedures that would happen in the PAFF Box, and I didn't quite know what that meant yet. What was more certain was that I had been plugged into research funding circuits that ran back to the EU's capital. As sure as the commuter train, which transported me from Brussels to Gembloux each morning, a drip feed of virtual instalments would be sent to my bank account to reimburse my labour. This fact alone made me one of the most privileged inhabitants of the plant pathology laboratory.

I was entering into an extended experiment that had been running intermittently for over two years. The objective was simple, over the course of a complete two-and-a-half month growing cycle the micro- and macro-nutrient content of each component of the aquaponic system would be collected, as well as a whole range of other system parameters (temperature, dissolved Oxygen, pH, energy consumption, fish and plant growth rates, plant nutrient content). Gathering together these various material and energy flows, the aim was to build the most holistic picture of aquaponics yet published. It was a novel experimental approach, and if everything went according to plan the data produced would allow strong questions to be posed about the future of the fledgling field of aquaponics.

I would be part of the final growing season before results were to be collated, analysed and published. Actively participating in scientific knowledge production involves risk and comes with the acknowledgement that theorizing within the established power relations of a lab captures one within those relations (Woodhouse et al., 2002). As Downey and Dumit (1997; 9) bluntly state: "where one gets located shapes where one can legitimately contribute". I was grateful (if a little apprehensive on account of my relative inexperience) therefore that my future colleagues had agreed at interview some months before that I was to have an integral place in the running of the experiment. My responsibilities would fall over the majority of the experimental procedure, including the maintenance of the aquaponic system as well as the collection and analysis of the data. Where Downy and Dumit are concerned with the *legitimacy* of their work in scientific settings, my interest fell more on *accountability* of becoming embedded within the field of aquaponics through active contribution. To what extent, could my ethnographic work be opened up to evaluation within the theoretical terms of the field? This was one question that I carried with me on that train to Gembloux, and I had no idea what the answer might entail.

'Integration' is increasingly used as a model for many STS engagements with technoscience (Viseu, 2015), but this term, at least in its typical usage, would not characterise the work I did in the PAFF Box. I was 'hired in', but as a scientist. This project had scientific objectives and the funding came with criteria that closed it to social scientists. My future colleagues had showed a polite interest in my ethnographic aims, but nevertheless, the terms of this engagement - its "sociomaterial orderings" as Viseu (2015; 643) might have it - were structured around traditional funding arrangements and power asymmetries. There would be no interdisciplinary framework and no mechanisms of scholarly accountability to follow beyond the technical imperatives of the experiment. As Susan Leigh Star once put the hybrid work of ethnography in scientific institutions: "We began with the experience of being *simultaneously* outsiders and insiders" (Star, 1990; 100). Like her, I saw this as an opportunity to experiment with a speculative approach to ethnography and the field.

Power and knowledge converge in *situated* technoscientific practices (Haraway, 1988), foregrounding the intimate importance of *positionality* as a key feature of work in STS that gives rise to frames of reference and values within the worlds we study and co-construct (Harding, 1987). The lack of any official acknowledgement of my participation as a social scientist prefigured my work in the PAFF Box and gave me a position. To be in this scholarly environment as a geographer doing (non)scientific work alongside my 'scientific' tasks would be to work under the epistemological radar, beneath officially recognised modes of knowledge production. This said, as a white, English-speaking man with a marine biology qualification, a Belgian Laboratory would hardly qualify as a 'context of subordination' for me in the way that Berry et al (2017: 540) describe their hostile experiences of ethnographic fieldwork as 'black, brown, indigenous, and queer cisgender women'. Nevertheless, since "the tools needed to survive in the field cannot necessarily be found within traditional feminist anthropological approaches that hinge on uniformly horizontalizing the power of the researcher in the communities where she works", I found many inspirations and expressions of their *fugitive anthropology*[18] in my own ethnographic practice (Berry et al, 2017: 559).

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[18] Berry et al's (2017: 559) *fugitive anthropology* with its embodied feminist ethos, non-allegiance to the academic institution, a disloyalty to positivism and a willingness to embrace the inherent contradictions of politically engaged research, had many overlaps with my own practice.

I didn't rock up in Gembloux with a strong plan of action or predetermined methodology. Like Berry et al (2017), my ambition was not to do *fieldwork*[19] as such, but rather, be *active* within a field. To study not through the positivist impulse to extract aquaponic knowledge and take it home (Mackenzie and Murphie, 2008), but rather to chance something scholarly might arise from becoming aquaponically *activated*. With 'intervention as method' (Zuiderent-Jerak, 2016) the aim was to explore what it means to live the multiple membership of academically concerned communities and heterogeneous socio-material ecologies of the Gembloux Agibiotech. To this extent, I hoped, along with Papadopoulos (2018: 68), for an approach "as experimental as the worldings it engages with require it to be".

5.4 Getting to work.

To get to the PAFF Box aquaponic system from the office spaces of the Agrobiotech it's a walk that takes you past greenhouses filled with banana trees, then carefully delineated experimental plots often patrolled by white suited students spraying next generation bio-pesticides extracted from cinnamon bark. Further still, out past a line of full raspberry bushes busy with wasps, you approach the PAFF Box. It is a quiet spot. On my very first day at the Gembloux Labs, Boris, principal researcher of the PAFF box, had taken me along this route. Amongst the raspberry bushes, Boris had spun round and exclaimed with his hands in the air: "Aquaponics is about a dream. When people see the system it can be underwhelming, but you know, it's important for them to see its aims". I was taken aback, not only because his sharp, spinning statement had unexpectedly broken the quiet, but because what he said, in this very first introduction with the PAFF box, had vividly described the way this place was charged with powerful, emotional, yet humble ambition. The Agrobiotech is place filled with speculative and passionate human-plant and animal couplings. I was keen to find out just what was the dream of Aquaponics.

Open the container door to an eruption of splashing. "They're hungry…" Says Boris dodging the water kicked up, "…time for their morning feed". The container holds two large square fish tanks that are home to around 200 Nile Tilapia. While Boris makes the morning checks, he shows me around the system, introducing me to its features. Water from the fish is pumped through a circuit of pipes, first through a colony of bacteria, and then upstairs to a crop of '*giant'* basil and

[19] Berry et al (2017: 539) call to get beyond "the institutionalized notion of fieldwork as a masculinist rite of passage" that bolster positivist and colonialist research practices. For them, the *field* is typified when it "means a space far from home that can be easily entered and exited by an unencumbered male subject with racial privilege." Calling for "a rethinking of the contours of the political in co-creating spaces of liberation and transformation."

'*grosse blonde'* lettuce that float on rafts in the greenhouse, their roots suspended in the water which flows past then recirculates once more to the fish tanks. Under-bed LED's and state-of-the-art, spherical biofilters combine with a network of do-it-yourself pipework and algaed polystyrene floating rafts to give an aesthetic that cuts a line halfway between space-age and artisan, minimal and cluttered, machined and organic.

We had planned it so that my arrival in Gembloux would be a couple of weeks prior to the official start of the experiment. This time was scheduled for me to get to know the place, the people and the lab. Although I was working for Prof. Jijakli, I would actually spend more time with Boris Delaide, Ph.D. candidate in Biochemistry at the University of Liege, and the lead aquaponic researcher and technician in Gembloux. Boris worked more intimately with the PAFF box than anyone. Something of a self-taught maverick, the depth of his experience and technical finesse combined with a 'can do it' attitude that made the prototype and experiments in Gembloux a reality. Even when pipes were spraying water everywhere or oxygen pumps were failing, Boris brought an aura of collected calmness to the materials and groups he worked with. Just like the groups of organisms under his watch, this ethnography too, relied much on his calm demeanour. His willingness to patiently go over lab technique demonstrations or answer to my often elementary or obtuse questioning, meant that Boris as much as anyone had the greatest influence on my initiation into this circulating world of fish, plants and microbes.

The experimental protocol and laboratory techniques took precedent in my opening days. If the experiment was to yield accurate and rigorous data, water sampling had to be executed regularly and precisely. Some elements in the aquaponic water are present at such minute levels that even the smallest contaminant might skew the data. As a team we agreed the positions in the aquaponic systems that would be sampled (fish tanks, biofilter outlets, growbeds etc.), and together we repeated the process of sample collecting until we were confident the exact same procedure would be followed by each of us for the next two and half months. It was a process - my colleagues repeated - that required a sort of ritualistic discipline.

The same was true back in the lab where water samples would be taken for analysis. This is where the Nitrogen compounds Ammonia, Nitrite and Nitrate would be measured. The concentrations of these compounds would indicate how waste from the fish was being converted and assimilated in the Aquaponic system. Ultimately, we hoped, our measurements would describe an efficient aquaponic ecosystem, and give the green light to promising future research. Although many other measurements would be taken, including pH, temperature, and micronutrient data, it was the Nitrogen compound data that carried the greatest importance for the team. Prior to the experiment proper, the team spent hours in the lab with me, fixing a rigorous and shared laboratory procedure.

The lab was a place where the tasks are set by the 'protocol book'. A set of instructions describe how each sample must be handled to ensure the most accurate measurements from our instrument (a HI 83200, HANNA instruments, RI 02895 Woonsocket multiparameter spectrophotometer.) This spectrophotometer works through a relatively simple process. To ascertain the concentration of a particular element in a solution, one induces that element to precipitate. Then the machine shoots a laser through the solution and reads how much that precipitate blocks the beam. Each element (ammonia, nitrite, magnesium etc.) has a specific reagent and procedure to induce a controlled precipitation. The job of the scientist is to simply follow the precise procedure, as laid out in the protocol book, step by step; add a reagent and produce the correct physical conditions. Accurate results arrive through a combination of accurate measuring, good timing, and precise and regulated physical movements (shaking, turning, inverting the sample). Here, good lab practice involved no small degree of bodily coordination, often helped by the lab radio that offered a beat to shake to.

5.5 Multispecies matters

The painstakingly precise process of daily water sampling, combined with temperature, ,ph. and electroconductivity monitoring, formed a data collection apparatus that would ultimately judge the waste recycling capacities of our aquaponic ecosystem, and to a degree, indeed the potential of an entire field. I was quickly getting up to speed with the bodily attunements required in order to render rigorous data from our murky samples. But as I was to find in the day to day upkeep of the PAFF Box, the experiment itself hinged on much more than simply diligent lab skills and obedience to the protocol book. On top of the technical concerns about how to organise and focus an experimental apparatus to draw out data that our team needed to answer key questions of the field, there was also the issue of simply 'maintaining' the life within the PAFF box ecosystem. As it happens, the nature of the living, breathing, aquaponic ecosystem presents difficulties to everyday research:

"We have this issue where we have to balance the needs of fish, microorganisms and plants. They share the same water - pH, DO, nitrates, nutrients, temperature - of course we have to find a compromise. To put the animal, microorganism and the plant in their most optimized environmental condition… this is the challenge for aquaponics" (Boris Delaide, Laboratory scientist).

A challenge indeed. Fish and plants are not like fish tanks and greenhouses that can be bought and readily pieced together. They are what Lewontin (1998; 97) calls *reluctant commodities*, that is, constrained by vital growth requirements and cycles of reproduction; biological realities that offer resistance to the whims of theory. Although the basic arrangement of an aquaponic system is apparently simple, involving only three kinds of living organisms, the interrelations between these are highly complex and interdependent (Tyson et al., 2011). Fish, plants, and bacteria each have different needs if they are to flourish. These somewhat contrasting requirements make it difficult to achieve in recirculating aquaponic systems what those in the industry call 'maximum yield potentials' (Konig et al., 2016; 26). This is a point that becomes a bone of contention for those aquaponic researchers who pin their hopes on proving that aquaponics, on the basis of efficiency, can out-compete intensive aquaculture and horticulture. However, for our team working on the prototype system in Gembloux, there were more pressing concerns than 'maximum yields'. As I was finding out, simply maintaining a healthy, functioning ecosystem became a central feature of day to day tasks for the lab technicians and scientists including myself.

Fish and plants are not often seen as charismatic beings able to raise inspiration and they usually have a hard time capturing our attention (Driessen, 2013, Kopnina, 2013, Hartigan, 2015) but for the world of aquaponics they are pretty much the poster children. So it came as a surprise when my early questions about the system dynamics seemed always to lead back to an entirely different biological component of the aquaponic system: the bacteria. My first few days in Gembloux were consumed learning the dynamics of the biofilter and its bacterial community. My colleagues were keen to reinforce that a healthy functioning aquaponic system hinges upon its bacterial community, and its industrious propensity to consume and convert fish waste.

Aquaponic systems inherently contain a toxic component. Ammonia, a by-product of healthy fish digestion, is constantly being excreted by fish directly into the water around them. Diluted in enough water, ammonia presents very little danger, but when its concentrations rise it becomes threatening to piscine life. It is only when fish live at higher densities and in confined spaces that ammonia presents problems. It must be transformed via nitrifying bacterial action into less dangerous forms that can then nourish plant growth (Bittsánszky et al., 2015). Fish excrete, bacteria convert, and plants remove. 'Balance' between fish excretion and bacterial action, therefore, is the route towards a healthy aquaponic system. Yet, the metabolic processes of these interconnected creatures can easily fall out of sync if unchecked. With a build-up of toxic metabolites, aquaponic systems can shift into dangerous states within hours, endangering the sensitive inhabitants and increasing the chance of a 'system crash'. A crash in the PAFF box would be a disaster and would almost certainly result in a great loss of life. But when the fates of human endeavours are so tightly coupled with the non-human lives they experimentally enrol, as in the PAFF Box, a rising tide of Ammonia or Nitrite is able to quickly poison months of human planning and effort. Talk to any scientist in the field and they will tell you this ecosystem hinges on its microbial contingent. They are the mediators that invisibly connect the metabolic worlds of fish and vegetable. It is they who quietly convert waste to potential. And it is they who dynamically disrupt, alter, and unwind the balance.

The 'biofilter' is the purpose built component of the aquaponic system designed to house these bacterial communities. In the PAFF Box this biofilter looks much like a rounded casket. It has a small porthole on the outside, barely 10cm in diameter, which allows you to peer inside. You can't see far, for pressing up against the inside of the window are tiny off-white microbeads, designed with a texture that is particularly welcoming for microscopic colonisers. As Boris explains: "*The Biofilter is one of the most important keys of the system - and it's one where we get less information." P*ointing out some visible signs of biofilm through the porthole of the biofilter Boris continues: *"it's very complicated because [we] use microbiota in a microorganism consortium. So it's like in soil, you know… It's an interaction between a lot of microorganisms, not only bacteria."*

To the naked eye they appear to be no more than an orange-tinged slime, but these biofilm constituencies are known to harbour a world of complexity that two decades of research is only beginning to understand (Avnimelech, 2006). It is known now that the microbiome of recirculating systems is spontaneously derived from its surroundings during the start-up period, mostly from the air itself. Microbial diversity not only differs from one system to another, but constantly shifts within a system as it is impacted daily by various external inputs (Blancheton et al., 2013). Biofilms are dynamic, self-organising, symbiotic collections that function as a "cooperative consortium, in a relatively complex and coordinated manner… having the ability to aggregate into particular three-dimensional assemblages, differentiate and divide labour within these assemblages, and then disperse as part of their life cycle" (Davey and O'toole, 2000; 852).

Inside the biofilter different organisms compete for substrates, space, and oxygen within the biofilm. These bacterial communities remain almost completely invisible to our team in the PAFF box, yet I was beginning to see how my colleagues' understanding of the microgeographies of the biofilm was crucial for system functioning. Learning how to provide the optimum conditions for the bacterial communities most able to produce desirable 'aquaponic' functions was crucial. Two types of bacteria are central to the process that converts fish waste from a toxic to a nutritional state - from Ammonia to Nitrate. Firstly, bacteria known collectively by their genus name *Nitrosomonas* metabolise Ammonia into Nitrite. Nitrite can be even more toxic to fish at lower concentrations than Ammonia, and so a second genus of bacteria – *Nitrobacter* - are needed to digest this problem into Nitrate. These two very different and interacting communities must be present and able if a healthy biofilter is going to perform its aquaponic function. Boris: *"So you already involve microorganisms, with very specific environmental needs. Specific for DO and pH etcetera... So this is where the tricky part starts."* Boris explains how the maintenance of a specific environment is thought to give the greatest chance of healthy biofilter. Although, precisely selecting particular bacterial compositions is out of the question, one can encourage the 'right' bacteria by carefully maintaining conditions that would optimise their survival and flourishing. Boris would monitor closely to make sure well oxygenated water at temperatures around 25 °C were entering the biofilter. pH is a crucial factor that can quickly shift the efficacy of microorganism biochemistry, and so Boris adjusted this to fall between 6.8-7.2. Similarly, alkalinity could be raised using sodium bicarbonate ($NaHCO_3$).

Following my colleagues, I was quickly learning to read 'cues' given by the system that might provide insight into what kind of environment we were providing the biofilter. One morning, inside the PAFF Box with fellow researcher, Guillaume, I watched as he assessed a crucial aspect of biofilter health. Bending over the 'sump' tank (a large tank where exhaust water from the fish tanks collects before being pumped through the biofilter) he angled his head and squinted. It was obvious that he was trying to see through the glinting surface of the water. He told me he was looking for 'solids' (fish waste in non-aqueous form) I seized the opportunity to quiz him:

JG: Why don't we want [fish] waste in the sump?

GD: Because if we have waste in the Sump it may jam the Pump. Or it may go afterwards in the biofilter. And in the Biofilter, if there's waste accumulating here we'll have a shift in the bacteria, with bacteria that grow on the waste and not on the ammonium and NO2.

JG: So it changes the environment in the biofilter?

GD: Yeah, it goes anaerobic and it kills all the bacteria that we want. That's basically why this year we installed this filter, but as you have seen, it's not working that well, and we have to clean it every day.

Allowing solid waste to enter the biofilter alters the metabolic possibilities within. An influx in solid waste shifts the carbon:nitrogen ratio in the biofilm environment, and where carbon is abundant, heterotrophic bacteria become superior competitors for oxygen than their autotrophic neighbours. In such a situation the majority of the oxygen that diffuses into the biofilm is consumed by a proliferating heterotrophic bacterial bloom and nitrification slows or grinds to a halt (Elenter et al., 2007). In prolonged periods where the efficacy of nitrification is reduced, a 'crash' can occur, where whole populations of autotrophs perish causing the spatial composition and distribution of microorganisms to alter profoundly (Michaud et al., 2006). Hijacked by carbon loving intruders, a crash of this kind signals the breakdown of the aquaponic ecosystem.

On the most part, the 'swarming organismic operations' of these creatures unfold at scales below everyday human perception (Paxson and Helmreich, 2014). But I was learning how the team in Gembloux had developed ways to direct the lab apparatus towards the traces left by their vital processes.

"You really don't know if the bacteria are there or not. So what you have to do is just look at your data - the concentration in the solution - to see if they are working or not" (Guillaume).

Yes, pH, temperature, and dissolved oxygen readings would give us instant feedback on whether our biofilter environ was at its optimum, but they left us in the dark regarding any deeper questions about the bacterial dynamics contained within. It was here that the Nitrogen compound tests we were doing back in the lab offered a new dimension. Ammonia, Nitrite and Nitrate are the key bacterial metabolites. Our careful work collecting data on their concentrations therefore doubled as an indicator of the labours of specific bacterial communities. For instance, low levels of ammonia but rising concentrations of nitrite would indicate some problems in the *Nitrobacter* community. These samples gave an indication of which metabolic pathways are functioning, which bacteria are doing what.

Objective measures often equip the data holder with the ability to deflect quibble and opinion (Latour, 2004a), and there was no exception when it came down to caring for the biofilter. The lab analysis carried a particular type of significance for us all. It was the only way we could read exact concentrations of these nitrogen compounds - exact levels of danger. If the ammonia reading is high; the ammonia is high. There were no two ways about this. It signalled a situation that required immediate action to be taken if damage to the system was to be prevented. Indeed, in times of uncertainty, scurrying off to the lab to analyse fresh samples was often the only way to put one's mind at ease. It is here where the nitrogen sensing apparatus of our experiment doubled as a kind of rudimentary intensive care system.

But objectivity does not come without limit. As Donna Haraway so famously argued, the power of objectivity is achieved through 'partial connection' (Haraway, 1988). In terms of the PAFF Box apparatus, this partiality took on an extremely protracted and discrete temporal form. The nutrient data gained from our water samples took time to process, and its form could at best be likened to a Polaroid snapshot of the system. Our tests offered concentration values only for the precise moment those water samples were collected. But, of course the system never 'stood still'. At times of rapid change, like after fish feeding, plant harvesting, or water replenishment, often the team would run up against somewhat frustrating temporal limits of the nitrogen sensing equipment. I was taken aback to find my colleagues, in order to plug the holes of the frustrating and worryingly partial apparatus, had developed an intimate sensory relationship with the PAFF Box. They called it 'feeling the system'.

5.6 Sensing the PAFF Box

Entering into the PAFF box was a deeply sensuous experience. Inside the container the air is thick, humid, and organic. It is kept at a balmy 25℃ to keep the Tilapia at their most comfortable. Closing the door behind you cuts off all natural light. You work under the lamps set to photoperiods that mimic equatorial conditions[20]. Water burbles and flows, oxygen pumps fizz, fish splash or don't, the whirring motor of the water pump resonates with the shell of the container, its drone registers in the cells of your body and the bodies of those all around you.

The PAFF box was an unavoidably visceral experience for those who entered its confines. But other, non-human, members of the experiment experienced an altogether different level of somatic integration into the workings of the system. For the 200 Nile Tilapia of this experiment, water quality was something that must be lived and breathed through. Their world was directly impacted by the conditions that the PAFF Box was expressing, and it was clear to all of the team that their behaviour and appearance was a response, an extension, of this expression. To the trained eye then, changes in fish behaviour were invaluable visual clues that indicated shifts in the PAFF Box environment. For example, albeit a stark one, my colleagues explained that at concentrations exceeding 5mg/l Nitrite will bind to fish blood making methaemoglobin and will rapidly have the fish gulping for oxygen on the surface of the tank in a critical state within seconds (Yanbo et al., 2006). Thankfully, this drastic response never materialised during my time in Gembloux, but my colleague's example is useful to highlight the immediacy of our tilapia's situation and the acutely sensitive position they take up an aquaponic system like the PAFF Box.

Nitrite can produce drastic alterations in tilapia behaviour, but many other aspects of water quality alter the way these creatures inhabit their aquatic spaces of the PAFF box, and most of these were far more subtle. Slow moving, or 'quiet', fish might signal an issue in the oxygen supply, or it might signal rising ammonia levels. But it might simply be that the tank temperatures were lower than expected after an unusually cold night – being sensitive to the difference, I was

[20] The PAFF box used 12 hours light/ 12 hours dark. This is an industry standard for raising juvenile fish beyond the fingerling stage, providing optimal growth, feed utilization efficiency and survival, (and hence, profit) for producers. On the other hand Fry, (an earlier developmental stage of Tilapia) respond 'best' to extended light conditions, and are often subject to 24hour light regimes to improve weight gain, specific growth rate (SGR), feed efficiency and fish survival.

finding, makes all the difference in circulating world of the PAFF box. The sharpness of my colleague's sense of fish behaviour was really something impressive. Observing fish in a dimly lit shipping container is not the most straightforward task, especially so when the fish you are observing have highly adapted skin that can alter melanophore distribution in their dermis allowing them to reflect their surroundings like uncanny underwater chameleons. On most occasions, the fish had no difficultly quietly disappearing against the solid grey walls of the tanks, and often it would be the appearance of 'the water surface' that my colleagues would be 'reading' to tell if things were ok.

Fish behaviour was one aspect of the system that the team in Gembloux had learned to be responsive to. But as I was finding, the PAFF Box was a multi-sensory place, and my team mates were attentive to many of the diverse feelings it produced. *"It's a bit stressful actually…"* Boris tells me, "*you have to open all your senses, to perceive if everything is right. Look, listen, smell."* Particular sights, sounds, and smells gave important signals of system health or imbalance. For more enigmatic organisms like bacteria, smell became the channel through which to perceive possible population blooms within the microhabitats of the system. For instance, the unmistakeable smell of rotten eggs (Hydrogen sulphide), might indicate anoxic zones in the system somewhere – the only places where strict anaerobes can survive and develop their alternative metabolic economies[21].

'Fishiness' was a smell that carried a host of meanings. A low-level 'fresh' kind of fishiness pervaded all the work in the PAFF box. It was smell that permeated clothing and after a few weeks or so, eventually became part of your own smell. It was a kind of base level atmosphere that would slip out of your attention if you spent long periods inside the box. But other kinds of 'fishiness' were not so benign. More pungent, organic and localised fishiness, which even to my seasoned colleagues could trigger a body jerking repulsion, and could suggest water filtration had been hampered in some way, either by minor blockages or more dangerous mechanical filter problems. Metallic tinged fishiness, which happened on a few occasions, was altogether more mysterious. It was always followed by a light froth floating on the surface of the sump water. Boris had seen in other systems that in response to irritating ammonia levels tilapia are able to secrete mucus, possibly to protect their gills, he speculated a similar thing might have happened in the PAFF box.

[21] Giles put it very well : "Oh god, I know that smell… yeah that's the rotten egg smell. That's a characteristic of H_2S. It's the degradation of organic matter in aerobic [conditions]… so this is really a clue about a lack of oxygen and an accumulation of waste. In recirculating systems this can really be really an issue. So this smell is really an indicating smell and an alarming smell. If you smell this you have to be aware that problems are going to come."

‘Feeling the system’ sometimes required an eye or nose for extreme subtlety, but at other times it demanded a readiness for the unexpected. At points during the experiment I was convinced that my colleagues had some sort of sixth sense. They seemed able to intuit a problem even before it happened. They would make tiny adjustments to the system, for which I had no idea why, only to tell me later that they had noticed a slight change in water colour, or an inconsistency in the flow rate, or a whiff of something strange. Boris explains: “After a certain amount of time working with the system you can *anticipate.* You can see how a parameter is rising, and I will anticipate and do something to stabilise it. To avoid a big drop, or big spike”

I would witness a striking example of the way the creatures of the PAFF Box adapted to the human involvement. It was at a particular moment in the experiment when we need to take mass measurements of the fish - crucial to understand growth rates and feed conversion ratios (FCR). During this procedure fish needed to be carefully transferred to a bucket and weighed on a scale. This was a stressful moment for the team, (mostly because it was a stressful moment for the fish) but the morning went ahead smoothly. After weighing fish from one tank we stopped for a coffee break. On our return to the PAFF box something remarkable happened in tank 2, as the following entry from my ethnographic diary shows:

29-09-15 “*…These fish always seem to amaze me! We got back to the final tank of fish remaining to be weighed, and it was bizarre. The fish already seemed to know why we were here! They were hiding in the corners of the tank deep away from the surface, very touchy. But how did they know we were here to weigh them and not feed them? We hadn’t even touched this tank yet!”*

It was only later, I came across a possible answer looking at studies of fish stress communication. Apparently, a wide range of fish species display the ability to communicate chemically their stress levels to others in the same water body, even to those comrades of species relatedness whose presence they may not be aware of[22] (Barcellos et al., 2011). My ignorance that such a contagion of chemical stress could circulate around the system immediately rammed home a realisation that these organisms were connected in sophisticated ways not immediately recognisable to the team.

My study of the more-than-human arrangements of the PAFF Box would unfold alongside Boris’s own biochemical investigations. We engaged in different disciplinary projects in the same space,

[22] Finding chemical stress communication between separate tanks of Nile Tilapia Barcellos et al (2011) report: “The increased cortisol in the non-handled fish exposed to water from stressed conspecifics indicates that handled fish release a substance that induces a stress response in the recipient fish. This conspecific communication is interpreted as an adaptive mechanism that increases cortisol in anticipation of a potential threat, amplifying the animal's awareness of its environment. Chemical cues overcome visual barriers to communicate stressful conditions to conspecifics in other places.” (pg3)

and each of us, in the best possible sense, became entangled in the other's business. We each contributed towards the other's PhD investigations, though at times, we might not be entirely aware of the meaning of the work we did. Susan Leigh Star (1990) influentially described the way that ethnographies of scientific worlds become steeped in a complexity of relationships that implicate the researcher in positions of multiple membership *as well as* marginality. This would certainly apply to my attempts to bring more-than-human concerns to aquaponic science. On one level, Boris and I entered the PAFF box with a joint scholarly objective, but on another, we brought very different skills, experience, eyes, and feelings, to this ecosystem and I quickly realised I had to learn of the PAFF box community through my own carnal knowledges.

I was getting to grips with the way my actions were tied to others in the PAFF Box. But when Star discusses living and researching within the "high tension zone[23]" (Star, 1991; 51) she was not only describing the way that seemingly disparate disciplinary pursuits might converge in sites of scientific production. Taking inspiration from feminist thinkers before her, she was aware that the 'primacy of multiple membership' means that our ethnographic selves are never 'pure' – they are shot through by all manner of 'usually ignored' processes of 'nature and technique' (Star, 1990; 82). Eva Hayward (2010: 584) speaks of a similar aquatically attuned ethnographic setting, the Maine Marine Laboratory, as "a zone of multispecies and multidisciplinary coherences." This would be an excellent description for the PAFF box. At times we cohered, and so it was from within the practices of the aquaponic experiment that I helped conduct would grow a multispecies ethnography[24] that was only partly an ethnography of aquaponic scientists. Learning how to become sensitive and responsive to the way my (multiple) ethnographic selves were implicated in the happenings, matterings and lives of the PAFF box would grow into a central feature of my work in Gembloux.

[23] With reference to Latour (1987), Star (1991) articulates this 'high tension zone' as: "a kind of zero point between dichotomies or between great divides: male/female, society/technology, either/or." A fitting term for the experimental cyborg capsule called the PAFF Box.

[24] Kirksey and Helmreich (2010, 545) employ "multispecies ethnography" to denote a mode of ethnographic investigation that "centres on how a multitude of organisms' livelihoods shape and are shaped by political, economic, and cultural forces". As they point out, this approach isn't about simply celebrating the multitude of multispecies engagements but also, following Star's question of '*cui bono?'* – asking who stands to gain from these engagements by attending to power and its asymmetrie

5.7 Finding Balance

In the mind of the aquaponisist, each organism has a particular role to play in the aquaponic system. Although these organisms are separated functionally, taxonomically, and spatially (plants upstairs, fish down, bacteria in the biofilter), it's crucial to remember that materially they are all constantly connected to each other through their life medium – water. This medium is itself mediated by the technological infrastructures that ensure its constant circulation, temperature, aeration etc. In an interconnected system like the PAFF box, a change in one parameter has the potential to alter any other in the web of interrelation.

With all these variables at hand, the expression that my colleagues sought was 'balance'. Balance in the metabolic, the ecological, the technical. Balance was a 'steady state', a safe environment that secured and maximised the capacities of biological and technological nodes in the system toward the aquaponic goals of my colleagues. Keeping the balance in the PAFF box ecosystem was a fluid and improvised process that required gathering and acting across a host of heterogeneous elements - of data points, calculations, timings, feelings and sensory inspirations. My colleagues were teaching me how to bring these aspects together with a kind of rationale that placed engineering emphasis on the flows and interactions of bodies, instruments, water, figures. I was being taught how to 'engineer' an ecosystem, but this experience in the PAFF box seems to contrast sharply with other scientific settings. For instance, in the physics problem solving that White (1996; 104) discusses, the main challenge for practitioners is to learn to "think like a physicist" and bring that unique genius to the process of 'discovery'. 'Thinking like an aquaponicist', if we can call it that, contrasts also with Downey et al's (2006) experience of integrating engineering problem solving into one's body, a process they found that involves sharply separating "self" from "work". For Downey et al's engineers, thinking like an engineer is a method that is rigorous and invariant since allowing personal interests, desires, or concerns into methods equates a serious violation of sound engineering practice (Downey et al., 2006).

Sampling of the system had a protocol, and this was followed more or less religiously each day, but that sampling required a functioning aquaponic system. Keeping that system in balance was a different matter entirely. Balance required a reading-between-the-lines kind of attitude, a flexibility and agility to the situation, an understanding of the knock-on effects of actions, a reading of events in relation to the system's recent history. Watching the way my colleagues sensitively responded to the most fleeting expressions of the system, I was reminded of the way Tim Ingold (2000; 415) distinguishes between the 'cognitive scientist' and the 'skilled practitioner'. As he explains, for the cognitive scientist: 'every act has to be thought out in advance… attention *precedes* response'. The skilled practitioner, on the other hand, 'is able continually to attune his movements to perturbations in the perceived environment without ever interrupting the flow of action, since that action is in itself a process of attention' (Ingold, 2000). Separating 'self' from 'work' was not an option in the PAFF box. In actual fact, this recirculating environment was a place where one's actions rippled through the system and cycled back requiring more or less refinement. Working on the system meant entering loops of feedback, and work on the system, doubled as work on one's self.

The success of this experiment, this ecology, rested on an attunement (Ash and Gallacher, 2015) between the many bodies implicated and the swirling collective expressions they co-created. Erin Manning's (2013; 11) conception of affective attunement as "a tuning not of content but of expression-with" becomes a useful way of describing how the relational environment of the aquaponic system was co-created through movement and exchange. The PAFF box obligated the acknowledgement that expression, as Manning (2013) suggests, is always 'Expression-with'. To research in the PAFF Box was a situation where ones actions became tied to the responses of others, and vice a versa. It was to be drawn into an extended experiment in 'response-ability' (Haraway, 2008).

As the experiment in Gembloux progressed I had a growing impression that time spent in the lab felt far removed from time spent with the system. Each morning, sat behind the PAFF Box on decking that looked out over the agronomy school's experimental fields, our small team would regroup after the morning tasks to share things we'd noticed about the system. It was a time to raise issues, questions, or ideas. On a rare 'quiet' morning (the system was running smoothly) an opportune moment arose to ask the team about the difference between lab and aquaponic system. Boris offered his opinion:

"It's different [the lab], because you are dealing with products and protocols. You know exactly what you are doing. But when you are in the aquaponic system you're now working with living material. With a lot of uncontrolled behaviour or events that can happen… Sometimes it's new, you know, a new problem that you never had, or you've had it once and you don't remember how you fixed it, or anything. So it's much more complex. There's a thousand events that can happen in the system; in the lab it's more controlled."

Unlike the lab, the system was characterised by its capacity to produce surprising and unforeseeable events and these events could often be problematic. Any number of things could arise that would impact the team's ability to maintain the healthy aquaponic environment. Mechanical failure, pathogens, pests, power outages, even changes in the weather. Nevertheless, within this unpredictable system, experimental structures placed strict demands upon the team.

The way my colleagues negotiated issues, made decisions, acted, reminded me of the way de Certeau (1984; 32) classically described the *practices of everyday life* as "establishing a kind of reliability within the situations imposed on an individual… of making it possible to live in them by reintroducing into them the plural mobility of goals and desires".

With such vital energies pulling the system in different directions, the search for 'balance' necessitated a near constant 'tinkering' by our team (Knorr, 1979). Moments of joy were palpable when manipulations brought about good results, as Boris explains: "what I enjoy the most, is seeing it working you know. Seeing the fish growing, the plants growing, seeing that everyone is having a good environment to grow. Its good when you succeed through all the issues that you come across." As de Certeau (1984; 32) might have put it, at times, tinkering in the PAFF Box was "an art of manipulating and enjoying". Although Nutch's (1996) experience of 'gadget-scientists', whose joy of tinkering seemed to stem from the tinkering itself[25], my experience, and the words of my colleagues above suggest that tinkering in the PAFF Box was tied more to the ambition of drawing out positive material expressions from the constantly shifting, and challenging, forces. The specific relationalities at stake in the PAFF box, seem close to Puig de la Bellacasa's (2018: 207) experiences of soil sciences where she found 'the recalcitrant diversity of soils' brings about an 'unexpectedness and indeterminacy' that prefigures styles of tinkering. For my colleagues, achieving balance in the system was the product of a bodily invested intellectual synthesis of many given elements, and like in de Certeau's descriptions, emphasis was placed on "the decision itself, the act and manner in which the opportunity is "seized" (Certeau, 1984; 54) the way that a balanced aquaponic expression might be realised given the constraints.

'Balance', however, was not solely about the dreams of a neatly engineered and efficiently functioning system. Flowing through the ambition of balance was the idea it would bring about flourishing in this aquaponic system. Maintaining balance was the maintenance of system 'health', where the needs of the PAFF box inhabitants were kept clearly in view. Keeping the balance was a practice infused with *care*. Annamarie Mol has shown how a 'logic of care' might operate through social-material manipulation or "tinkering" (Mol et al., 2015, Mol, 2008). For her, the logic of care places emphasis on the emergent similitude of heterogeneous human and nonhuman relations that usher-in and demand the negotiation of different needs, goals, responses. Attending to the relational tinkering in the PAFF box, my own focus became drawn toward an 'anthropology of care' (Lutz, 2016) of attending the human-nonhuman efforts that

[25] In Nutch's (1996) ethnography of gadget scientists he describes how in their love of tinkering "they appear to be neither "doing science" nor tinkering toward success, but simply to be "messing around" for the joy of doing so with no obvious purpose or apparent application"

make and unmake (but are also simultaneously made and unmade) as they meld together in practice.

Care involved in knowledge making, Maria de la Bellacasa (2017; 78) points out, has the energy to elevate practices into “something of a “labour of love”. On more than one occasion, I had laughed with Guillaume as he reminisced about the demands of the system. “It’s like having a baby!” he would exclaim, and I was beginning to understand what this meant. Boris: “If you don't manage it, the system will definitely crash.” The system was a sensitive thing, it required much attention and care, and could never be left alone for too long. When the system was crying (and at one point it literally was, when we discovered a leak in one of the grow bed outlets) there was nothing to do but pour your attention into it until a remedy was found.

And so it was; I was learning the types of caring practices needed to sustain aquaponic ecologies, to culture populations of bacteria amenable to aquaponic imaginaries and to become attuned to the chemo-semiotic interplay between populations of humans and tilapia. Soon, however, my own ‘fleshy interpretations’ (Hayward, 2010) would carry much greater significance, because at the end of week 4 in the experiment it was scheduled in that my colleagues would leave Gembloux for over a week, and I would take the reins of the experiment and responsibility of the system alone.

5.8 Intervening

Harry Collins devoted several books (Collins 1990; Collins and Kusch 1998) to show that ‘expertise’ can never be entirely formalized, that some knowledge is essentially tacit in that it is irreducibly tied to social action (Sismondo, 2010; 109). But the PAFF Box, viewed as an ongoing technoscientific production of multifarious ideas, efforts, energies, and responses, thickens this plot as knowledge production becomes distributed within the efficacy and ineffability of more-than-human action. The PAFF Box is a ‘thing’ of technoscience in the making, and as Haraway (2008; 250) might have it, ‘things’ are “never purely themselves,” but are, rather, “compound, made up of combinations of other things coordinated to magnify power, to make something happen, to engage the world, to risk fleshly acts of interpretation”. I had a place in this compound thing, and when my colleagues said their goodbyes and I was left in charge of the PAFF box, I began to learn of the risks involved in my own fleshy acts of interpretation.

Without my aquaponic colleagues the days were long. I felt the absence of verbal communication and the reassuring structure that it provides for collective decision making and action. In the space left by human silence, a deeper alliance with my non-human counterparts grew. I had become accustomed to greeting the fish each morning and tried to spend a good 20 minutes watching them before starting any of the water sampling and maintenance tasks of the day. *Oreochromis niloticus* are intelligent cichlids (Bekoff, 2007) that form complex social arrangements and are able to communicate in responsive ways that are alien to ourselves including chemical signalling, body and eye colour changing[26]. Although distant in many respects, physiologically and phenomenologically, tilapia intersect with humans in some important ways – they have what Lorimer calls 'ecological affordances' that allow interested humans the chance of tuning to their behaviour (Lorimer, 2007). Colour, shape, speed, and degree or style of movement, were all important cues in this regard, and in learning these, I was becoming accustomed to the character of these fish.

Most mornings they would be jostling back and forth, gliding on the surface to take a look at me, splashing water in anticipation of food, or even biting the probe. But subtle changes in their expressions and appearance were beginning to register in my own feelings as I moved throughout the PAFF Box. Take for example these notes, recorded around 5 weeks into the experiment:

Field notes 02-09-2015 08.25am

"Another bright, crisp morning. I step inside the box. *Wonder why they didn't splash?* Placing a step ladder beside one of the above-shoulder fish tanks I step up to see the fish, looking over the rim of the tank slowly, careful not to startle or excite them. A*re they slower today? Are they moving the same as yesterday?* I lean forward to get a closer look. They don't rush to the surface like usual. *It's not the same as yesterday.* As I get down from the ladder, I'm trying to decide whether that slight smell of ammonia is different to normal. Could be. Could be my imagination. One more look at the fish to be 'sure'. *Yes, definitely – Damn! They're not interacting with each other nearly as much. They have that slow, sulky behaviour on – I bet the Ammonia levels are high*.*"*

This was a morning that called for a fast response. I needed to find out what was causing the fish to behave so 'sulky'[27]. I bought some time by adding fresh water to the tanks, a temporary

[26] Despite these amazing qualities, Nile Tilapia are most often chosen for a different set of attributes: Tolerant of brackish water, able to survive in temperatures between 8 and 42 °C, and omnivorous, these fish display astonishing adaptability, resilience, and fast growth rates. Each of these make Tilapia highly compatible with the 'race to the bottom' production of high intensity farming, setting them as one of the globe's most commercially important fish species - with a population 'j' curve worthy of the Anthropocene.

[27] My team mate Giles described this behaviour so elegantly when he said: "They go a little bit away.". Giles like all of us, described the fish behaviour with colours from the palate of human

measure that works to dilute any offending water quality parameters and ease the discomfort of the fish. I rushed some samples off to the lab. Waiting anxiously for the spectrometer to give its decision, my phone buzzes on the workstation. It's a message from Boris:

"*Greetings James from Provence! The alarm*[28] *went off last night. Power cut around 4am. How are you and the fish*?"

The text brought some relief. Although a power cut in the early hours could have been very serious, the fact that the system was back up and running again without any casualties was a great sign. The power cut would also explain why the fish were behaving so differently. Without electricity, the water flow in the PAFF box stops and the fish tanks become cut off from the rest of the system. The ecosystem disintegrates. Rather than flowing out of the fish tanks to the biofilter, aqueous fish waste hangs around in the tanks, and if the power is off long enough ammonia will begin to rise in concentration.

A few moments later, with a beep of the spectrometer, up flashed the water sample results: Nitrite was low, Nitrate was stable, and Ammonia was high. This was great news, a relieving confirmation that ammonia was the issue and the power cut was (most likely) responsible. With the power now back on and the ecosystem reunited, the ammonia build-up in the fish tanks would be carried through the biofilter and be readily converted - there was every chance the system would return back to a healthy state. But more than this, the results of high ammonia had confirmed that my intuition had been correct, I'd read the fish and in the moment, I had acted well. This was a great boost to my aquaponic spirit.

'Reading' the fish was, at times, a crucial act of interpretation. Taking time to watch, listen, smell, feel the expressions of the Tilapia, was a way of asking how the PAFF Box system was, a way of opening up my own body, of becoming more responsive and attuned to their and the system's needs – *feeling the system*. Here, I'm drawn to the work of Vincienne Despet (2013; 70) when she uses the troublesome idea of *empathy* in her accounts of human-animal interaction. For her, empathy is not a term used to conjure romantic notions; "empathy is not feeling what the other feels, it is rather making the body available for the response of another being.". Empathy, Despret (2013; 70) suggests, is not compassionate thinking, but a somatic gesture, a "process by which

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emotions (happy, sad). What I described as sulky, he portrayed as: "They are swimming slowing, and they won't come to greet you with splashes. Yeah they're swimming a little bit sadly." For Lorimer (2007), it is the aesthetic charisma of (particular) non-humans that engages our ethical and caring sensibilities; a charisma that is relational, ethological and affective too.

[28] The PAFF Box was linked to a remote satellite alarm system. If there was a malfunction, or power cut an alarm response sent a text message directly to Boris's mobile phone.

one delegates to one's body a question, or a problem, that matters and that involves other beings' bodies. Bodies are articulating, and become articulated, in the asking and in its responses."

Often enigmatic, at times joyous[29], and on occasion quite distressing, reading the fish was a bodily invested interpretation filled with ambiguity, a 'somatic sensibility' (Greenhough and Roe, 2011) that relied on emotional receptivity as much as rational problem solving. Take for instance this passage taken from my diary from week 7:

"The fish look great today. I'm beaming. It's hard to describe them as 'happy', but they are palpably more alive. They seem to have more choices about how to go about their business. Some swim up to you and look at you. Some stay back. Some peck at the surface. Others swim on their side a little, almost playfully. It's like they are exploring possibilities. They express more ways of being. When the system is healthy like this, it's like they are more alive."

For Isabelle Stengers (2000: 148) "every scientific question, because it is a vector of becoming, involves a responsibility". Importantly however, this does not lead simply to a "strictly ethical question" in Stengers' view, but rather to aesthetic dimensions that call on "one's capacity to feel: the capacity to be affected by the world, not in a mode of subjected interaction, but rather in a double creation of meaning, of oneself and the world". Opening up and training my sense of the Tilapia's aesthetic allowed me to more accurately respond to system fluctuations, but it also involved the opening of myself to the flows of emotion, however uncomfortable or celebratory, that different Tilapia expressions were able to stir up. Learning of the capacities of these fish to respond doubled as a process of realisation of my own capacities to integrate into the PAFF Box in more ecologically sensitive, effective, and caring ways.

But as I explored - sometimes with a sense of ontological revelry – the *correspondence* (Despret, 2013) between myself and the amazing acuity and behavioural flexibility of my counterparts, it must be stated, that these fish remained objects of biological and ethnographic research. I do not wish to side step this point. Reading the expressions of these creatures was a 'choreography' (Manning, 2013) filled not only with emotional connection (however disproportionate), but was also preloaded with stark and obvious asymmetries of power. There was no escaping the fact that these fish had to live within the bounds of an experiment designed to ask of them only one productivist question – what FCR (feed conversion ratio) can be achieved in a recirculating

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[29] Resonating with my own experience, Donna Haraway (2008; 241), in different multispecies encounters, also takes up the notion of joy as "a high of "getting it" together in action…" when "Unexpected conjunctions and coordinations of creatively moving partners in play take hold of both and put them into an open"

aquaponic system? Becoming attuned to the Nile Tilapia circling their square tanks gave me a deeper sense of how these animals are "induced and selected under the instrumental force of experimentation" leaving them open to suffering, or worse (Hayward, 2010; 583). Taking on deeper responsibility in the PAFF box ecology meant giving up the (irresponsible) comfort of distance. My own actions impacted lives much more directly, placing heavy ethical consequences on works of ill attention, misunderstanding, or error. To research in the PAFF Box was a situation where 'one's actions became tied to the responses of others, and vice a versa. It was to be drawn into an extended experiment in 'response-ability'[30] (Haraway, 2008).

The deeper I moved/was pulled into these eddies of relation inside the PAFF box the more a new imperative creeped into my planning and action. A different feeling was growing that wasn't simply about experimental success. There was "more to this process than the extraction of data" (Gabrys and Yusoff, 2012), my actions began coalescing around the question of "what worlds will [my] care become enrolled in sustaining" (Puig de la Bellacasa, 2018; 205).

As important as critiques of captivity and the instrumentalisation of life are, I see value in Haraway's (1997) point when she stresses how laboratory practices are never totalizing productions, but instead always overspill with unexpected effects. With the brutal reality that some members of the PAFF box were clearly more compounded[31] than others, I tried to focus my energies on the dimensions of interspecies contact that offered something beyond incarcerating limits. Tilapia are articulate and articulating beings, and with them I was learning how to 'interfere in productive ways' as John law puts it (Moser, 2007; 343). What happens if I clean the system at different times, in different ways? What happens if I alter the flow rate of the system? what happens if I feed the fish differently? Where can I sense a positive response in the tilapia? I was honing a different mode of engagement within this experiment, something that shared the impulse Haraway (2008; 223) speaks about in her discussions of human-dog training[32]: "The coming into being of something unexpected, something new and free, something outside the

[30] As Haraway (2016; 34) puts it: "passion and action, detachment and attachment, this is what I call cultivating response-ability; that is also collective knowing and doing, an ecology of practices."

[31] As mentioned earlier, Haraway (2008; 250) reminds us that technoscientific productions are compound, built from proliferating hybrid associations, yet she also alludes at another dimension when she asks us to "Remember also, one of the meanings of compound is 'an enclosure, within which there is a residence or a factory' —or, perhaps, a prison or temple." A perspective that works to draw out the differential forms of enclosure brought to bear upon the inhabitants of the PAFF box experiment.

[32] Here, my emphasis is on the spirit of engagement. I do not wish to imply an undue similarity or overlap between the relations that dogs and tilapia can form with humans. I also do not wish to extend the idea of 'training' in the sense Haraway uses it to my own interactions with the fish in the PAFF Box.

rules of function and calculation, something not ruled by the logic of the reproduction of the same, [this] is what training with each other is about."

I'm talking here about the way degrees of emergence within scientific practices intersect with forms of care. The work of Isabelle Stengers resonates powerfully with what I was doing here. She conveys the way in which 'the possibility of a new practical engagement' emerges within the experimental settings of science, where new worlds and new possibilities appear through the terms of inquiry set by experiments (Stengers, 2000; 92). Such engagements, for Stengers (2000; 91), appear 'in the aesthetic, affective, and ethological sense', a point that rings with great relevance to my work in the PAFF Box. As I discussed in the previous section, beyond the strict protocol of the experimental procedure, maintenance of this aquaponic community was heavily invested in a tacit, intuitive, sensorial attunment of labour. I began to sense this dynamic interpretative ground as a space of possibility. How might I interpret the system differently? How might I make myself available to it in a different way? Ultimately, what is "the possibility of a new practical engagement" (Stengers, 2000; 91).

Viewed at from this angle developed by Stengers and her collaborators, science becomes less about facts and more about relations and enquiries that reorder and realign the practices of world-making. How might an aquaponic engagement be reconfigured from the inside around different, more caring objectives? Or, to put it in the terms of Dmitri Papadopoulos (2010), how to enact a *constituent politics in technoscience*[33]*?* It is here, that my colleague's own practices of tinkering and fine-grained responses of care were a great inspiration. With my own situated responses I hoped to extend these directions. The best I could, I tried to engage their attentive, responsible, yet playful exchanges with the materials and processes at hand in the PAFF Box. I looked and felt around within the constraints of the experimental context for opportunities to maximize the possibility of animal and plant flourishing. I carefully began tweaking nodes in the aquaponic apparatus, experimenting with ways to bring about conditions that allowed the Tilapia to express with the health and vibrancy described in my diary passage above. '*Dissenting-within'* the PAFF Box collective was, as Maria de la Bellacasa (2017; 80) puts it, a way of "testing the edges of a "we," of what we consider "our world."

To some degree, what happened in the PAFF Box might be described as a kind of *study* in the sense that Moten and Harney (2013) have developed, a kind of collective learning that is resistant to the disciplining that configures knowledge production in the academy. For them, study is

[33] Papadopoulos (2010; 18) describes constituent politics in technoscience as an **"**attempt to create material alliances between *particular* groups of people (there is no such thing as 'humans') and *particular* non-human others (there is no such thing as the 'non-humans') in order to confront injustice and to make new conditions that ultimately challenge how a certain region of objectivity works."

something already going on underneath or inside (or despite of) the structuring of knowledge. *Study*, as Andrew Goodman (2018; 24) points out, "is not a usual kind of methodology – rather it might be thought of as a becoming-methodology immanent with the problem." My engagements with the system were essentially open-ended, they formed in relation to the specific conditions that the PAFF box threw up, and my responses had to be reinvented as the flow of conditions changed. Essentially, these actions were *tactical* in the sense de Certeau (1984) envisioned the improvisation of everyday action.

For De Certeau (1984, xix), the 'tactic' opportunistically reuses, redeploys, elements of a system, "insinuates itself into the other's place, fragmentarily, without taking [the system] over in its entirety, without being able to keep it at a distance". Tactics, being co-composed with the events in which they seek to intervene, must be reinvented through practice without recourse to the rigidity found in sets of rules or protocols. There are affinities here with how the Invisible Committee (2015; 124) contrast the 'engineer' with the 'hacker': "Whereas the engineer would capture everything that functions, in such a way that everything functions better in service to the system, the hacker asks himself "How does that work?" in order to find its flaws, but also to invent other uses, to experiment." I altered flow rates and took note of what changes happened. I experimented with the water levels in the system and tracked this through the water sample readings. I reorganised the cleaning schedule and feeding styles. I found myself becoming attentive to the weather patterns, watching out for forecasts of particularly cool nights or hot days, adjusting the fish tank heaters a touch where needed to keep things at a comfortable level. And at the end of the day, sat on the train home, my thoughts would swirl with fish and pumps and oxygen bubbles as I retraced my moves and questioned where all this was going.

For De Certeau (1984; xvii) "the tactics of practice" are deployed without guarantee or a predetermined end point having 'no base… [to] secure independence from circumstance'. This aspect of my tactical intervention in the PAFF Box carried quite serious risks. When I went wrong, I had to live with consequences and so did the fish, though the balance of burden was sickeningly skewed in this regard. When the fish were sulking and hid from view it was clear I'd turned from friend to foe. In those lonely moments where each party felt discomfort, though of notably different degrees, there was no justification that could bridge the gulf that lies between those whose worlds are lived out in water and those others lived out in air. Yet, when the fish turned to evasion and their presence merged with the tanks that contained them, it was also clear to me that these creatures too had *ways of operating*[34], of reinterpreting materials and others, of

[34] De Certeau (1988; xx) extends his analysis of "*ways of operating*" to non-human acts, and in particular the behaviour of fish when he describes them as: ""victories of the "weak" over the "strong" (whether the strength be that of powerful people or the violence of things or of an

turning bounds into refuge, of repitching bodies to escape my gaze. This resilience was admirable and it galvanised my desire to become more careful. De Certeau seemed to know the risks involved in deploying ungrounded tactics, but like him I tried to re-spin events and forces in an optimistic way, to learn from mistakes, to reinvent my practice, as he puts it: “Whatever it wins, it does not keep. It must constantly manipulate events in order to turn them into "opportunities." (De Certeau, 1984; xix). Again, as for the ‘hacker’, the drive of all this *experimenting* is in “exploring what such and such a technique implies *ethically*” (Invisible Committee, 2015; 125 italics in original).

Experimenting with different tweaks and their combinations had lead me to make three considerable changes: 1) I had raised the total water in the system towards the maximum level. With more water in the system there was a greater level of dilution across the PAFF box. I’d learned this slowed the impact of detrimental chemical accumulation, giving more time to respond. 2) I had reduced the solid filter cleaning rate but spent longer on each clean doing a more thorough job. Although this was an exhausting and less than enviable task that cost me a lot of time, a cleaner system reduced the amount of solids reaching the biofilter, with what seemed to be the benefit of bringing greater stability to the bacterial populations. 3) I had increased the overall flow rate of the system. Faster flow rates mean greater water recycling, greater bacterial action, and therefore should reduce the residence time of toxic metabolites, ammonia and nitrite. But this was a contentious point[35]. Increasing flow increases system pressure. On a system like this, higher pressures give greater chance of mechanical failure (seals leaking, pipes bursting, pumps wearing out etc.).

By the time my colleagues came back, the system was already operating in a different way. With my intervention in the PAFF box I hoped to open questions about the nature of experimental practices and to some extent this meant challenging the ‘traditions’ of my colleagues. Many scholars of science have pointed out that to get ‘in the presence of’ demands work, speculative invention, and ontological risks (Stengers, 2000, Barad, 2007, Despret, 2013). If bailing heavy buckets of exhaust water, reading a slippery tilapia semiotics, and pushing to the limit a Projet SE 20/8 tri, 280watt aquaculture pump could guarantee such commitments, I would surely be on to

imposed order, etc), clever tricks, knowing how to get away with things, "hunter's cunning," maneuvers, polymorphic simulations, joyful discoveries, poetic as well as warlike. The Greeks called these "ways of operating", 'metis’. But they go much further back, to the immemorial intelligence displayed in the tricks and imitations of plants and fishes.”

[35] My colleagues had warned me a number of times that they had never managed to push the pump above 67/100 with causing something to explode. But by the time they returned, I had the pump running at 74/100. This was a risky move, but the payoff of sparkling clean waters and bright lively fish seemed at the time to justify the risk.

something, I thought. But truth be told, none of us knew how these practices would integrate, flow into and out of, transform, this aquaponic enterprise.

5.9 Back home – following data

The final ten-week growing cycle came to an abrupt close. Leaves squeaked and aromatic perfume spritzed the greenhouse as we pulled, roots and all, billowing plants of giant basil and frilly lettuce from their 'plugs'. Aside from the algae eking a fine living in the grown beds, every last bit of green was removed from the greenhouse, chopped, weighed and sent to the ovens to be dried ready for molecular analysis. Carrying the fruits of our labour to the lab, this was an exciting time filled with enthusiasm and laughter, but equally, it was also a strange point, a moment where the end became visible. The fish stayed put; without another experiment lined up for the autumn, they would take up a position of purgatory. I said my goodbyes to the team, and I got the final train back to Brussels. The end of an experiment, the end of summer, the end of an aquaponic world.

We had successfully maintained the ecosystem for the entirety of the experiment, and that alone felt like an achievement, but we couldn't be certain of the experimental success of the work until the final analysis had been completed on our data set. Back in Southampton I exchanged emails with the team in Belgium, and the results slowly emerged over a couple of weeks. What they described was that the PAFF box prototype contained some rather serious flaws, the most notable of which was an excessive nutrient loss from the system on a magnitude that surprised the team and had us scratching heads for a couple of weeks.

The nutrient loss indicated by the nutrient data readings signalled that the PAFF Box prototype was inefficient, not hitting the levels of nutrient recycling that the team had hoped for. Regardless of this, our team were delighted. Although this surprise highlighted a failure in the PAFF Box system, *experimentally* the PAFF box was regarded by the team as a success: without too many anomalies, or causes for concern, the data appeared to rigorously describe the material flows of the system – even if that system was flawed. For my colleagues, this was a problem that came down to system configuration. In their eyes, the problem might easily be remedied in future with some fairly straightforward changes in system design or alterations to running parameters. The data further confirmed the central importance of careful system design for efficient nutrient cycling in aquaponic systems. In this regard, the results brought light to an extra aspect of system dynamics that must be accounted for in future studies, and contributed toward building an holistic picture of nutrient cycling in an aquaponic systems. This result became something of a punchline to our PAFF Box publication (Delaide et al., 2017). I was delighted to have been actively part of the process, to be part of the many interleaving ecologies of practice that had made the PAFF Box experiment a success.

Nevertheless, there was something puzzling about the excessive nutrient loss. None of the team had suspected something like this. There were no obvious signs in the outward appearance of the system, which by all indications was behaving in a stable way with strong indications that the fish and plants were flourishing. Then one of the team noticed a spike in water consumption during the third growing cycle. This was strange, but it seemed to explain the mysterious missing nutrition. A few quick-fire emails went back and forth. Something about this captured the interest of Boris, so I encouraged him to go further. “In June and July…” Boris explained, “the water exchange was below 3% and when you came it went to 5%. So it drastically increased… it was actually very very interesting, because if you see here on this graph [points to graph] of nutrient accumulation and EC, you can see that after you came, we basically stabilised the EC and other nutrients in comparison to the beginning of the experiment when we had a constant increase, almost linear accumulation of nutrients. So this high water exchange impacted pH – we kind of controlled it”. Boris was referring to a graph that appears in our published paper (Delaide et al., 2017). Although inconspicuously rendered in page 6, it is possible, as Boris highlighted, to see the point where increased water exchange coincides with the moment I entered the experiment. Further effects can be traced through the pH values and plateauing Nitrate concentrations displayed on page 5.

The data appeared to carry evidence of my intervention. This was quite a thing. What’s more, their distribution suggested that the system had displayed greater stability. Falling pH and alkalinity levels had been kerbed, nitrite remained at baseline, and the EC (electric conductivity, a crude measure of the total ions present in the system water) along with the nitrate, stabilised. On top of this, data on the fish was very pleasing. FCR ratios for our fish (1.56) were significantly better than the results published by the forerunning aquaponic research team in Hawaii led by Rakocy (2006), and although fish mortality averaged across all three runs of the PAFF box experiment fell within levels deemed acceptable for industry (5%), during the final run this dropped to 2%. Joining the dots between the objective material pointers and my intervention gave an immediate thrill. A certain consistency held between my own situated impressions, those of my colleagues, and our collective understanding of what the data expressed. There was something deeply satisfying in the way my ‘careful doings’ had precipitated out into the readings.

Actively and critically participating in the experimental success of the PAFF Box had been an amazing experience, but the thrills of becoming entangled in our teams lives and data sets was short lived. As we worked towards the publication of our paper, the discussions of our data analysis continued. Interpretations progressed, and as shared meanings coalesced around data points, some issues and viewpoints arose that complicated the (my) narrative. Deep realisations struck home that put question to the impact of my work in the PAFF Box and cast the whole ethnography in a different light.

5.10 Unravelling matters of aquaponic care.

By tracing the relationships between elemental flows and fluxes in the PAFF box environment, the nutrient data had allowed the team to uncover a central flaw in the functioning of the PAFF Box. The fish were producing waste faster than could be assimilated by vegetative growth. It was a case of balance, or rather imbalance, in the ratio between fish stocking density and surface area of the grow beds. A lack like this in the root system nitrogen sink becomes the source of a persistent problem in a closed aquaponic system whereby nitrogenous wastes accumulate in the water as Nitrate and become a rising danger to the fish. In the absence of balance between fish excretion and plant uptake, the most important factor dictating nutrient loss from the system becomes water exchange. It was here where my actions within the experiment gathered important material consequence because the data suggested that a key feature of my interventions was a considerable increase in water exchange for the system.

If the nutrient data gave the opportunity for our team to revisit hidden associations of material and movement within the PAFF box, it also started materialising serious problems in this ethnographic narrative by opening up my own intervention to post-experimental scrutiny. The unexpected data cast the coordinates of my actions over a very different material context than we had thought. What the nutrient data showed was that my interventions were at the heart of the excessive nutrient loss. My commitments towards a practice of attunement, sensitivity to vulnerability, and responsiveness had taken my intervention down a particular path. The extra cleaning, faster flow rates, and numerous other interventions had instigated a shift in the aquaponic system towards a dynamic of higher water consumption. The molecular reality of all this was that I was washing away nutrients before they reached troublesome concentrations. Without realising, I was passing on a chemical debt downstream: creating a solution by externalising a problem. Sparkling and stable waters in the PAFF Box ecosystem had come at a price, and importantly, this price was not one that could be covered solely by my own busy labour, no matter how caring it had seemed at the time.

This realisation was troubling on a number of levels. One of the strongest justifications given for pursuing aquaponic science is the pressing need to develop solutions to resource hungry and environmentally damaging practices that typify intensive aquaculture production. Here I was, essentially abandoning large amounts of water, material resource, and (potentially) destructive nitrogenous waste down the drain, ignorant of the hidden, though certain, ecological and economic consequences. In pursuit of greater attunement with an aquaponic ecology, I had simply expunged those inconvenient materialisations of our collective labours that had presented difficulties to the inhabitants of this citadel known as the PAFF Box. Disappointingly, my caring practices appeared to have reproduced what Fortun (2014; 313) describes as 'the insipid habits of late industrialism', the function[36] whereby 'production is protected; pollution is externalized.' (Fortun, 2014).

The nutrient data had rendered me complicit in what appeared now rather obvious acts of anti-aquaponic polluting. But this point requires some perspective. We are talking here about a proportion of the waste generated by no more than 200 fish - this was not *Deepwater Horizon*. My intention here, is not to over-stress whatever environmental stress I may have caused in pursuit of aquaponic flourishing. Rather, the point is that the nutrient data exploded any unproblematic or innocent image of the situated ethics of care I might once have held, showing my actions had blind spots and carried ramifications of which I was ignorant and unable to contain. Little did I know, this was only the beginning of the breakdown of the neat narrative of intervention that I still held close.

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If the first shock came from the cold and calculated renderings of nitrogen molecules in our graphs, the next would come from frank and piercing questions directed at me by my human peers. According to the data, my intervention had registered clearly in the material constitution of

[36] Morton's (2016; 43) *Agrilogistics* offers a similar reading to that of Fortun's (2012*) late industrialism,* in the way it highlights the difficulties we face in escaping the paucities of our intellectual heritage. "Agrilogistics promises to eliminate fear, anxiety, and contradiction— social, physical, and ontological—by establishing thin rigid boundaries between human and nonhuman worlds and by reducing existence to sheer quantity". Reading these words after the fact was an uncomfortable process for me, simply by their worrying resemblance to the logics behind my own intervention. Consider here also Tim Cohen's (2012) diagnosis of the powerful, often latent, psychotropes that populate and reproduce the Anthropocene predicament, even from within our own research practices - as Morton puts it (2016; 44): "How we write and what we write and what we think about writing can be found within agrilogistics."

our system, precipitating as it did, some disingenuous dimensions of my own work that I was still coming to terms with. The same, however, could not be said of my colleagues, for whom the intervention seemed to lack any equivalent purchase. The data had opened up many questions, around my role in the experiment, the way I 'felt the system', and I took these to the team.

We all agreed that 'feeling the system' took an 'adaptation time' and necessitated a responsive, 'subjective' dimension to our work, but where I found a politics in "experimenting with matter's inherent movements and constraints" (Papadopoulos, 2014; 76), the team situated the process within a different normative frame entirely. As Boris explains: "our interpretation is, our feeling is, directly connected to the measurements we take, all the parameters we monitor…. Yes, it can be different for different people, but the goal will be the same for everybody – get the right parameters for the organisms to grow in the best condition."

For the team in Gembloux 'feeling the system' was a pragmatic process. Although it was 'very interesting' that my manipulations appeared to have brought a certain stability to the PAFF Box, there was nothing 'deep' to be found in the way my intervention had flowed into the data. When I asked: "is there a 'politics' within the experiment that hasn't really been appreciated?" Boris gave the reply: "There is definitely a question of how you manage, or 'a politics' like you say, in how we do the experiment. But, when you design an experiment and protocol, you set up this kind of politic within the protocol. If we take the example of this water exchange: a good protocol would be 'when you see the ammonia go above 3ppm you clean the filter, for example; when you see nitrite go above 1ppm, you clean the filter' - something like that."

For my colleagues, 'feeling the system', like other areas of laboratory technique and experimental design, was imbued with the need for standardisation[37](Birke et al., 2007). Where I found 'feeling the system' to be a function loaded with ethico-political content, something situated in the unique and immediate human-animal realities thrown up in the experimental process, my colleagues experienced it as a more mundane procedure, one where ethico-political commitments were located in agreed upon targets for water quality parameters, that were themselves based on welfare studies concerning populations of model organisms. Tora Holmberg (2008; 332) has described a similar experience in her work with 'experimentalists', where the push for standardisation when developing a 'feeling for the animal' in laboratory spaces, is one that places concerns "not on individuals but the animal as a model or case." If my experience of 'feeling the system' was of a situated response operating below, or before, or even in spite of the

[37] As Burke et al (2007; 36) observe: "Not only are the animals made into standard forms through breeding, but so too is their living space, the animal house, as well as the structure of the whole laboratory— all of which is aimed at reducing experimental variability."

rules, for my colleagues, the responsibly was in the following of welfare standard guidelines by making the correct adjustments. Thus, when asked about the significance of my acts of care within the experimental procedure, Boris could flatly conclude: “The way that we take care will maybe impact, but not on the big picture. On the big picture we want to keep the water quality parameters close to a target.”

These alternative readings cast ‘feeling the system’ in a less significant light. Although I wasn’t expecting my team mates to articulate a ‘politics of experimentation’ in the same way I had learned through the niche enclaves of more-than-human scholarship, it nevertheless surprised me that they felt the endeavour was inconsequential. To be clear, it wasn’t simply a case of trying to hold up my actions to demonstrate the importance of attending, and indeed the impossibility of distancing oneself from, the immediate multispecies relations that are implicated in scientific productions - my colleagues knew fine well about this, and more than I did[38]. Rather, and more specifically, my intervention had struggled to show how a multispecies experiment might be anticipated as a ‘contact zone’ - that is; “fraught with power, knowledge and technique, moral questions” (Haraway, 2008; 205). I was interested in how coming into the process with different expectations might reorganise experimental directions around a different kind of aquaponic system, or more speculatively, might extend towards a different kind of researcher or maybe even a different kind of science[39].

Now, although my colleagues understood very well that their manipulations in the PAFF Box were loaded with uncertainty, opportunity, and consequence, clearly, they had no need to relate to it as a ‘contact zone’, nor did they see it as a terrain that harboured revolutionary potential. It was obvious that we brought very different aesthetic and ethical viewpoints to the circulating flows of this small shipping container. My point here is not that my colleagues were simply ‘ignorant’ of the potential at the heart of the experiment. On the contrary, hearing my teammate’s take of things, put to question this very potential and directed the spotlight back at my own position.

This was a perspicuous moment in my research project, where both data points and the opinions of those involved in the PAFF box began to coalese in formations that threatened the very heart of my practice. On the one hand, surprises in the nutrient data had exploded any unproblematic or innocent image of this ethical intervention that I might once have held, showing my actions had

[38] Boris, who had much more experience than I at intervening in aquaponic events had summed this up succinctly: “If you don't manage it, the system will definitely crash. The system itself requires an intervention from the researcher or farmer who has to take care of it.”

[39] Consider Stengers (2018; 102) speculative point here, when she asks us to consider: “If relevance, rather than authority or objectivity, had been the name of the game, the sciences would have meant adventure, not conquest.”

blind spots and carried ramifications of which I was ignorant and unable to contain. On the other hand, my colleagues challenged my belief in the very possibility of intervention within this experimental setting, as well as the hope I had in the efficacy of my caring actions. Back home in Southampton, dislocated from my team and increasingly from the idea that any guarentees about my work might have travelled with me back to England, this was a moment of deep questioning, one that Atkinson-Graham et al. (2015; 739) have experianced, a moment where 'one notion of care sits uneasily with another', where care is 'felt as an absence or ambivelant presence'. 'Looking at the big picture' as Boris put it, encouraged me to revisit my caring practices with a different focus. I felt the need to re-examine my practice in Gembloux and the nature of my intervention. In the next section, I turn toward my own caring practices - not looking for justifications or excuses or as an act of self-criticism - but in the hope, like Atkinson-Graham et al. (2015; 739), that by reflecting on these moments 'new ways of relating to and within [my] research project' might open up.

5.11 Reflections on care and intervening

One thing must be stated. Neither the surprises in the nutrient data, nor the scepticism of my colleagues, nor even the pangs of unwanted reflexive hindsight, had the authority to annul entirely my intervention. Reconfiguring the workings of the system the best I could to improve the environment of these fish and other creatures was a situated ethical imperative. It carried an immediate kind of urgency for the beings involved. A commitment to real-time ethical engagements in experimental spaces is one I still feel should be persistently provoked by all sorts of experimental collaborators, and, as Haraway (2006; 83) puts it, "No one knows how to do that in advance of coming together in composition." However, although the importance of my situated response can be stressed through claims to immediate ethical responsibility, both the data and my colleagues opened up more problematic dimensions to these claims, shoring up the dangers in my framing of matters of care too narrowly within the situated entanglements of the experiment. The discussions below will aim to tease out some more subtle points of this predicament, drawing out aspects of my work that speak as much to current theories of care, as they do to notions of intervention in technoscience.

It is true that scholars have stressed the 'non-innocent' role of care in human/non-human encounters, especially when attempts at minimizing animal stress often run side by side with the need to 'manage' animals more effectively (Haraway, 2008, Despret, 2013). Yet, even when this is acknowledged, it is often argued that care nonetheless fosters responsibility and harbours potential for epistemological and ethical change. For instance, when Haraway (2008: 82) insists upon the need to stop abandoning ourselves to the temptation of innocence in our explorations of the articulation of scientific animals, she adds to this that the responsible work of care might, where necessary, bring "the enterprise to a halt". Seemingly, she is implying that care has an efficacy to effect important change in technoscientific networks, but my work in Gembloux raises questions regarding the of the nature of care for bringing such transformative results when intervening in laboratory settings.

The point raised by my teammates was that beyond the immediate 'utility' of my intervention to the experiment (my teammates recognised my actions increased the chance of experimental success), my caring practices could so easily be dismissed as inconsequential. This idea suggested that my intervention of care was insignificant except in the way it furthered the experimental conditions it sought to disturb. There was something very troubling in this point. Giraud and Hollin (2016) have importantly demonstrated that care is not always in negotiation with or opposed to instrumental processes. Rather, their reading of the events of an experimental beagle colony at Davis University, California complicate notions of care, showing for instance that in certain contexts care is precisely what *enables* the instrumentalization of life. Looking back, in many respects, my tweaking interventions in Gembloux were actually not in opposition to the overall aims of the experiment. Looking back, the case for an embodied ethics steeped in attunement, sensitivity to animality, vulnerability and responsiveness, in fact, carried an alluring affirmative energy from within the experiment: more careful attention to the system and its inhabitants, leads to; greater chance of system stability and group flourishing, leads to: greater chance of experimental success. No human member of our team would argue against my efforts to more attentively attune to the needs of these aquaponic creatures, on the contrary, I was praised on a number of occasions for this, since in many respects it was perceived as a positive contribution to the experiment. Spiralling in this positive feedback loop of affirmative (re)action, it was easy to slip into the view that my interventions were catalysing a 'win-win' situation, out of which all - the organisms, the team, the experiment, myself - stood to benefit. Was this what Giraud and Holin (2016) describe as 'Affective Utopia'?

For Downey and Dumit (1997; 10) the main scholarly risk for engaged researchers who take on official roles within scientific worlds is what they call "co-optation: allowing one's work to be subsumed completely by the categories and goals, hence, the power relations that define the field of intervention." Had my deep involvement in the experimental procedure, my 'hiring in', come with too great an epistemological price? It was only through an essentialist trick of privileging the bodies and boundaries of our aquaponic system, that the functionalist justifications of our experimental success could be made. But more shocking for myself, was the realisation that my own commitments to care during this experiment had been guided by very similar principles. My actions took an 'overwhelmingly positive' perspective with a focus on 'what works' with 'little time for what doesn't', features of action that for Fortun (2014; 313) deny the 'complexity and controversy' of situations. With a heavy bias towards the 'functionalist' responses of the most charismatic (more easily bounded) 'species' of the system the concept of care that I had acted upon had not only side-lined considerations of equally important molecular actors (N compounds), but had left, more or less untouched, the deeper seated 'productionist' and 'essentialist' commitments that were foundational to the experiment and foregrounded much of what happened in Gembloux. The style of my action - the 'tactics' of my intervention - of incorporating and tinkering with processes and events might well have gotten me 'into the science' of the PAFF box, but they might also have locked my research on trajectories I hadn't bargained for, that I couldn't justify back at my desk coolly writing up this account.

With such intense focus on scientific *practice* I had run the risk of responding only to the objectives and spatial rationales laid out by the scientists themselves (Greenhough, 2006), becoming epistemologically boxed-in by the bounds of the experiment in Gembloux. Taking the PAFF box at face value, as a bounded entity, and working within those limits, my intervention of care had inadvertently protected, embellished even, the experimental context. And so, even though my intervention challenged aspects of experimental configuration and deployment (particularly those aspects that concerned the lives of tilapia) it left unchallenged or indeed internalised and performed many of the undergrounding logics and epistemological assumptions that founded this experiment.

These moments were difficult for me to palate, for they highlight my enrolment into subjectivities of experimentation I'm less eager to associate with. They underline the ambivalent side of Maria Puig de la Bellacasa's (2017; 80) measured point, that bringing matters of care to scientific collectives may well require an "openness to accepting one's thought as inheritor, even of the threads of thought we oppose and worlds we would rather not endorse". Learning to inhabit scientific worlds, as I found, might well mean placing oneself within, embracing even, epistemologically uncomfortable terrain. But there is more to this, because inhabiting technoscience, as I found, also means opening one's body to its movements and demands.

Actively working within the PAFF box was a lesson in how human bodies become assimilated in technoscientific productions. By inhabiting the aquaponic space in Gembloux, I had opened up to forces, demands, a '*form of life'* (invisible committee, 2015) that was unexpected and that influenced greatly my ability to act[40]. The PAFF Box asked questions of me and in response, I did surprising things. In my apprenticeship of this *form of life* available in the PAFF box I had incorporated particular techniques into my world that had materialised some relations over others (invisible committee, 2012). Becoming aware of the more-than-human forces that shape how our bodies react and respond in fields of technoscience, as in my own case in the PAFF Box, might cast Downy and Dumit's (1997) point of 'co-optation' through a posthuman lens. The affective tonalities that resonated between and across actors in the PAFF box expressed how technoscientific assemblages generate indeterminate experiences that are not solely the result of human planning or intent, nor can they be planned for. I had been caught up in the event and it was conducive of very particular, and restricted, patterns of care. Coming to terms with this, I now read in a new light Law and Lien's interpretation[41] of the more-than-human obligations set forth in an industrial salmon farm assemblage. Sensing a similar reversibility to my actions and obligations in Gembloux, I found myself asking: 'what did the [aquaponic system] make of me?' (Law and Lien, 2014).

The above discussion highlights the way my practice took on subtle epistemological and ontological characteristics particular to the task at hand, having important consequences for my research. Writing about these events is not simply an exercise in reflexivity, nor is it about airing the anxieties I had about my own research, and what, if anything it 'achieved', or whether this was important. I discuss these aspects of limitation inherent to my intervention, because Gembloux gave me a deeper sense of what Martin et al (2015, 635) mean when they stress the importance not only of paying attention to the *acts* of care but also to "the very conditions of possibility for care." My work appears to join a collection of other recent studies that have relayed the dangers associated with an ethics garnered too narrowly from situated entanglements. From the links between laboratories and military apparatuses (Johnson, 2015), industrial agriculture (de la Bellacasa, 2017), disability politics (Hollin, 2017) and the aforementioned experimental standardization of laboratory beagles and their personnel (Giraud and Hollin, 2016), these studies each have underlined a point my own research speaks of: that certain responsibilities and

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[40] The invisible committee (2015; 120) develop a useful and relevant angle for me on the concept 'form of life': "there's no generic human essence: because there are only particular techniques, and because every technique configures a world, materializing in this way a certain relationship with the latter, a certain *form of life*. So one doesn't "construct" a *form of life*; one only incorporates techniques, through example, exercise, or apprenticeship".

[41] Observing the more-than-human demands (trappings?) of an industrial salmon farm Law and Lien (2014; 8) state: "Even at a highly ordered site such as a salmon farm, it is also plausible to argue that salmon, in fact, control people. If humankind is to consume salmon on an industrial scale, then people are put to immense effort to fit round the demands made of them and their (multispecies) surroundings by the salmon that they farm."

manifestations of agency may already be foreclosed in the gathering of situations around particular forms of experimental apparatus or structures. Within the experimental context of the PAFF box, the possibilities available for realising certain types of relations and care were, to a large degree, prefigured by the apparatus well before my arrival.

5.12 Apparatuses

Following this convoluting narrative as it breaks down and flows through and around points of ambiguity, imperfection, and trouble, we now turn to the apparatus. In the case of the PAFF box, dimensions of care that fell outside the immediate temporalities of the ongoing experiment carried at least as much consequence for multispecies flourishing as the consistent upkeep of the experiment through caring practices of tinkering. More specifically, in Gembloux, an imbalance between fish and plants became a defining aspect of the ecology that prefigured patterns of existence, consuming the attention and effort of human and non-human participants alike, and contributed significantly to the 'form of life' available to those in this specific aquaponic world.

Karan Barad's (2007; 141) ideas of the *apparatus* become useful here. For her the apparatus expands well beyond what might be recorded in the final publication of scientific results, the official 'laboratory set-up'. Rather, the term takes on a whole range of material-discursive inputs that combine to maintain a particular experimental apparatus. Barad (2007; 167): "Apparatuses are not static laboratory setups but a dynamic set of open-ended practices, iteratively refined and reconfigured." In many ways echoing earlier ideas of technoscientific networks[42] (Latour, 1987), the apparatus, for Barad, is an expansive composition of heterogeneous relations, emergent through practice. "Apparatuses are not mere observing instruments but boundary-drawing practices -specific material (re)configurations of the world - which come to matter" (Barad, 2007; 206). If apparatuses become constituted through particular practices that are "perpetually open to rearrangements, rearticulations, and other reworkings", then getting the instrumentation to work in a particular way for a particular purpose is, for Barad (2003; 817), "part of the creativity and difficulty of doing science".

Importantly for us here, Barad's rereading of events of early quantum physics emphasises how the apparatus makes a 'cut' – at once allowing certain things to become *determinate*, whilst

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[42] Consider for instance "Apparatuses have no inherent "outside" boundary... Apparatuses are open-ended practices." (Barad, 2003; 815)

simultaneously *excluding* others[43]. There are obvious affinities here between Barad's conceptions of how scientific apparatuses make 'cuts' in reality and other feminist scholars ideas concerning the practices of care in technoscientific contexts (Mol, 2008, de la Bellacasa, 2017, Haraway, 1997). Bringing these ideas to the PAFF box we can appreciate the way certain discursive-material arrangements specific to the apparatus in Gembloux acted as a boundary setting process, a way of deciding what comes to matter in aquaponics. More specifically, the apparatus gathered for the PAFF box experiment had a very specific arrangement that had been focused towards a strict set questions. What mattered in this apparatus were the flows of a select collection of organic and inorganic molecules, as well as the consumption of elections and water. Directing the probes, metres, our bodies, our material-discursive attention, towards these features, had rendered certain things determinate whilst others were excluded. In this way, the apparatus helped cut the boundaries to a particular manifestation of aquaponics.

Understood through the conceptual lens of the apparatus, it is little surprise that my intervention would be regarded as insignificant by my colleagues. Barad (2007; 26) maintains that in the practice of science "which properties become determinate is not governed by the desires or will of the experimenter but rather by the specificity of the experimental apparatus." The fact was, that the apparatus (of which I was a part) had been gathered in such a way that my pursuit of care within the experimental context could be perceived only to the extent that it registered in the presence and movements of specific molecular components. This explains why my presence had made a difference, but crucially - as my colleagues pointed out - this difference had hardly *mattered*. The apparatus of the PAFF Box was simply not arranged to respond to those aspects of the system that concern the effects of human intervention on dimensions of fish, bacterial, and plant flourishing. In this way, framing the events in Gembloux through the idea of the apparatus becomes especially relevant for my experience of the PAFF box, offering a slant of sober (agential) realism to the interpretation of my intervention.

If, as Barad (2003; 823) points out, "all bodies, not merely "human" bodies, come to matter through the world's iterative intra-activity—its performativity", then the question becomes what bodies? What type of bodies? Or which parts of bodies (Birke, 2012, Roe, 2010)? Other than the mass readings of the tilapia (taken at the end of the experiment to gauge their growth) the PAFF box data is not particularly directed at the animal, plant, bacterial, or human bodies involved in

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[43] Barad (2003; 816 emphasis in original) stresses that apparatuses "are neither neutral probes of the natural world nor structures that deterministically impose some particular outcome… apparatuses are not mere static arrangements *in* the world, but rather *apparatuses are dynamic* (*re*)*configurings of the world, specific agential practices/performances through which specific exclusionary boundaries are enacted."*

this experiment. With its focus on the molecular constituents that populate the PAFF box, the emphasis was placed on the *flows* of material into and out of bodies, how compounds are assimilated or excreted. These molecules are transformed by and transforming of bodies, but the object that compels the PAFF box aquaponic experiment is the 'budgets' of these molecular cycles, and thus our experiment renders those bodies of this aquaponics system in particular dimensions and scales intelligible to discursive circuits of biochemistry and nutrient cycling. This point runs parallel to Candea's (2013; 122) observations in a different scientific context - the 'Kalahari Meerkat Project' - where, as he explains, the object of study for researchers "is not the furry critter itself, but a more uncanny entity made up of bits of its weight, environment and 'cooperative behaviour'" (Candea, 2013). We might adapt Candea's point and claim that for the PAFF box, the object of study was not the fish, plants or bacteria in themselves, but the metabolic traces that flow through and are left behind from their collective becoming. This 'uncanny entity', this compound of biological, technical and discursive things, this collective metabolism, is the 'ecosystem' of aquaponics, an ecosystem made determinate by the particular aquaponic apparatus configured in Gembloux.

Highlighting the way aspects of bodies are rendered determinate or invisible, productive or insignificant, part of an ecosystem or not, is an attempt to "contest and rework what matters and what is excluded from mattering" (Barad, 2003; 827). Looking back, it is now plain to see that the move to render certain molecular realities of the PAFF box determinate, had the effect of excluding certain dimensions of bodies and relations between them. The most obvious case is the omission of the PAFF box's human personnel from the description of the PAFF Box in our final publication. Having experienced the depth of human involvement in this ecosystem, after living this ethnographic account, the moves in our paper to invisiblise our involvement might well appear audacious in its censorship; the way it rushes to reinstate that tired 'cordon-sanitaire' of the modern scientist (Haraway, 1988), a line forcefully etched somewhere inside this collective metabolic act between the 'ecosystem' and its 'human' contingent.

My ethnographic account shows the way many dimensions feature in the creation of aquaponic ecosystems beyond those described in the budgets of nutrient cycles. This account however, is not only about exposing a process for the way it reinstates hierarchies of power into our technoscientific productions, for instance in the way we organise our apparatuses around particular objects over others. If we turn back towards my own intervention, we find that by prioritising one node in the PAFF box ecology over others - centring my attention so intensely upon the needs of the tilapia – I had taken a narrow path and become insensitive to realities of other actors in the system (most notably the compounds of Nitrogen). In so doing, my account, my intervention, was dicing with what Isabelle Stengers describes as "the ever-present risk of "silencing" the very thing one is interrogating." (Stengers, 1997; 18)[44]. The revelation springing from these inadequate manifestations of care is that the objective measurements of micro and macro nutrient levels - those data points that might appear at first glance to populate a disembodied and disinterested scientific knowledge – actually carried with them dimensions of potential care that had been ignored by this supposedly engaged, risk taking, ethically sensitive, somatically attuned, more-than-human researcher. Or, to put it along the lines drawn by Stengers, the experimental apparatus in Gembloux had allowed the ecosystem of the PAFF box to speak back, object, against my account of experimental care which now appears unduly totalising and short sighted.

If the data had exposed the shortcomings of my intervention in that my actions had rendered certain families of Nitrogen molecules unaccountable, the very same moves of mine within this apparatus had highlighted the narrowness of a science able to perceive/perform animals only as mechanisms of an elaborate Nitrogen cycling scheme. Importantly, both of these material-discursive arrangements were able to render crucial aspects of this aquaponic world that must be taken into account if the pursuit of a more caring food system in the Anthropocene is to be taken seriously. My view of aquaponics had changed. The words of Dimitri Papadopoulos sum up perfectly this shift. As he explains, the question 'Who is not included?' is not necessarily the most important regarding presence and absence in technoscience. Rather, the more appropriate question concerns: "why the existing political and productive assemblies we have produce absences and render specific actants and their practices residual…. Absence is not about the recognition of a missing other but of creating different ecologies that can become inhabited by these others" (Papadopoulos, 2014; 75).

On a fundamental level, then, my account draws attention to 'how different human material and semiotic constructions and orderings of space/place create differential conditions for moral behaviour and social/ethical practice with respect to non-humans' (Buller, 2015b; 424). What this work implies in the production of aquaponic systems, is the necessity to consider a larger 'ecology' at work, an ecology that is excluded if our knowledge practices maintain overly narrow, essentialist commitments. My work suggests that response-ability extends outwards, both temporally and spatially, along the chains of material-discursive practices that combine to set those technoscientific objects in motion, to put them to the test. As Haraway would tangle it, it matters which "systems systematize systems." (Haraway, 2016b; 101). The question of care in

[44] Stengers (1997) has developed a sensitivity to how the social and material construction of experimental spaces can render the subjects of empirical inquiry either articulate or silent by enabling or suppressing respectively their capacity to respond. Not allowing our objects the 'power to object', as she says, is to run the risk of silencing that object of analysis by producing results that reflect more the effects of experimental set ups than the effects of the substance, compound, or in this case, ecosystem in question.

aquaponic systems comes with the obligation to think about how non-human components of a system have capacities to interact with each other, how they afford or foreclose certain patterns of existence, with real consequence for the possibilities of living carefully. As Elizabeth Johnson (2015; 309) points out, “if we are to care for a more-than-human future, *how* encounters come together matters as much as the lively and material elements that congeal within them.” And so, towards the end of a deep and challenging personal journey lived out in the thick present of the aquaponic world known as the PAFF box, my account opens up and points attention to the *milieu,* the collections of material discursive practice that gather together, maintain and sustain particular aquaponics systems for particular purposes (Stengers, 2016).

5.13 Parting words – Of ecologies: the PAFF Box and TERRA

This chapter opened by situating the PAFF box and this ethnography on the edge of wider developments that are afoot in the Belgian town of Gembloux as the University of Liege implements a major expansion of its Agro-bio-tech facility. TERRA, soon to be one of Europe’s premier bioengineering facilities, looks likely to secure into the future Gembloux’s historically significant role at the forefront of agronomic science. Developers relay their awareness of the stark challenges faced by our current food system and are eager to position TERRA as the place that brings us “the agriculture of tomorrow” (Moreau, 2018). Albert Corhay, Rector of the University of Liège, raises the flag high: *"Here at Gembloux Agro-Bio Tech, researchers have a front row seat for the agricultural challenges of the future. They help us to innovate and enlighten society's choices. With the promise of the TERRA, they open the fields of possibilities where man and nature are reconciled."* But before we rush with Corhay to mobilize this promise of a reconciliatory agricultural tomorrow, what happens when we slow down - pay attention to - the mobilizations of agricultural research today? There are some lessons to be learned from my own mobilization within the Agro-bio-tech.

The forward thinking setup of TERRA speaks of a growing dilemma for science brought about by the Anthropocene. Witnessing the anthropogenic transformation of earth systems at a global scale - possibly towards irreversibility - brings forth a reality where ecological ‘baselines’, however previously construed, are everywhere vanishing. The Anthropocene thrusts us into a ‘post-natural’ situation one where Nature has been replaced with “a fully worked-over world” characterised by the explosion of *natures,* each marked with the indelible traces of human activity (Braun, 2015; 107). As humans become entangled (blatantly, mysteriously, and increasingly disastrously) in ‘multinatural’ alliances (Lorimer, 2012), serious concerns arise for the sciences, especially those dealing in ecologies, where the ‘normal’ conditions that once undergirded objective assessments for advocating interventions in the world are fast disappearing (Robbins and Moore, 2013).

The symptoms are even more acute in those sciences that took as their goal, not merely the ‘description’ of ecologies, but an active participation in their alteration. The functional and rationalised distillates of modern agriscience, the solutions that ensured progress, now come back to us as ‘monsters’ (Latour, 2011). The monocrop, the gene, ‘round-up’; these essential components of our industrial food system are not the neatly bounded products they were meant to be, nor do they possess solely what Fischer (2003; 315) calls a ‘generativity’, that is, “producing surplus meanings beyond what may have been wanted”. Rather these technical achievements become active participants in an earth system run amok, able to generate ecologies on their own terms, ecologies that come back to surprise us, sometimes in the most terrifying of ways. The realisation is that the formations of resources and infrastructures, those ways of doing and knowing that had mobilised so much to modernise agriculture, to stabilize and universalise productivity, are now running up against limits.

Where do we go from here? TERRA seemingly offers up some answers to these huge concerns. A redeployment of university resources and global investment around more responsive and ‘durable networks’, a reshuffle of departments and personnel around shifting multidisciplinary configurations, and a refocus of research towards multiple scales and novel collective entities that affect agricultural science and its questions (Moreau, 2018). An ‘ecological imaginary’ seems to be at the heart of TERRA (Hörl and Burton, 2017), not just enveloped in the Ecotron’s $1m^3$ test cube of agroecosystem, but within the proposed ecologies of practice that make up its institutional environment in the Agro-bio-tech. Biological ecologies interleave disciplinary ecologies interleave infrastructural ecologies. As an institutional response, TERRA might be viewed as an attempt to align and model research more intently on novel ecologies, showing how they are not only the source of peril, but also of promise (Paxson and Helmreich, 2014). Indeed, in my own investigations with the PAFF box I learned how the promise of the ‘model ecosystem’ (Paxson and Helmreich, 2014) becomes a source of inspiration and aspiration for the emerging field of aquaponics, capable of channelling human desires and energies (amongst much else), and inflecting our conceptions of the world we share and the projects we undertake.

If model ecosystems are informing and energising our response to issues in the Anthropocene, we might caution against the impulse to idealise, essentialise, totalise; re-modernise (Latour, 2010). The ‘imminent, hybrid and discordant ontologies’ brought into focus by the Anthropocene problematic alert us to the partiality inherent to our descriptions of ecologies, whether in notions of biodiversity (Lorimer, 2012; 597), or the functioning of ecologies that populate our lab spaces

(Hayward, 2010, Papadopoulos, 2014). My own work in the PAFF box shows the difficulty of attending complex ecological problems when those aquaponic ecologies are gathered around either the chemical language of global planetary nutrient budgets, or equally, collapsed into accounts of situated affective encounters. A problem is confronted here, namely; that detectability is no longer down to the prowess of the observer, but directly relies on the character of the more-than-human ecologies we are able to gather and become-with. There is a question of control. So when the First Vice-Rector of the Agro-bio-tech, Eric Haubruge claims: "the Ecotron is unique because we have personally imagined and designed the 6 speakers to allow us access to a completely controlled environment" (Moreau, 2018), and the director of TERRA states the Ecotron "will enable us to study, under perfectly controlled conditions, the behaviour of an ecosystem, while working simultaneously on all the environmental parameters – the atmosphere, the temperature, the rainfall… all this, to model the behaviour of the crop and the ecosystem" (Jacques, 2018), some alarm bells might start to ring. More specifically, it is not simply about whether or not the instrumentation assembled in TERRA is indeed as powerful as the claims suggest. The grounds for this question have shifted. Rather, we might ask, what *kind* of 'model ecosystem' will be the product of an experimental environment arranged under the grand pretence of such authority and control?

Accommodating and becoming sensitive to challenging distributions of agency is a key task in the Anthropocene (Latour, 2014a). The PAFF box, for instance, persistently resisted the ambitions of 'balance' that our team (including myself) so desired. Instead, the system presented itself as a dynamic, unruly and unpredictable entity that demanded our attention and much care. Not an object masterfully controlled, but a flawed relationship into which all parties had to become cultured. Interestingly, the rhetorical figure of Gaia, summoned by Isabelle Stengers (2016), seems strangely fitting for the model ecosystem gathered in Gembloux. For Stengers, Gaia is "a ticklish assemblage of forces that are indifferent to our reasons and our projects" (Stengers, 2016). Confronting us scientists with acts of recalcitrance, the PAFF Box, in its small way, stood to expose precisely the cutting edge of the Anthropocene thesis by demonstrating "the illusionary character of what lies behind the human technological achievement, namely, the illusionary character of the monopoly on agency in general" (Hörl and Burton, 2017; 13). In such a way, did these efforts with the PAFF box open up a space to question the "underpinning masculinism, solutionism and scientism of [anthropocene] discourse" (Zylinska, 2014; 125)? Furthermore, how might future aquaponic and other ecologies develop this line further? – a question I take up in the next chapter.

Where bravado is no longer a useful guise for technoscientific experimentation, modesty might become a possible and desirable feature of ecologies (Haraway, 1997, Heath, 1997). Latour has spent much time pointing out how this shifts the discussion away from what is or isn't constructed[45], "toward the crucial difference between what is *well* or *badly* constructed, *well* or *badly* composed" (Latour, 2014a; 474). Just how an ecosystem qualifies as worthy in and for our time of the Anthropocene is an open question without a straightforward answer. When ecologies cannot easily be located 'out there' (or indeed, 'in here', in the case of the PAFF Box laboratory) but are, as Lorimer (2006: 540) puts it, 'the discursive and material outcome of a socio-material assemblage of people, practices, technologies and other non-humans', the objects of science are rendered much less available to the command of 'authenticity' and the moral codings that flow through it (Hörl and Burton, 2017). As Thom Van Dooren (2014; 60) puts it so well: "Inside rich histories of entangled becoming—without the aid of simplistic ideals like "wilderness," "the natural," or "ecosystemic balance"—it is ultimately impossible to reach simple, black-and-white prescriptions about how ecologies 'should be.'"

Drawing on my experience in Gembloux, we might posit that the question of how an ecosystem 'should be' is one that is to be determined in the collective capacities of *all* the actors who might be gathered around that particular ecological question at hand. This point nods not only toward the daunting task of becoming responsive to and responsible with the breath-taking complexity of more-than-human actors that are increasingly being recognised as participants in our collective situation. It speaks also of the more mundane, all-too-human, concerns of disciplinary participation. It's clear there is a necessity to develop transdisciplinary, multisited, multiscalar knowledge practices in the hope that we might generate a sensitivity to the emergent, complex, and vast challenges ahead. In this regard, there appears much to be commended in the spirit of TERRA's developers who freely seek to move beyond the thresholds of the configurations that typify the modern university. And yet arts, humanities, and social sciences, are conspicuous by their absence in the slick marketing of TERRA, a move that worryingly seems to fall short of the possibilities for scholarly inclusion envisioned by many in the 'Anthropo-scene' (Lorimer, 2017) - what Haraway (2016; 63) calls the 'New-new-synthesis'. The issues are too big, and time too short, to reproduce and entrench the disciplinary asymmetries that keep some interested parties outside in the cold, and others still, struggling on the inside of fugitive anthropologies.

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[45] Much of Latour's work is concerned with wrestling meaning out of the tight grip of fact based ideas of truth. As he puts it in his *compositional manifesto (2014: 474):* "The energy taken up by answering the question "is it constructed or is it true?" leaves no stamina to deploy the complex casuistic that answers, always locally and practically, the question "is it well or badly composed?"'

Chapter 6: **Moving on; following a field-in-the-making.**

Many who study emerging scientific worlds have underlined the importance of recasting scientific events around the struggles, specificities, and paradoxes of lived experience. As Donna Haraway (2016; 199) repeats time and again; 'It matters what stories tell stories". Here, I have followed the same impulse as Atkinson-Graham et al (2015; 745) in wanting to "stay with the feelings and textures of moments that might have otherwise been forgotten or side-lined as research projects develop, and experiences are smoothed into explanatory narratives for dissertations… and publications." Dwelling on the ambiguities or difficulties of caring research and opening them up for consideration might be a way to become more *involved* with those questions and practices (Hustak and Myers, 2012), a way to live with uncertainty and contestation around what counts as care in technoscientific contexts in-the-making (Asdal and Moser, 2012).

"The 'data-' or 'evidence based' sciences…" Isabelle Stengers (2018; 26) points out, "have given themselves the project of defining any situation or choice in terms that allow objectively measurable data to evaluate and decide the issue." The move to objectify the PAFF Box system was, unsurprisingly, one that had stripped the lived experience from our venture. The knowledge produced in our published scientific paper (Delaide et al., 2017) felt overly narrow and selective. In return for reliable and transportable data (Latour and Woolgar, 1986 [1979]) the turbulence of daily life and death and the somatic investment of human and non-human labourers had been excluded. I wanted this ethnography to produce an account that could expand, and challenge, the scientific version of events. An ethnographic exploration from within the experiment, I had hoped, would contest the simplified, instrumentalising account of this ecosystem portrayed in our finished scientific paper.

But I wanted more than just an alternate reading of events, a different story to add to other interpretations. As I pointed out in the beginning of chapter 5, one of my objectives was to push at the question "To what extent could my ethnographic work be opened up to evaluation within the theoretical terms of the field?" The answer, both resounding and frustrating in equal measure, was: not much. Feeling the possibility and imperative of care within the experimental setting of the PAFF box, and directing a speculative practice around a situated ethics I brought questions of how more caring patterns of existence might be brought about within the aquaponic system of Gembloux. This intervention, I chanced, might make a difference that mattered, might “disrupt a matter of fact into a matter of care” (de la Bellacasa, 2017; 89). Unexpectedly, however, at least in part, the opposite was true – the facts had disrupted my care. For all the “making and unmaking, picking up threads and dropping them” (Haraway, 2016b; 3), of becoming-with the PAFF box ecology, only a few small traces of our collective emergence filtered through into the official publication, and these, on top of being viewed without any real significance by my colleagues, likely remain hidden to any readers of our paper not privy to the events that unfolded in Gembloux. I had to come to the frustrating realisation that my intervention had not brought any strong signs of epistemological or ontological change.

Ash and Gallacher (2015; 23) explain that cultivating a sensitivity to the non-human involves “a modesty on the part of the researcher in the sense that one should not assume that human beings are necessarily the most important actor in shaping what happens within an event or situation”. My limited capacity within the experiment to bring about careful change was a realisation that demanded a loosening up of my own underlying humanist inflected ideas concerning researcher lead action and volition in the field. Once again, I found Haraway’s (2016; 130) words welling up with relevance, this time, a mantra of disarming humility that is well worth repeating: “Visiting is not a heroic practice; making a fuss is not the Revolution; thinking with each other is not Thought.” Gembloux had for me been a deep lesson in becoming a researcher, of learning to slow down and become more careful. My experience of the PAFF Box had exposed and reigned in an unquestioned faith in what Berry et al. (2017; 537) call “The givenness of fieldwork as an individualistic rite of passage”. I had expected to find potential in the valorisation of the more-than-human entanglement of relations in the PAFF Box, but instead my account was drawn towards the realities that are excluded as cuts emerge through these very relations, in part down to my own situated ethics. Unable to digest the less than agreeable by-products of my own intervention, I had to come to terms with the realisation of the fallibility of my own situated ethics. Something serious happened here to my research and to me, something *snapped*[46] (Ahmed, 2017), and I knew a new relationship to my work, to aquaponics, to science and its participants had to be pursued.

But this process of becoming incorporated within this technoscientific world of aquaponics, of breaking down the boundary between researcher and researched, is one that cuts both ways. If

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[46] For Ahmed (2017; 3), the *snap* “is about how we collectively acquire tendencies that can allow us to break ties that are damaging as well as to invest in new possibilities.” It is important to emphasise that for Ahmed (2017; 162), the snap is not solely a point of cut-off, “that moment when she does not take it anymore, the violence that saturates her world, a world”, but also a generative moment; to learn “where and how we can be wilful and creative… finding other ways of relating.”

the approach had been less careful than I imagined, and the destination less fecund with possibility, the perspective I gained from within this peculiar 'cut' of aquaponics in Gembloux offered an experience of the field I would not get anywhere else. Feeling the 'inertia', the indifference, of this aquaponic apparatus in my lived experience was also to gain an intimate, first-hand sense of its workings, of its boundaries, of its weaknesses. I understood better the Invisible Committee's (2015; 125) point, that learning the way we are implicated in technoscientific productions "brings an immediate increase in power, giving us a purchase on what will then no longer appear as an environment, but as a world arranged in a certain way and one that we can shape." The thick experience of the PAFF Box would, I was soon to find out, allow me greater credibility in discussions with colleagues and at conferences. But this was more than simply gaining extra purchase in circuits of expertise, for the PAFF Box experience had expanded my *sense* of aquaponics. Just as my presence had made a mark on the PAFF box ecosystem, the reverse was also true; that very ecosystem had etched something in me. I had cultured a more resolute understanding of aquaponics, what Haraway might call a "hardy, soiled kind of wisdom" (Haraway, 2016b; 117). This was something I carried and that carried me into the wider networks of aquaponic research that formed a new moment in my research process. This journey becomes the focus of the next section of this thesis.

6.1 Out into the field

Some things ended when I left Gembloux, and other things began. After the intense focus that characterised my time in the PAFF box experiment, a new phase of my research opened up that would see me out into the field of research communities and aquaponic enterprises that were growing in the UK as well as in Europe. I spread myself widely hoping the change would spark new opportunities for my research. This phase, that lasted around two years, can be loosely organised around three poles of attention. Firstly, I got involved with two aquaponic start-ups in Bristol – the *Bristol Fish Project* and *Grow Bristol*. Second, I began to engage more with the COST Action (FA1305) European Aquaponic hub. Third, I continued to collaborate with the team in Gembloux towards the publication of the PAFF box data (Delaide et al., 2017), as well as the data of a second experiment that I had also contributed to (Delaide et al., 2016). Although I did not realise at the time, each of these three broad attractors would contribute to my final project, the manifestation of which is the next chapter of this thesis. My intention below is to outline some key features of these three areas of research and how they made possible the final chapter, after which follows a short introduction to the chapter.

When I began meeting with the *Bristol fish project* they were just starting a major new project and didn't yet have an aquaponic system up and running. Over four months I went to fortnightly meetings offering help with the planning wherever I could using the experience from my time in Gembloux. I helped bang nails and rip out bits and bobs from their newly acquired premises in preparation for the instalment of their aquaponic system. Bristol Fish Project were pioneering eel culture, and their prototype system had very different configuration to that of Gembloux. When I joined a second aquaponic start-up, *Bristol Grow,* I found that the skills I had acquired in the PAFF box had much more immediate transferability. The team at Bristol Grow planned to have a tilapia system in a confined space that grew microgreens. I helped them install their aquaponic system and travelled to Bristol once a week for around 5 months to help with the running of their enterprise.

I mention these two aquaponics projects in Bristol not make these the focus of a second ethnography in this thesis. My intention here is not to ethnographically present them as a central feature of this work, but to *recognise* them for what they were to me and this project. These busy aquaponic innovators gave me space and encouraged me to become part of the aquaponic niche they were trying so hard to make into a reality. I could 'give back' some things that I had learned in Gembloux, and in return they gave me access to their little worlds of fish and plants, and the hard work it takes to maintain them. The openness and inclusivity of these groups was refreshing and very beneficial for me as it provided an outlet away from the desk based PhD tasks, a way to keep my hands, as well as my head, aquaponically agile. It was inspiring to see how these groups created and carried a dynamism and energy out into the 'real world' beyond academia, but likewise I also got a strong impression of the very real pressures (financial, time, intellectual, physical, legal etc) these groups faced trying to carve out their aquaponic niches. Aquaponic systems, by their nature, are complicated things that require strong knowledge of different domains (fish biology, horticulture, engineering, legal). Getting aquaponic systems to work can certainly be a challenge, but these start-ups had also to simultaneously secure funding, develop premises, create a niche for their product, market an often alien food stuff, meet fish welfare and regulation standards and food hygiene requirements. In short, working with these aquaponic start-ups allowed me to see the huge challenges facing those trying to make aquaponics a reality - a significant point that I take up in the next chapter and develop further.

Although I separated out my work in the Bristol start-ups, the COST Action (FA1305) and the team back in the Agro-bio-tech, this was more for clarity's sake. It is important to highlight that these three areas of research were not mutually exclusive domains. Both the Bristol start-ups, and the team in Gembloux had a presence in the COST Action, though the later were most invested in the network. The whole idea of the EU aquaponic hub was to facilitate the flow of ideas and the sharing of resources and expertise between different aquaponic groups. Networking like this creates a gathering of interested scholars/participants from many fields. As I flowed between domains of aquaponic interest, I too became a facilitator of ideas, news and more general aquaponic gossip amongst the European network.

Working with the Bristol aquaponic projects gave me a space to mull over what had happened in Gembloux, and time to consider where it could take me next. I had half expected something more to come out of the time I spent with the Bristol based aquaponic projects. An ethnography of aquaponic start-ups seemed an obvious outcome, or even the more tantalising possibly of undertaking something experimental with the systems they had, but in all honesty, for reasons that still elude, no strong connection would strike up between what the Bristol projects needed to achieve and the work I had started in Gembloux. It wasn't until the March of 2016 when my activities began to pick up pace and started coalescing around the next stage of my research.

The University of Ljubljana, Slovenia were hosting the '*Aquaponics research matters'* conference, organised by the EU COST Action (FA1305). I had agreed to present some of the preliminary findings of our PAFF Box experiment. This presentation, on the whole, was well received by the large audience gathered in the main conference hall, albeit with some rather puzzled looks when I discussed my use of ethnography in aquaponic settings. The surprise came later when Boris presented some of the data we had been working on for a second publication. We had been busy with this data since the completion of the experiment in the summer of 2015, and had an inkling of how hot the data was, but we had no idea it would become such a contentious point within the Aquaponic Network. Our results seemed to spark both excitement and outrage. The questions for Boris over ran our time slot and went right into the break. They immediately restarted in the next session.

There is little space to go in to the specifics of the results of our second experiment (Delaide et al., 2016), but it is worth pointing out the main thrust of the argument. Our experiment was designed to test the difference in growth rates between three batches of lettuce each given different growing solutions - commercial hydroponic solution, aquaponic solution and 'complimented' aquaponic solution. This was a rather simple test of how well aquaponic water compares to that of commercial hydroponics. The results that we gathered were a huge surprise for our team. Now, hydroponics is a well-developed field; its fine-tuned techniques achieve efficiency figures are the envy of most other methods of industrial food production. Hydroponic solution is specifically formulated with high levels of nutrients at specific balances to bring optimum plant growth rates. Aquaponic water on the other hand must have much lower concentrations of key nutrients because at higher concentrations they become dangerous for the fish. The theory was that aquaponics water provides sub-optimal conditions for plant growth. But our results, you could say, blew this out of the water. Our tests showed that the aquaponic solution, although having significantly lower nutrient concentrations, gave equivalent yields to the Hydroponic solution. Furthermore, plants grown in the 'complimented aquaponic solution' (that had identical nutritional values to that of the hydroponic solution), showed significantly (+39%) higher growth rates. There was something special about aquaponic water, and we knew we were on to something big.

It was clear that our data had some sort of efficacy within the ecologies of aquaponic knowledge production gathered in Slovenia. Disparate views were brought to the surface and the hall became rather tense. For what seemed a majority, our data was precisely what the field of aquaponics 'needed' – objective validation that aquaponics could compete with its closest competitor hydroponics. But there was a more sceptical cohort who could not entertain our results. This group was mostly comprised of some seasoned aquaponic researchers, as well as a group of commercial growers experienced in large hydroponic operations in the Netherlands and Belgium. They were not content until every single technical aspect of our experiment had been turned over, scrutinised and critiqued: Size, scale, timing, repeatability, instrumentation, plant choice, solution composition, protocol, and a huge question mark was placed over our aquaponic water. The polarising effect of our results on those gathered in Slovenia was plain to see. This caught my attention. Of course, aquaponics was an emergent field of research that lacked the coherence and foundations of more established fields, but the reaction we got when unveiling the preliminary results of our second experiment brought to the fore how aquaponics was very much a contested concept. The terms of Aquaponics as a field had yet to be 'fixed' and this was a fascinating process of which to be a part.

"Every field carries promises and contradictions, but this feature of science and scholarship is particularly evident when a field is being born" write Swanson et al. (2015; 162) in their review of the emerging spectre of Anthropocene scholarship. They argue that an examination of conferences rather than an assessment of existing publications, might better attend an emergent field, for "in conference performances, we glimpse the themes and tensions of a field-to-come" (Swanson et al. 2015; 150). Like them, I sensed that the annual aquaponic conferences organised by the COST Action FA1530 presented an opportunity to engage scholarship as it emerged. I decided to pay closer attention to the way the aquaponic conferences initiated possible new trends in aquaponics and articulated connections across aquaponic research groups and areas: "reading conferences as fields coming into being." (Swanson et al., 2015; 163). I began to actively attend the working group meetings of COST Action FA1305, began taking notes concerning the atmosphere and direction of the gatherings and conferences, and where I felt the opportunity, I conducted semi-structured interviews with participants[47].

6.2 Conferences: engaging a field-in-the-making

The annual EU Aquaponic hub conferences and working group meetings were more than simply professional event spaces organised for aquaponic researchers to showcase their work. They were moments away from home institutions, their commitments, their deadlines, their reality, where thoughts and friendships were fostered at a different pace, in a different place. The faces in the COST Action FA1305 conferences always struck me as quite an unlikely group - meetings invariably included: awkward, nerdy PhD students; suave, start-up entrepreneurs; seasoned, comfortable, white-hair professors; and always one or two less-at-home food activists. The common thread that pulled us together was aquaponics. The feelings developed at these conferences were overwhelmingly communal and positive. At the early conferences especially, there was an enthusiasm that aquaponic technology had real potential and this created a buzz around the gatherings, a palpable feeling of dynamism, direction, optimism. Having said this, of course, Aquaponics was a field (in-the-making) like any other - vested with interests, contradictions, language barriers, knowledge hierarchies. Unveiling of our results at the '*Aquaponic research matters*' conference in 2016, and the reaction that we received, made me realise the way our research commits us to certain ideas and manifestations of aquaponics, and it did this in a very different way to what I had experienced in the Gembloux.

The question of contestation and scholarly commitments was one that became even closer to home as the team in Gembloux and I worked up the second experiment for publication. Our results highlighted above all, the "beneficial effect of recirculating aquaculture system (RAS) water on plant growth" (Delaide et al., 2016; 466) and suggested that something beyond the nutritional constitution of conventional hydroponic water was stimulating root and shoot growth in aquaponic plants. This was exciting. Although our experiment couldn't determine what exactly about the aquaponic water had caused the growth benefits, it pointed to something special arising from the plant/fish/bacterial ecology – most likely either some humic acid growth promotion in the dissolved organic matter, and/or the presence of plant growth-promoting rhizobacteria and/or fungi. Our research showed how aquaponic production, with a reduced

[47] I do not wish to frame this as an 'ethnography' of aquaponic conferences. The idea is not to present the particular cultural reality of aquaponic conference goers or 'take the reader there'. Rather, my object of interest was as Swanson et al (2015; 150) put it "the field-in-the-making, not the conference-in-the-making."

nutrient requirement, could bring comparable yields to hydroponics, and this was potentially a huge finding for our emerging field.

The sticking point came in the interpretation of this result. Inside our paper we argued that: "these results confirm AP [aquaponic] systems as an alternative to conventional hydroponic systems… Notably, with respect to the increasing scarcity of phosphorus, it is remarkable that, in AP solution, significantly lower nutrient concentrations gave equivalent yields to HP solution" (Delaide et al., 2016; 8). However, in the final moments before submission, some parties of our research team pushed to take our conclusions further, so that the punchline of the study took on a different flavour. In the abstract of the published piece, the interpretation of our results shifted focus: "The findings represent a further step toward developing decoupled aquaponic systems (i.e. two- or multi-loops) that have the potential to establish a more productive alternative to hydroponic systems" (Delaide et al., 2016; 1). There is a subtle difference in the two interpretations contained in our paper. By opting for the later, our publication pinned our results to an aquaponic future that was in direct (capitalist) competition with industrial hydroponics. It did this at the expense of the equally justifiable interpretation of aquaponics being an alternative to hydroponics capable of producing the same yield with lower inputs. This subtle, and seemingly insignificant, difference is one that draws a line between contrasting visions for aquaponics. Put more technically, in the language of agronomic science, this line is one that separates *productivist* ambitions from those of *ecological intensification* – another point that is taken up in detail in the next chapter.

The nit-picking of interpretations within our paper might appear rather trivial, but I draw attention to the line between productivism and ecological intensification because it was part of a greater schism that began to develop under and through the activities of the EU Aquaponic hub. Productivist vs ecologically intensifying was just one of a number of contrasting positions that concerned the nature of what we were dealing in, the nature of aquaponics. Others included: Intensive vs extensive, high tech vs low tech, Coupled vs Decoupled. Although there are no hard or fast rules in the fluid exchanges that characterise conference spaces, and although things were rarely as black and white as these binaries suggest, they nevertheless became important attractors when discussions began to flow. Aquaponics, the field-in-the-making, was getting complex.

One of the great challenges that the hub came up against in conferences and in meetings was the way aquaponics seemed to demand an ever-expanding set of considerations. The field simply could not be contained by questions of fish biology and horticulture – even if these were the dominant regions of expertise in the Hub. Getting systems to work well involved comprehending an escalating set of dimensions: What about microbiology and the aquaponic microbiome? What about pathogens? fish welfare? Fish feed composition? Life cycle analysis? What about supply chains? Consumers? Legislation? Funding streams? Each of these considerations worked to complicate and extend aquaponics beyond its simple metaphor of 'fish/plants/bacteria'. Thinking aquaponically seemed to open up the truly perplexing ecological[48] question – just where do aquaponic considerations end? For those in the network who had taken as their task the *definition* of aquaponics this was a huge source of frustration. The ever-thickening sets of relations aquaponics pulled in meant that meetings would too often become bogged down by lengthy discussions that lacked direction. There was little solace to be found in a concisely defined 'aquaponics' because someone could always point out an extra aspect/dimension/factor that must be taken into consideration. The ecological challenge presented by aquaponics pointed to questions of interdisciplinarity, or even transdisciplinarity, that were not easy to answer, demanded new areas of expertise, and hinted towards the need to innovate existing knowledge practices – another point taken up in the next chapter. But these challenges are, of course, huge considering the forces that structure, facilitate, and pressurise current scholarship. Instead of openly engaging these challenges, it was clear that aquaponic research in the Hub was moving down well-trodden paths that carried a strong disciplinary focus.

"Hegemonies of knowledge are not easily surpassed" state Swanson et al, (2015; 163) in their discussion of the difficulties of realising transdisciplinary knowledge pathways within the emerging field of the Anthropocene scholarship. A similar experience played out in the European aquaponic hub. Natural sciences dominated the hub's membership. Unsurprisingly, the publication output of the hub was dominated by studies of aquaculture, hydroponics, water quality and engineering (König et al., 2018). What these disciplines were excellent at doing was pinpointing specific aspects of aquaponic system functioning, and generating robust, transferable, objective data. The PAFF box experiment stands as an excellent example. As the publications rolled out, these disciplinary pursuits made big jumps forward in our collective understanding of system dynamics in aquaponics. They gave the hub solid facts to exchange and share at the meetings, and they provided clear routes to go down for future studies. The conferences began to revolve more and more around scientific technicalities, efficiency measures, and disputes of objectivity.

[48] In Dark Ecology, Timothy Morton (2016; 6) explains the challenge of ecological thought is that "in the thinking of interdependence at least one being must be missing. Ecognostic jigsaws are never complete."

By April of 2017 it was time for the next annual conference, this time hosted by the University of Murcia, Spain. The conference was titled '*Aquaponics.biz'*, capturing the intent of conference organisers to give aquaponic enterprises around Europe a centre stage, and to facilitate greater integration with university-based research teams that made up the majority of the Hub's membership. In front of a lively and bright-eyed hall, the first talk of the conference was given by Ivo Haenen, entitled: '*Small successes and big failures: lessons from the aquaponics facility at Uit Je Eigen Stad (UJES), Rotterdam, the Netherlands'.* Haenen discussed his role in a flagship €1milllion project funded by the Dutch ministry of economic affairs. Started in 2012, by 2016 the project was bankrupt and disbanded. Haenen described an operation hamstrung by numerous technical, financial, operational and market failures. This unusually frank and open presentation set the tone of the entire '*Aquaponics.biz*' conference. Although none of the following talks from businesses would be as dramatic as Haenen's it was obvious that the emerging commercial aquaponic sector across Europe was struggling. When, after the interval, the university research teams were invited back on stage, a bombardment of dry, complicated material and super technical discussion followed, that was clearly a different language altogether from that of the earlier talks. It served only to heighten the isolation of the struggling start-ups and fed the growing feeling that aquaponics research was out of touch. Close to the end of the conference, Maja Turnšek Hančič, director of a failed Slovenian start-up, and social scientist from the University of Maribor, delivered the most unexpected talk of them all. It was titled: *Have we all been techno-optimistic? Aquaponics in a Slovenian context.* Reflecting on her frustrating experience at the helm of a failed aquaponic business as well as her participation in the EU Aquaponic hub, she put forward the controversial idea that the aquaponic network needed a reality check, we had swallowed the 'hype' of aquaponics, placed our faith in its technological power, and it was failing. At the end of her talk, when someone raised a hand and coolly asked the obvious question: 'so what do we do then?' Maja replied: "The field is dominated by engineers that look to technological fixes. But we need a heart to grow nice tomatoes." In her view, as a field of researchers we were producing technological fixes for aquaponic problems that were actually social in nature (how do we produce and distribute ethically, how do we engage and educate a market etc).

At the end of the *Aquaponics.biz* conference, Murcia, I knew we had reached a watershed moment. Murcia seemed to crystallise somehow the low-level hum that was growing in the corridors and over wine fuelled lunches; that of promising start-ups limping along, burning out, or simply disappearing. Being part of the conferences was a way to get behind the veneer of neatly packaged publications and sparkling websites that would soon be diagnosed as contributors to an 'aquaponic hype' (Junge et al., 2017). Having said this, it wasn't all doom-and-gloom within the

Hub. Some strands of research looked to respond to the challenges that *Aquaponics.biz* threw up, and a collection of more diverse scholarship was initiated that sought to get at some of the serious problems facing the field (Miličić et al., 2017, Yavuzcan Yildiz et al., 2017, Junge et al., 2017, Hoevenaars et al., 2018). Another source of excitement for some were the rumours circulating that researchers pushing for 'de-coupled' Aquaponic systems had been noticed by investors with very deep pockets, and the possibility to take the technology truly large-scale, industrial was on the horizon.

Benz Kotzen opened the proceedings to the penultimate annual aquaponic conference in Dubrovnik, Croatia. It was hosted inside Aquaculture Europe's 2017 conference *Cooperation for Growth*– one of the biggest aquaculture events on the planet gravitating over 1600 participants. As the chair and co-founder of the of COST Action FA1305, Benz explained to the audience that from the beginning, the COST Action was possible only because he and a few others managed to convince EU money holders that aquaponics had potential to bring about food solutions. This was a point made all the more pertinent in the funding climate leading up to the EU 'horizon 2020'. He underlined the importance of conferences like this one in Dubrovnik for developing aquaponic technology. It was here, in these affirmative opening words, that he made a quite an unusual and telling emission: "We are all gathered here today because Aquaponics holds potential for future food solutions [laughs] but I've been discouraged from saying 'sustainable' because, as someone pointed out to me not so long ago; 'no one knows what sustainability means anymore". This tongue-in-cheek, self-reflexive moment spoke of a much wider uncertainty that was hanging over the fledgling field of aquaponics in 2017. Aquaponics at its heart had been premised on the justification that it was sustainable but if, as Benz put it, 'no-one knows what sustainability means anymore', what did this mean for aquaponics?

In the intervals of the Dubrovnik conference, aquaponicists could grab coffee in glitzy atriums and share conversations out on the sunset verandas of the 5* beach resort that hosted this monstrous *Cooperation for Growth* festival. Moving around the venue, we were kettled through halls lined with aquaculture equipment brokers polishing the next generation technologies aimed at an industry that produces half of the earth's edible fish. One person drew the comparisons with an arms fair. Conversations amongst colleagues and friends were distracted, but then, how to talk about 'sustainability' in a place like this?

With one year remaining before the EU Aquaponic Hub was scheduled to end, the working group meetings in Dubrovnik aimed at a view of the future – what had been achieved? Where was the field going? What needed to be done? Away from the beach resort and with deadlines looming, discussions were focused, much ground was covered, there was a cohesiveness to the work being done. We knew more about our field now, and more than this, there was a frankness to the whole proceedings, an openness to views that had not been aired in previous meetings. When the chair of the first session asked: “Do we think aquaponics is a specific thing, could we agree on a definition? Or do we think that it is just a concept that relates many different issues?” Most people in the room felt we needed a definition, but no-one could provide one. The room highlighted a tension in our ideas about what aquaponics was about. Most people agreed that our aquaponic activities in the hub had revolved around a common problem, what the Hub called ‘closing the loop’. This referred to the shared commitment towards ‘circular economies’ – recycling waste streams, circular infrastructures, ecosystems - having roots in economic theory[49] (Nemethy and Kőmíves, 2016). And yet, the centripetal impetus of ‘closing the loop’, had driven a centrifugal disintegration of the field as it split into many specific aspects of environmental engineering /biochemistry /horticulture/ microbiology /pathogens /supply chains etc. Specifics had become key to the field, it was claimed, but there was no single idea of aquaponics that needed to be, or should be, pursued. There would be no closure on ‘closing the loop’.

Those who could most compellingly argue the case for ‘closing the loop’ were the modellers, engineers, and biochemists whose calculations showed that aquaponics could be ‘better’ than either conventional hydroponic or aquaculture production methods. For them, aquaponics needed to be pushed toward economies-of-scale that would unlock key efficiency potentials. Their equations showed that productivity and waste reuptake of aquaponics at industrial scales would outstrip the competition, but for this to work aquaponics had to be ‘decoupled’. The argument for ‘decoupling’ was to get around a central ‘problem’ in coupled systems. In coupled systems like the PAFF Box, fish, plants, and bacteria all share the same recirculating water and a compromise must be found in water quality parameters because each of these creatures require different environments to flourish. Decoupled systems would isolate these creatures into separate compartments, and efficiently manipulate the water that would be passed between them, allowing for optimum growing conditions in each compartment. The demands of such a scheme called for cutting-edge technology, extremely complex management systems, and huge upfront investments. It all worked out on paper the model(ler)s told us, but the empirics were lacking because there were simply no systems, at least in Europe, capable of operating at the scales decoupling was calling for. Another problematic here was that the Hub knew very well that the only aquaponic farms in Europe turning a profit were actually the opposite of what was being envisioned in decoupled systems. All the success stories in Europe so far were small-scale, low

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[49] This point is exemplified in the offshoot academic journal eco-cycles that was initiated by some members of the Hub. Nemethy and Kőmíves (2016) trace these commitments back to the famous “Limits to Growth” report (Meadows et al., 1972).

tech, low maintenance, mostly extensive systems. This was of little importance in the eyes of the 'decouplers', the fact was that everything about decoupling added up; it was only a matter of time - and investment - before aquaponics went big.

The forceful arguments of the 'decouplers' brought to a head a bigger, more existential, question for the Hub. Many of those attending the meetings had been attracted to researching aquaponics because they felt strongly a need to intervene in our current food system. The prospect of mega-scale, industrial, decoupled systems did not fit the image of aquaponics some of us had brought to the Hub in the beginning, back in 2015. The mammoth systems envisioned by some clashed with the sentiment of many in the Hub that aquaponics could part of a larger reconfiguration of the food system towards something that was, among many other things, more localised/ urbanised/ decentralised. However, these views invited questions that could not be resolved in any simple way for they opened up the devilish and politicised subjects of food sovereignty and sustainability. Whenever such issues were raised, they would be so easily shrugged off by arguments that claimed the higher ground of the rational, reasonable, or realistic. Despite Maja's warnings in Murcia 2016, ethical and political questions were still being answered by technical solutions out of place. It was at this point, at the end of the Dubrovnik working group meetings, that I realised something must be done to offer a platform for the different ideas of aquaponics that were being suppressed. As the Hub members proposed chapters for a book that would become one of the main outputs of the Network - a survey of, and guide to, the state-of-the-art of our field - I made connections with members who had also shared concerns with where things were going, and we sketched out some loose plans for a chapter. This was the beginning of what eventually became the next chapter of this thesis.

6.3 An introduction to Chapter 7

The coming chapter was born out of a collaboration between five members of the EU Aquaponic hub, one of those being myself. In the official publication (Gott et al., 2019), only three names are listed as authors of the chapter: Myself, Rolf Morgenstern[50], and Maja Turnsek[51]. Two of the five members of the team contributed no written words to the chapter, and didn't feel it was right to take any credit for the final piece[52]. Our group skype calls were filled with energy and ideas, a

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[52] Although we honoured their decision and removed their names (and I continue to honour their choice by maintaining their anonymity) I feel it necessary to maintain that others were a part of the discussions and ideas that ultimately lead to this piece. Their ghostly presence here might

point that Rolf suggested in some way flowed from the very dynamic 'possibility space'[53] that was aquaponics itself. But my colleagues were under much more pressured time constraints than I and in the end could contribute very little in the way of actual words. With the chapter's deadline looming, I decided to take our concepts and run with them, worried that all this work, and purpose, and shared concern for our field would end up fizzling out. Below is short introduction to the ideas behind the piece.

Aquaponic scholarship was fragmenting along disciplinary lines, and in our eyes, this was a challenge we wanted to take up. Of course, strong disciplinary work functions well when research is focused towards elements that most directly yield to the methods available in that discipline. One effect of this, is that good disciplinary research involves the selection of problems most tractable to solutions with the knowledge produced by that discipline. In a field with a broad number of disciplinary pursuits there is always a question about how different disciplinary problems/solutions might become integrated or synergised within a given field – this is usually where the typical calls/disputes for 'inter/multi/transdisciplinary' innovation begin. But our experience of the scholarly activity in the Hub made us realise a different problem associated with strong disciplinarity in asymmetric formations.

The scholarly outputs of the Hub were dominated by technicalities of system parameters – production potentials, efficiency, biochemical constitution etc. There was no denying that these studies had huge value for the field, giving intimate knowledge about the material make up of systems and furthering aquaponic theory. And yet, when discussions in the hub began to circulate around the issues of these disciplines alone, the danger for everyone involved was that our field was becoming myopic. When certain disciplines dominate a field there is a risk that the problems identified by that discipline become taken in a more general sense as *the* problems of the field. The dominance of natural science and engineering in the hub was producing an asymmetric discourse that related most closely to the narrow problems identified by those disciplines. As such, we felt the Hub was selecting and proliferating particular aquaponic formations at the expense of alternatives.

The issue for us, to paraphrase Isabelle Stengers (2012; 2) point, became one of "how... to keep the question of [aquaponics]… from being framed in terms that verify Science's right to define it as an object". We shared a sense that accepting certain disciplinary problems as *the* problems of

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serve as a reminder about the dangers of authorship used as a function in the process of knowledge capture, as well as the excessive character of what Moten and Harney (2013) call *Study.*

[53] The 'possibility space' was a term introduced to me by Rolf Morgenstein, an efficient term that contributes a feel of the magnitude or fecundity of aquaponic possibility.

our field was a dangerous move, that allowed the lively and challenging potential of aquaponics to be "deadened through the crafting of questions that already had answers, or whose answers were close at hand, contained within pre-existing academic discourse" (Manning, 2016; 9). It wasn't so much a task of denouncing certain narrow disciplinary pursuits, but rather of challenging the idea that these were the only pursuits necessary. Nor was it a task of simply showcasing and extolling the virtues of those disciplines on the periphery, such as geography, social science etc – a task that too often ends up extending further the feeling of disciplinary incommensurability. Rather, the chapter wanted to bring to question ways of resisting the longstanding temptation of "brutally opposing the sciences against the reputedly 'nonscientific' knowledges" by emphasising "the necessity of inventing the ways of their coupling" (Stengers 2016; 44). Our chapter then, aimed at reclaiming a more lively, challenging and richer vision of aquaponics, one that demanded the attention of everyone.

For this task of reclamation, we needed a trope, a common concern, that could bring together every discipline involved with problems that were as demanding as the issue of aquaponics would allow. For better or for worse, we decided to inherit the troubled concept of sustainability as a common and central concern of aquaponics. Sustainability is a near ubiquitous justification for all aquaponic research, and yet, following the inspired comments of Benz Kotzen at the Dubrovnik 2017 aquaponics conference (above), we had witnessed how sustainability had gradually been disowned by the Hub in its discussions and activities. We had some ideas about why this might be. To say that 'sustainability' is a complex, multidimensional notion that persistently resists simple definition or application is to understate somewhat, so with sustainability as a central driver for aquaponic research, the field had come up against a huge problem. There was, to some degree, a recognition in the Hub that sustainability was much 'bigger' and more enigmatic than could be apprehended by the current tools and knowledge devices at the Hub's disposal. The problem was that rather than engaging and pushing against this challenge, it was clear that aquaponic research had retreated back to the safe and familiar epistemological landscapes of disciplinary scholarship (pursuits, it must be said, that are also much more amenable to modest research budgets, limited time frames, and the ever-present demand for outcomes). It is precisely because the concept of sustainability is so ambiguous, slippery, and not easily resolved, that we wanted to bring it back to the system and our systems. The aim was to inherit the trouble of sustainability in such a way as to find once again some promise in it. No matter how corrupt and insurmountable a concept it proved, we felt that it had a semantic reach that overlapped many of the Hub's concerns, as well as an obliging complexity that seemed a good way to keep at bay what Stengers (2012; 67) calls the "simplifications that would still ratify [the] story of progress". For myself, it was also a way to openly explore the limits of the authority of science in aquaponic research.

The coming chapter is then both a challenge and plea to the aquaponic community, and it was a challenge for us to write. Writing to, and for, and by the aquaponic community came with the responsibility of writing something relevant. What is the use in writing an intricately weaved account of a situated more-than-human aquaponic ethics in this situation? Clearly, the finer the argumentation by our disciplinary standards, the less use it becomes. And so, the point becomes trying to find some common ground, something that draws us both in, challenges us all. The writing then, becomes a kind of *negotiation* in the sense that John Palmesino describes when he states: "To negotiate, you have to be able to give up something and you have to be willing to change what your claims are. It is not a game of who will win, a competition; rather, it's a transformative relation." (Turpin, 2013; 17). A central term for negotiation in the coming chapter, as discussed above, is sustainability. Bringing this term back to the table involved a great deal of work and required me to study the field of sustainability science, looking for what could be salvaged of this term that could be applied to aquaponics in a way that challenges us all. There is some compromise involved in negotiation.

I wanted to shake loose this idea of 'social science writing' as something that stands outside, describing and prescribing. If this is the function proper of social science, then I was not doing social science. The chapter was written by aquaponicists for aquaponics and for this reason it is addressed to 'Us'. But with this understanding, it is also a piece of writing that I hoped would challenge MTH geographies and feminist science and technology scholarship. By dragging these, (what I now consider my 'home disciplines') into the centre of this aquaponic mess, I hoped to push the edges of what is the accepted language and format considered as scholarship by these fields. As Palmesino puts it: "Somehow we can take the discipline away from the central condition it imagines and have it negotiate with other practices" (Turpin, 2013; 17). For those outside the aquaponic research community, the coming chapter should be read with an eye for the negotiation I discussed above. Though this could very well be a difficult task as these negotiations are of the field of aquaponics, I propose they mark the presence of a technique[54] of intervention in technoscience. Negotiation is a technique of ethico-political intervention.

One of the things that Bruno Latour (2017) and others have worked hard to show is how the circumstances of the Anthropocene are such that we no longer have the luxury of believing in a clear division between science and politics. A point that becomes a reoccurring focus of this thesis. In an interview with Latour, Heather Davis questions whether the collapse of these two

[54] For Manning and Massumi (2014; ix) *technique* is an act. *Techniques* "are not descriptive devices—they are springboards. They are not framing devices—they activate a practice from within. They set in motion." As such, *techniques* are for "composing of creative practice, for composing emergent collectivities, for composing thought in the multiplicitous act."

domains might result in a greater epistemic shift in the sciences towards “alternate world-making devices, such as narration and storytelling” (Davis and Turpin, 2015; 43). Latour thinks this is wishful thinking on Davis’s part, prefering instead ideas of postnatural diplomacy over narration for bridging gaps between epistemic cultures. Chapter 7 contributes to this discussion, and one happening across the Anthropo(s)cene about methods of narration as devices of intervention (Veland and Lynch, 2016, Haraway, 2016b). In chapter 7 then, we offer to the aquaponic community, not a neat blueprint for bringing about aquaponic solutions, but a way of problematizing as collective practice, a way of “crafting of problems greater than their solutions.” (Manning, 2014; 10). If this speculative endeavour is of any worth, it will be picked up by an aquaponic community to come, to be modified and made use of like the process Haraway (2016) conjures in her ‘string figures’. If this can happen, there is a chance that it challenges also the coordinates of current geographic and STS scholarship, and the idea of how narrative, and which narrative forms, can influence worlds of science.

Chapter 7: **Aquaponics for the Anthropocene: towards a 'sustainability first' agenda**

7.1 Abstract

'The Anthropocene' has emerged as a unique moment in earth history where humanity recognises its devastating capacity to destabilise the planetary processes upon which it depends. Modern agriculture plays a central role in this problematic. Food production innovations are needed that exceed traditional paradigms of the green revolution, whilst at the same time can acknowledge the complexity arising from the sustainability and food security issues that mark our times. Aquaponics is one technological innovation that promises to contribute much toward these imperatives. But this emergent field is at an early stage that is characterised by limited resources, market uncertainty, institutional resistance and high risks of failure – a developmental environment where hype prevails over demonstrated outcomes. Given this situation, the aquaponics research community potentially holds an important place in the development path of this technology. But the field needs to craft a coherent and viable vision for this technology that can move beyond misplaced techno-optimist accounts. Turning to sustainability science and STS research, we discuss the urgent need to develop what we call a 'critical sustainability knowledge' for aquaponics, giving pointers for possible ways forward, which include: 1) expanding aquaponic research into an interdisciplinary research domain; 2) opening research up to participatory approaches in real world contexts 3) pursuing a solutions-oriented approach for sustainability and food security outcomes.

7.2 Introduction

Key drivers stated for aquaponic research are the global environmental, social and economic challenges identified by supranational authorities like the Food and Agriculture Organization (FAO) of the United Nations (UN) (DESA, 2015) whose calls for sustainable and stable food production advance the 'need for new and improved solutions for food production and consumption' (Junge et al., 2017, Konig et al., 2016). There is growing recognition that current agricultural modes of production cause wasteful overconsumption of environmental resources, rely on increasingly scarce and expensive fossil fuel, exacerbate environmental contamination, and ultimately contribute to climate change (Pearson, 2007). In our time of 'peak-everything'

(Cohen, 2012), 'business as usual' for our food system appears at odds with a sustainable and just future of food provision (Fischer et al., 2007). A food system revolution is urgently needed (Kiers et al., 2008, Foley et al., 2011), and as the opening chapters (1, 2) of this book attest, aquaponics technology shows much promise. The enclosed systems of aquaponics offer an especially alluring convergence of potential resolutions to that could contribute towards a more sustainable future (Kőmíves and Ranka, 2015). But, we ask, what kind of sustainable future might aquaponics research and aquaponics technology contribute towards? In this chapter we take a step back to consider the ambitions of our research and the functions of our technology.

In this chapter we situate current aquaponic research within the larger scale shifts of outlook occurring across the sciences and beyond due to the problematic that has become known as 'The Anthropocene' (Crutzen and Stoermer, 2000b). Expanding well beyond the confines of its original geological formulation (Lorimer, 2017), the Anthropocene concept has become no less than 'the master narrative of our times' (Hamilton et al., 2015b). It represents an urgent realisation that demands deep questions be asked about the way society organises and relates to the world, including the *modus operandi* of our research (Castree, 2015). However, until now, the concept has been largely side-lined in aquaponic literature. This chapter introduces the Anthropocene as an obligatory frame of reference that must be acknowledged for any concerted effort towards future food security and sustainability.

We discuss how the Anthropocene unsettles some key tenets that have underpinned the traditional agriscience of the Green Revolution (Stengers, 2018) and how this brings challenges and opportunities for aquaponic research. Aquaponics is an innovation that promises to contribute much toward the imperatives of sustainability and food security. But this emergent field is in an early stage that is characterised by limited resources, market uncertainty, institutional resistance with high risks of failure and few success stories – an innovation environment where hype prevails over demonstrated outcomes (König et al., 2018). We suggest this situation is characterised by a misplaced techno-optimism that is unconducive to the deeper shifts towards sustainability that are needed of our food system.

Given this, we feel the aquaponics research community has an important role to play in the future development of this technology. We suggest a refocussing of aquaponics research around the key demands of our food system – sustainability and food security. Such a task entails we more thoroughly consider the nature of sustainability, and so we draw on the insights from the fields of sustainability science and STS. Addressing sustainability in the Anthropocene obligates the need to attend more holistically to the interacting biophysical, social, economic, legal and ethical dimensions that encroach on aquaponic systems (Geels, 2011). This is no small task that places great demands on the way we produce and use knowledge. For this reason, we discuss the need to develop what we call a 'critical sustainability knowledge' for aquaponics, giving pointers for possible ways forward, which include: 1) expanding aquaponic research into an interdisciplinary research domain; 2) opening research up to participatory approaches in real world contexts 3) pursuing a solutions-oriented approach for sustainability and food security outcomes.

7.3 The Anthropocene and Agriscience

> *"Today, humankind has begun to match and even exceed some of the great forces of nature . . . [T]he Earth System is now in a no analogue situation, best referred to as a new era in the geological history, the Anthropocene" (Steffen et al., 2004: 81).*

The scientific proposal that the Earth has entered a new epoch – 'The Anthropocene' – as a result of human activities was put forward at the turn of the new millennium by the chemist and Nobel Laureate Paul Crutzen and biologist Eugene Stoermer (Crutzen and Stoermer, 2000a). Increasing quantitative evidence suggests that anthropogenic material flows stemming from fossil fuel combustion, agricultural production, and mineral extraction now rival in scale those natural flows supposedly occurring outside of human activity (Steffen et al., 2015a). An early paper by Crutzen (2002: 23) does an excellent job of introducing these terrific perturbations:

"About 30–50% of the planet's land surface is exploited by humans…More than half of all accessible fresh water is used by mankind. Fisheries remove more than 25% of the primary production in upwelling ocean regions and 35% in the temperate continental shelf… Energy use has grown 16-fold during the twentieth century, causing 160 million tonnes of atmospheric sulphur dioxide emissions per year, more than twice the sum of its natural emissions… More nitrogen fertilizer is applied in agriculture than is fixed naturally in all terrestrial ecosystems… Fossil-fuel burning and agriculture have caused substantial increases in the concentrations of 'greenhouse' gases — carbon dioxide by 30% and methane by more than 100% — reaching their highest levels over the past 400 millennia, with more to follow."

An accumulating evidence base suggests humanity's current cumulative actions on earth have begun to press against the planetary boundaries expressed by our finite earth (Rockstrom et al., 2009). The growing literature on global tipping points suggest the Earth system now operates in a ‘no-analogue state’ (Crutzen and Steffen, 2003), while biodiversity studies show the Earth is in the midst of its sixth mass extinction event (Ceballos et al., 2015, Barnosky et al., 2011). This is a moment marked by unprecedented and unpredictable climatic, environmental and ecological events (Williams and Jackson, 2007). The benign era of the Holocene has passed, so the proposal claims; we have now entered a much more unpredictable and dangerous time where humanity recognises its devastating capacity to destabilise planetary processes upon which it depends (Rockstrom et al., 2009, Steffen et al., 2015b). For the first time in history, human activities are so pervasively modifying our own life-support system that the ability of the Earth to provide conditions suitable for our species to thrive can no longer be taken for granted (Crutzen, 2002, Zalasiewicz et al., 2010). The Anthropocene is, therefore, a moment of realisation, where the extent of human activities must be reconciled within the boundaries of biophysical processes that define the safe operating space of a stable and resilient Earth system (Steffen et al. 2015b).

A profound intertwining of the fates of nature and humankind has emerged (Zalasiewicz et al., 2010). The growing awareness of environmental and human calamity - and our belated, tangled role within it – puts to test our faith in the key modernist assumption, namely, the dualisms separating humans from nature (Hamilton et al., 2015b). This is a shocking and unprecedented moment, because, since the birth of modern thinking in the 1600’s, modernist epistemologies have proven exceedingly powerful, contributing significantly towards the organisation of society right to the present day (Latour, 1993). As such, amongst many other things, conceptions of unique and stable human agency, and the presumption of progressive norms such as liberty or universal dignity, and the existence of an objective world separate from human doings are all put to test (Latour, 2015, Hamilton et al., 2015b). This insight, without doubt, applies to the food system of which we all inherit. The Green revolution was underpinned with modern aspirations, being founded on ideas such as linear notions of progress, the power of human reason, and faith in the inevitable technological resolution of human problems (Cota, 2011). These conceptions, that have traditionally secured the role of science in society, begin to appear increasingly unreliable with the advent of the Anthropocene (Savransky, 2012, Stengers, 2015b). The inconvenient truth is that the technoscientific interventions which have been implemented as modern agrarian solutions onto our world over the last two centuries or so have carried with them serious and unexpected outcomes. What’s more, these escalating biophysical disruptions (e.g. Greenhouse gas emissions and Nitrogen and Phosphorous cycle perturbations) that have only recently become perceived, must be added to a much broader series of environmental, biological, and social repercussions brought about by particular aspects of our modernised food system.

To understand the magnitude of the Anthropocene problematic leaves little doubt that our contemporary food system faces enormous challenges (Kiers et al., 2008, Baulcombe et al., 2009, Pelletier and Tyedmers, 2010). Prominent studies point to agriculture as the single largest contributor to the rising environmental risks posed in the Anthropocene (Struik and Kuyper, 2014, Foley et al., 2011). Agriculture is: the single largest user of freshwater in the world[55] (Kabat 2013); the world's largest contributor to altering the global nitrogen and phosphorus cycles[56] (Carpenter 2005), and; a significant source (19-29%) of greenhouse-gas emissions (Vermeulen et al., 2012, Noordwijk, 2014). Put simply, 'agriculture is a primary driver of global change' (Rockström et al, 2017:6). And yet, it is from within the new epoch of the Anthropocene that the challenge of feeding humanity must be resolved. The number of hungry people in the world persists at approximately 900 million (FAO, Ifad and WFP. 2013). Even then, in order to feed the world by 2050 best estimates suggest that production must roughly double to keep pace with projected demands from population growth, dietary changes (particularly meat consumption), and increasing bioenergy use (Kiers et al., 2008, Baulcombe et al., 2009, Pelletier and Tyedmers, 2010, Kearney, 2010). Complicating matters even further is the need not simply to produce more, but also to manage the entire food system more efficiently. In a world where 2 billion suffer from micronutrient deficiencies, whilst 1.4 billion adults are over-nourished, the need for better distribution, access, and nutrition is glaring (FAO 2011a), as is the drastic need to reduce the deplorable levels of waste (conservative estimates suggest 30%) in the farm-to-fork supply chain (Parfitt et al., 2010, Lundqvist et al., 2008, Stuart, 2009).

The Anthropocene problematic presents serious questions about modern industrial agriculture, which in many guises is now deemed inefficient, destructive, and inadequate for our new global situation. But the fallout of this situation is more considerable still. The Anthropocene strikes a challenge at the very agricultural paradigm currently dominating food provision (Rockström et al., 2017). For this reason, the challenge extends well beyond 'the farm' and incorporates a much wider set of structures, practices, and beliefs that continue to enact and propel the modern agricultural paradigm into our newly demanding epoch. With the Anthropocene comes the urgent need to reconsider the methods and practices, ambitions and goals that define our current

[55] Best estimates suggest that with 70% of the totally withdrawn water (of almost 6000 km3 year-1) being diverted for agriculture approximately one quarter of the world's major river basins now no longer reach the ocean (Comprehensive Assessment of Water Management in Agriculture 2007).
[56] Anthropogenic uptake of N from the atmosphere (for industrial and intentional biological fixation of N) today exceeds the natural global uptake of N for biomass growth (Galloway and Cowling 2002; Gruber and Galloway 2008) and currently at approximately 150 Tg N year^{-1} the global uptake far exceeds the boundary value of 62–82 Tg N year-1 (Steffen et al. 2015a).

agriscience research. Are they fit for the challenges of our new epoch, or do they merely reproduce inadequate visions of modernist food provision?

7.4 Getting beyond the green revolution.

The Anthropocene marks a step change in the relation between humans and out plant. It demands a rethink of the current modes of production that currently propel us on unsustainable trajectories. Until now, such reflexive commitments have not been required of agriscience research and development. It is worth remembering that the Green Revolution, in both its ambitions and methods, was for some time uncontroversial; agriculture was to be intensified and productivity per unit of land or labour increased (Struik, 2006). Without doubt, this project, whose technological innovations were vigorously promoted by governments, companies, and foundations around the world (Evenson and Gollin, 2003), was phenomenally successful across vast scales. More calories produced with less average labour-time in the commodity system was the equation that allowed the cheapest food in world history to be produced (Moore, 2015). In order to simplify, standardize and mechanize agriculture toward increases in productivity per worker, plant and animal, a series of biophysical barriers had to be overridden. The green revolution achieved this largely through non-renewable inputs.

In the Anthropocene, this agricultural paradigm that marked the Green Revolution runs up against (geological) history. Growing awareness is that this 'artificialized' agricultural model, which substitutes each time more ecological processes with finite chemical inputs, irrigation and fossil fuel (Caron et al., 2014), literally undermines the foundations of future food provision. The biophysical contradictions of late-capitalist industrial agriculture have become increasingly conspicuous (Weis, 2010). Moreover, the dramatic environmental, economic, and social consequences of contemporary models of high intensity artificialized agriculture have become an escalating concern for a globalised food system manifesting accelerating contradictions (Kearney, 2010, Parfitt et al., 2010).

During the post-war period (mid 40's -70's) secure economic growth was founded on the accelerated extraction of fossil fuel, and as Cota (2011) notes, agriscience development during this time progressed more in tune with the geochemical sciences than the life sciences. Agricultural production designed around the cheapest maximum yields had been simplified and unified into monocrops, made to depend on mechanization, agrochemical products. Although highly effective when first implemented, the efficiency of these commercial inputs has witnessed diminishing returns (Moore, 2015). Following the oil crises of the 70's the productivist ideals of the Green Revolution fell more upon the life sciences particularly in the guise of agribiotech, which has grown into a multibillion dollar industry.

Feeding the globe's exploding population has been the key concern in a decades-long productivist narrative that has served to secure the prominent position of agricultural biotech in our current food system (Hunter et al., 2017). The great shock is that this highly advanced sector has done little to improve intrinsic yields. World agricultural productivity growth slowed from 3 percent a year in the 1960s to 1.1 percent in the 1990s (Dobbs et al., 2011). Recently, the yields of key crops have in some places approached plateaux's in production (Grassini et al., 2013). Mainstream agroscientists have voiced concern that the maximum yield potential of current varieties is fast approaching. On top of this, climate change is estimated to have already reduced global yields of maize and wheat by 3.8% and 5.5% respectively (Lobell et al., 2011), and some warn of sharp declines in crop productivity when temperatures exceed critical physiological thresholds (Battisti and Naylor, 2009).

The waning efficiency gains of artificial inputs added to the biological limits of traditional varieties is a situation that, for some, further underscores the need to accelerate the development of genetically engineered varieties (Prado et al., 2014). Even then, the greatest proponents of GM - the biotech firms themselves – are aware that GM interventions rarely work to increase yield, but rather to *maintain* it through pesticide and herbicide resistance[57]. As such, agricultural production has become locked into a cycle that requires the constant replacement of new crop varieties and product packages to overcome the growing negative environmental and biological impingements upon yield [58]. Melinda Cooper's (2008: 19) influential analysis of agro-biotechnology has traced how neoliberal modes of production become relocated ever more within the genetic, molecular, and cellular levels. As such the commercialisation of agrarian systems increasingly extends toward the capture of germplasm and DNA, toward 'life itself' (Rose, 2009). Cooper's (2008) diagnosis, is that we are living in an era of capitalist delirium characterized by its attempt to overcome biophysical limits of our earth through the speculative biotechnological reinvention of the future. In this respect, some have argued that rather than overcoming weaknesses of the conventional paradigm, the narrow focus of GM interventions seem only to intensify its central characteristics (Altieri, 2007).

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[57] For instance, consider the following statement issued by Monsanto: "The main uses of GM crops are to make them insecticide- and herbicide tolerant. They don't inherently increase the yield. They protect the yield." Quoted in E. Ritch, "Monsanto Strikes Back at Germany, UCS," Cleantech.com (April 17, 2009). Accessed July 18 2009.
[58] Especially important here are the effects of climate change, as well as the 'superweed' phenomenon of increasingly resistant pests that significantly diminish yields.

Amidst the deceleration of yield increases, the estimated targets of 60-100% increases in production needed by 2050 (Tilman et al., 2011, Alexandratos and Bruinsma, 2012) appear increasingly daunting. Furthermore, as compelling and clear as these targets may be, concerns have been raised that productivist narratives have eclipsed other pressing concerns, namely the environmental sustainability of production (Hunter et al., 2017) and food security (Lawrence et al., 2013). The current agricultural paradigm has held production first and sustainability as a secondary task of mitigation (Struik et al., 2014). Thirty years of frustrated sustainability talk within the productivist paradigm are testament to the severe difficulties for researchers and policy makers alike to bridge the gap between sustainability theory and practice (Krueger and Gibbs, 2007). 'Sustainability' as a concept had initially had revolutionary potential. Key texts such as the Club of Rome's '*The Limits of Growth'* (Meadows et al., 1972) for instance, contained an imminent critique of global development narratives. But researchers have pointed out the way that 'sustainability' throughout the 80's and 90's became assimilated into neoliberal growth discourse (Keil, 2007). We now have a situation where, on the one hand, global sustainability is almost unanimously understood as a prerequisite to attain human development (UN GSP 2012) across all scales - from local, to city, nation, and the world (Folke et al. 2005), whilst on the other, despite substantial efforts in many levels of society towards the creation of a sustainable future, key global-scale indicators show that humanity is actually moving away from sustainability rather than towards it (Fischer et al., 2007). This is in spite of the increasing regularity of high-profile reports that evermore underscore the grave risks of existing trends to the long-term viability of ecological, social and economic systems (Steffen et al., 2006, Stocker, 2014, Assessment, 2003, Stern, 2008). This situation -the widening gap between our current trajectory and all meaningful sustainability targets - has been discussed as the so called 'paradox of sustainability' (Krueger and Gibbs, 2007). Prevailing discourse on food security and sustainability continues to galvanise growth oriented developmental imperatives (Hunter et al., 2017).

Agriscience research and development proliferated in accordance with the dominant politico-economic structures that defined planetary development over last 30 years (Marzec, 2014). Although the negative effects of the so called 'Chicago School' of development have by now been well documented (Sen, 2001, Harvey, 2007), biotechnological innovation remains rooted within neoliberal discourse (Cooper, 2008). These narratives consistently present global markets, biotech innovation, and multinational corporate initiatives as the structural preconditions for food security and sustainability. The empirical credibility of such claims has long been challenged[59], but

[59] Productivist discourse invariably ignores Amartya Sen's (1981, 154; Roberts 2008, 263; WFP 2009, 17) classic point that the volume and availability of food alone is not a sufficient explanation for the persistence of world hunger. It is well established that enough food exists to feed in excess of the world's current population (OECD 2009, 21).

seem especially relevant amidst the accumulating history of chronic distributional failures and food crises that mark our times. It is worth repeating Nally's (2011; 49) point: "The spectre of hunger in a world of plenty seems set to continue into the 21st century… this is not the failure of the modern food regime, but the logical expression of its central paradoxes." The situation is one where malnutrition is seen no longer as a failure of an otherwise efficiently functioning system, but rather as an endemic feature within the systemic production of scarcity (Nally, 2011). In the face of such persisting inconsistencies, commentators note that neoliberal appeals to human prosperity, food security, and green growth appear out of touch and often ideologically driven (Krueger and Gibbs, 2007).

The Anthropocene is a time where ecological, economic and social disaster walk hand in hand as modern economies and institutions geared toward unlimited growth crash against the finite biophysical systems of the earth (Altvater et al., 2016, Moore, 2015). Cohen (2013) describes the Anthropocene as an 'eco-eco' disaster, paying heed to the rotten relationship in which eco*nomic* debt becomes compounded against the eco*logical* debt of species extinction. Now more than ever, faith in the modernising powers of neoliberal food interventions proclaiming just and sustainable futures wears thin (Stengers, 2018), yet the resemblance noted by some commentators (Gibson-Graham, 2014), between our food system and the unhinged financial systems of our neoliberal economies charts an alarming trend. It's worth noting this resemblance runs deeper than the mere production of debt (one being calorific[60] and genetic, the other economic). The truth is our food system hinges on a cash nexus that links trade tariffs, agricultural subsidies, enforcement of intellectual property rights and the privatisation of public provisioning systems. Viewed from above, these procedures constitute a pseudo corporate management of the food system, which according to Nally (2011: 37) should be seen as a properly *biopolitical* process designed for managing life, "including the lives of the hungry poor who are 'let die' as commercial interests supplant human needs". Petrochemicals and micronutrients are not the only things being consumed in the Anthropocene; future possibilities are (Collings, 2014, Cardinale et al., 2012).

The dramatic environmental, economic, and social consequences of contemporary models of high-intensity, artificialized agriculture have become an escalating concern for a globalised food system manifesting accelerating contradictions (Kearney, 2010, Parfitt et al., 2010). What once might have been considered necessary side-effects of the modernising imperative of the Green Revolution, the 'externalities' of our current food system are increasingly exposed as a kind of

[60] Although the calculations are complex and contested, one common estimate is that industrial agriculture requires an average 10 calories of fossil fuels to produce a single calorie of food (Manning 2004), which might rise to 40 calories in beef (Pimentel, 1997).

‘deceptive efficiency’[61] bent toward rapid production and profit and very little else (Weis, 2010). The disturbing realisation is that the food system we inherit from the Green Revolution creates value only when a great number of costs (physical, biological, human, moral) are allowed to be overlooked (Tegtmeier and Duffy, 2004). A growing number of voices remind us that costs of production go beyond the environment into matters such as the exclusion of deprived farmers, the promotion of destructive diets (Pelletier and Tyedmers, 2010), and more generally the evacuation of social justice and political stability from matters of food provision (Power, 1999). The relation between agrarian technological intervention, food security, and sustainability emerges as far wider and complex issue than could be acknowledged by narratives of the Green revolution.

Situating the contemporary food system within dominant recent-historical processes, the above discussion has paid particular attention to destructive links between modern agriculture and the economic logics of late-capitalism. It is important, however, to remember that numerous commentators have cautioned against over simplified or deterministic accounts regarding the relationship between capitalist relations of production and Anthropocene problematic (Stengers, 2015b, Haraway, 2015, Altvater et al., 2016). Such a discussion is made possible by close to four decades of critical investigations by feminists, science and technology scholars, historians, geographers, anthropologists and activists, that have endeavoured in tracing the links between hegemonic forms of science and the social/environmental destruction caused by industrial capitalism (Kloppenburg, 1991). This ‘deconstructive’ research ethic developed important understandings of the way modern agriscience progressed down trajectories that involve the neglect of particular physical, biological, political and social contexts and histories (Kloppenburg, 1991). In many instances, the modernising narratives of ‘development’ like those put to work in the Green Revolution became seen - by anthropologists, historians and indigenous communities alike - as a kind of modified successor to pre-war colonial discourse (Scott, 2008, Martinez-Torres and Rosset, 2010). In anthropological terms, what these studies taught us was that although modern agriculture was rooted in developmental narratives of universal prosperity, in reality, ‘progress’ was achieved through the displacement or indeed destruction of a great diversity of agricultural perspectives, practices, ecologies and landscapes. It is for this reason Cota (2011: 6) reminds us of the importance of the critical work that explicitly positioned the biopolitical

[61] Externalities of our current food system are often ignored or heavily subsidised away. Moore (2015: 187) describes the situation as ‘a kind of “ecosystem services” in reverse’: “Today, a billion pounds of pesticides and herbicides are used each year in American agriculture. The long recognized health impacts have been widely studied. Although the translation of such “externalities” into the register of accumulation is imprecise, their scale is impressive, totalling nearly $17 billion in unpaid costs for American agriculture in the early twenty-first century.” On externalities see: Tegtmeier and Duffy (2004).

paradigm of industrial agriculture “not first and foremost as an economic kind of imperialism, but more profoundly as an epistemic and culturally specific kind of imperialism”.

This is a key point. The Green Revolution was not merely a technical, nor economic intervention, but involved the spread of a more profound reconfiguration of the epistemological registers of food provision itself. It was a process that deeply influenced the way agricultural knowledge was produced, propagated and implemented. As Cota (2011: 6) explains: ‘the use of physicalist and probabilistic discourse, a purely instrumental conception of nature and work, the implementation of statistical calculations disconnected from local conditions, [as well as] the reliance on models without recognizing historic specificities’ were all ways of enacting the biopolitical agenda of the Green Revolution. This list of commitments describes the fundamentals at the sharp end of the Green Revolution, but as we have seen, such commitments alone have proven insufficient for the task of creating a just and sustainable food system. It becomes apparent that any research agenda fit for the Anthropocene must learn to move beyond the modern food paradigm by forging a different research ethic with different commitments.

7.5 Paradigm shift for a new food system

To claim that agriculture is ‘at a crossroads’ (Kiers et al., 2008) does not quite do justice to the magnitude of our situation. The gaping ‘sustainability gap’ (Fischer et al., 2007) amidst unanimous calls for sustainability, are increasingly being met with common response amongst researchers: Pleads for revolutionary measures, and paradigm shifts. Foley et al. (2001: 5) put it quite directly: “The challenges facing agriculture today are unlike anything we have experienced before, and they require revolutionary approaches to solving food production and sustainability problems. In short, new agricultural systems must deliver more human value, to those who need it most, with the least environmental harm.” Somehow, world agriculture’s current role as the single largest driver of global environmental change, must shift into a ‘critical agent of a world transition’ towards global sustainability within the biophysical safe operating space of the Earth (Rockstrom et al, 2017: 5).

The Anthropocene lays steep demands: Agriculture must be intensified, it must meet the needs of a growing population, but at the same time it is mandatory that the pressures exerted by our food production systems stay within the carrying capacity of Planet Earth. It is increasingly understood that future food security depends on the development of technologies that increase the efficiency of resource use whilst simultaneously preventing the externalization of costs (Garnett et al., 2013). The search for alternatives to our current agricultural paradigm has brought to the fore ideas such as agroecology (Reynolds et al., 2014) and ’sustainable intensification’, with the acknowledgement that real progress must be made toward ‘ecological intensification’, that is, increasing agricultural output by capitalizing on the ecological processes in agro-ecosystems (Struik and Kuyper, 2014).

There has been well-documented debate on what constitutes ‘sustainable intensification’ (SI) of agriculture as well as the role it might play in addressing global food security (Struik and Kuyper, 2014, Kuyper and Struik, 2014, Godfray and Garnett, 2014). Critics have cautioned against the top-down, global analyses that are often framed in narrow, production-oriented perspectives, calling for a stronger engagement with the wider literature on sustainability, food security, and food sovereignty (Loos et al., 2014). Such readings revisit the need for developing regionally grounded, bottom-up approaches, with a growing consensus claiming that an SI agenda fit for the Anthropocene does not entail ‘business- as-usual’ food production with marginal improvements in sustainability, but rather a radical rethinking of food systems not only to reduce environmental impacts but also to enhance animal welfare, human nutrition, and support rural/urban economies with sustainable development (Godfray and Garnett, 2014).

While traditional ‘sustainable intensification’ (SI) has been criticised by some as too narrowly focused on production, or even as a contradiction in terms altogether (Petersen and Snapp, 2015), others make it clear that the approach must be broadly conceived, with the acknowledgement that there is no single universal pathway to sustainable intensification (Garnett and Godfray, 2012). Important here is the growing appreciation of ‘multifunctionality’ in agriculture (Potter, 2004). If, during the 20th century ‘Malthusian’ demographics discourse had secured the narrow goal of agricultural development on increasing production, the growing rediscovery of the multiple dimensions of farming currently taking place is altering the perception of the relationship between agriculture and society.

‘Multifunctionality’ as an idea was initially contested in the context of the controversial GATT and WTO agricultural and trade policy negotiations (Caron et al., 2008), but has since gained wide acceptance, leading to a more integrative view of our food system (Potter, 2004). In this view, progress in seeing agriculture as an important type of ‘land use’ competing with other land functions (Bringezu et al., 2014) interrelates with a number of other perspectives. These have been conceptualised through several important categories: 1) as a source of employment and livelihood for a rural and future urban population (McMichael, 1994); 2) as a key part of cultural heritage and identity (van der Ploeg and Ventura, 2014); 3) as the basis of complex value chain interactions in ‘food systems’ (Perrot et al., 2011); 4) as a sector in regional, national and global economies (Fuglie, 2010); 5) as modifier and storehouse of genetic resources (Jackson et al., 2010); 6) as a threat to environmental integrity, that exerts destructive pressures on biodiversity

(Brussaard et al., 2010, Smil, 2011); and 7) as source of greenhouse-gas emissions (Noordwijk, 2014). This list is by no means comprehensive, but what is important is that each of these interacting dimensions are understood to impact sustainability and food security in one way or another and must be apprehended by serious attempts toward SI.

Sustainability outcomes are increasingly seen as a complex interplay between local and global concerns (Reynolds et al., 2014). Biophysical, ecological, and human needs intermix within the complexities and idiosyncrasies of "place" (Withers, 2009). The "one size fits all" solutions characteristic of the Green Revolution fail to acknowledge these unique sustainability potentials and demands. The result is that changes in food production and consumption must be perceived through a multiplicity of scales *and* styles. To this end, Reynolds et al. (2014; 101) suggest an approach to sustainability that takes advantage of the insights of agroecological principles. They forward a "custom-fit" food production focus "explicitly tailored to the environmental and cultural individuality of place and respectful of local resource and waste assimilative limits, thus promoting biological and cultural diversity as well as steady-state economics."

If the issues at stake are inherently *multi-dimensional*, others have also underlined that they are *contested*. Trade-offs between the plethora of biophysical and human concerns are inevitable and often exceedingly complex. Sustainability thresholds are diverse, often normative, and can seldom all be realized in full simultaneously (Struik and Kuyper, 2014). It has been emphasized that new directions towards sustainability and food security require simultaneous change at the level of formal and informal social rules and incentive systems (i.e., institutions) that orient human interaction and behaviour, and hence that 'institutional innovation' is held to be a key entry point in addressing challenges (Hall et al., 2001). Insomuch as the complexity of sustainable intensification derives from human framings (which entail and flow from contexts, identities, intentions, priorities, and even contradictions), they are, as Kuyper and Struik (2014: 72) put it: 'beyond the command of science'. Attempting to reconcile the many dimensions of food production towards sustainable ends and within the bounds of our finite planet, involves a great deal of uncertainty, irreducibility, and contestation (Funtowicz and Ravetz, 1995); it requires an awareness and acknowledgement that such issues are shot through with *political* implication.

Food systems and sustainability research has come a long way in expanding the narrow focus of the Green Revolution, bringing greater clarity to the steep challenges we face in the pursuit of a more environmentally and socially sustainable food system. Thanks to a broad range of work, it is now apparent that food production lies at the heart of a nexus of interconnected and multi-scalar processes, on which humanity relies to meet a host of multidimensional - often contradictory - needs (physical, biological, economic, cultural). As Rockstrom et al (2017: 7) have stated: "World agriculture must now meet social needs and fulfil sustainability criteria that enables food and all other agricultural ecosystem services (i.e., climate stabilization, flood control, support of mental health, nutrition, etc.) to be generated within a safe operating space of a stable and resilient Earth system." It is precisely within these recalibrated agricultural goals that aquaponics technology must be developed.

7.6 Aquaponic potential or Misplaced Hope?

Contemporary aquaponic research has shown keen awareness of particular concerns raised in the Anthropocene problematic. Justifications for aquaponic research have tended to foreground the challenge of food security on a globe with an increasing human population and ever strained resource base. For instance, Konig et al (2015: 26) precisely situate aquaponics within the planetary concerns of Anthropocene discourse when they state: "Assuring food security in the twenty-first century within sustainable planetary boundaries requires a multi-faceted agro-ecological intensification of food production and the decoupling from unsustainable resource use". Toward these important sustainability goals, it is claimed that aquaponic technology shows much promise (Goddek et al., 2015). The innovative enclosed systems of aquaponics offer an especially alluring convergence of potential resolutions that could contribute towards a more sustainable future.

Proponents of aquaponics often stress the ecological principles at the heart of this emerging technology. Aquaponic systems harness the positive potential of a more or less simple ecosystem, in order to reduce the use of finite inputs whilst simultaneously reducing waste by-products and other externalities. On these grounds aquaponic technology can be viewed as a primary example of 'sustainable intensification' (Garnett et al., 2013), or more precisely, as a form of 'ecological intensification' since its founding principles are based on the management of service-providing organisms toward quantifiable and direct contributions to agricultural production (Bommarco et al., 2013). From this agroecological principle flow a great number of potential sustainability benefits. Chapter 1 and 2 of this book do an exemplary job of highlighting these, detailing the challenges faced by our food system and situating aquaponics science as the potential locus for a range of sustainability and food security interventions. There is no need to repeat these points again, but it is worth noting this perceived convergence of potential resolutions is what drives research and strengthens the 'conviction that this technology has the potential to play a significant role in food production in the future' (Junge et al., 2017; 7).

However, despite the considerable claims made by its proponents, the future of aquaponics is less than certain. Just what kind of role aquaponics might play in transitions to sustainable food provision is still largely up for debate – crucially, we must stress, *the publication of sustainability and food security outcomes of aquaponic systems remain conspicuous by their absence across Europe* (König et al., 2018). On paper, the 'charismatic' attributes of aquaponics ensure that it can easily be presented as a 'silver bullet' type of innovation that gets to the heart of our food system's deepest sustainability and food security issues (Brooks et al., 2009). Such images have been able to garner considerable attention for aquaponics far beyond the confines of academic research – consider, for instance, the significant production of online aquaponic 'hype' in comparison to similar fields, usefully pointed out by Junge et al. (2017). It is here we may take time to point out the relationship between the perceived potential of aquaponics and 'techno-optimism'.

The introduction of every new technology is accompanied by myths that spur further interest in that technology (Schoenbach, 2001). Myths are circulated amongst early adopters, and are picked up by the general media often long before the scientific community has time to thoroughly analyse and answer to their claims. Myths, as Schoenbach states (2001, 362), are widely believed because they "comprise a clear-cut and convincing explanation of the world". These powerful explanations are able to energise and align individual, community, and also institutional action toward particular ends. The 'beauty' of aquaponics, if we can call it that, is that the concept can often render down the complexity of sustainability and food security issues into clear, understandable, and scalable systems metaphors. The ubiquitous image of the aquaponic cycle - water flowing between fish, plants and bacteria – that elegantly resolves food system challenges is exemplary here. However, myths on technology, whether optimistic or pessimistic, share a techno-deterministic vision of the relation between technology and society (Williams 1974, Tehraninan 1990, Schoenbach 2001). Within the techno-deterministic vision of technology it is the technology that causes important changes in society: if we manage to change the technology we thus manage to change the world. Regardless whether the change is for the better (techno-optimism) of the worst (techno-phobia), the technology by itself creates an effect.

Techno-determinist views have been thoroughly critiqued on sociological (Tehraninan 1990), philosophical (Bradley, 2011), marxist (Hornborg, 2013), material-semiotic (Latour, 1996), and feminist (Haraway, 1997) grounds. These more nuanced approaches to technological development, would claim that technology by itself does not bring change to society, it is neither inherently good, nor bad, but is always embedded within society's structures and it is those structures that enable the use and effect of the technology in question. To one degree or another, technology is an emergent entity, the effects of which we cannot known in advance (De Laet and Mol, 2000). This might seem like an obvious point, but techno-determinism remains a strong, if often latent, feature within our contemporary epistemological landscape. Our innovation-driven, technological societies are maintained by discursive regimes that hold on to the promise of societal renewal through technological advancement (Lave et al., 2010). Such beliefs have been shown to have an important normative role within expert communities whether they be scientists, entrepreneurs, or policy makers (Franklin, 1995, Soini and Birkeland, 2014).

The rise of aquaponics across Europe is intertwined with specific interests of various actors. We can identify at least five societal processes that led the development of aquaponics: (a) interest of public authorities in funding high-tech solutions for problems of sustainability, (b) venture capital financing, motivated by the successes in IT start-ups, looking for "the next big thing" that will perhaps discover the new "unicorn" (start-up companies valued at over $1 billion), (c) mass media event-focused interest in snapshot reporting on positive stories of new aquaponics start-ups, fuelled by the public relations activities of these start-ups, with rare media follow-up reporting on the companies that went bust, (d) internet-supported growth of enthusiastic, do-it-yourself aquaponics communities, sharing both sustainability values and love for tinkering with new technology, (e) interests of urban developers to find economically viable solutions for vacant urban spaces, and greening of urban space, and (f) research communities focused on developing technological solutions to impending sustainability and food security problems. To a greater or lesser degree, the spectre of techno-optimistic hope permeates the development of aquaponics.

Although the claims of techno-optimist positions are inspiring and able to precipitate the investment of money, time, and resources from diverse actors, the potential for such standpoints to generate justice and sustainability has been questioned on scales from local (Leonard, 2013) and regional issues (Hultman, 2013) to global imperatives (Hamilton, 2013). And it is at this point, we might consider the ambitions of our own field. A good starting point would be the 'COST action FA1305', which has been an important facilitator of Europe's aquaponic research output over recent years, with a number of publications acknowledging the positive impact of the Action in enabling research (Miličić et al., 2017, Delaide et al., 2017, Villarroel et al., 2016). Like all COST Actions, this EU funded transnational networking instrument has acted as a hub for aquaponic research in Europe, galvanising and broadening the traditional networks amongst researchers by bringing together experts from science, experimental facilities and entrepreneurs. The original mission statement of COST action FA1305 reads as follows:

"*Aquaponics has a key role to play in food provision and tackling global challenges such as water scarcity, food security, urbanization, and reductions in energy use and food miles*. The EU acknowledges these challenges through its Common Agriculture Policy and policies on Water Protection, Climate Change, and Social Integration. A European approach is required in the globally emerging aquaponics research field building on the foundations of Europe's status as a global centre of excellence and technological innovation in the domains of aquaculture and hydroponic horticulture. The EU Aquaponics Hub aims to the development of aquaponics in the EU, by leading the research agenda through the creation of a networking hub of expert research and industry scientists, engineers, economists, aquaculturists and horticulturalists, and contributing to the training of young aquaponic scientists. The EU Aquaponics Hub focuses on three primary systems in three settings; 1) 'cities and urban areas' - urban agriculture aquaponics, 2) 'developing country systems' - devising systems and technologies for food security for local people and 3) 'industrial scale aquaponics' - *providing competitive systems delivering cost effective, healthy and sustainable local food in the EU*." (http://www.cost.eu/COST_Actions/fa/FA1305, 12.10.2017, emphasis added)

As the mission statement suggests, from the outset of COST action FA1305 high levels of optimism were placed on the role of aquaponics in tackling sustainability and food security challenges. The creation of the COST EU aquaponics Hub was to "provide a necessary forum for 'kick-starting' aquaponics as a serious and potentially viable industry for sustainable food production in the EU and the world" (COST, 2013). Indeed, from the authors' own participation within COST FA1305, our lasting experience was without doubt one of being part of a vibrant, enthused and highly skilled research community that were more or less united in their ambition to make aquaponics work towards a more sustainable future. Four years down the line since the aquaponic hub's mission statement was issued, however, the sustainability and food security potential of aquaponics remains just that – potential. At present it is uncertain what precise role aquaponics can play in Europe's future food system (König et al., 2018).

The commonly observed narrative that aquaponics provides a sustainable solution to the global challenges agriculture faces unveils a fundamental misconception of the capabilities of this technology. The plant side of aquaponics is horticulture, not agriculture, producing vegetables and leafy greens with high water content and low nutritional value compared to the staple foods agriculture on farm land produces. A quick comparison of current agricultural area, horticultural area and protected horticultural area, 184.332 km2, 2.290 km2 (1,3%) and 9,84 km2 (0,0053%) in Germany (Destatis 2015) reveals the flaw in the narrative. Even if considering a much higher productivity in aquaponics through the utilization of controlled environment systems, aquaponics is not even close to having the potential to make a real impact on agricultural practice. This becomes even more obvious when the ambition to be a "food system of the future" ends in the quest for high value crops (such as microgreens) that can be marketed as gourmet gastronomy.

It is well known that the development of sustainable technology is characterized by uncertainties, high risks, and large investments with late returns (Alkemade and Suurs, 2012). Aquaponics in this regard, is no exception; only a handful commercially operating systems exist across Europe (Villarroel et al., 2016). There appears considerable resistance to the development of aquaponic technology. Commercial projects have to contend with comparatively high technological and management complexity, significant marketing risks, as well as an uncertain regulatory situation that until now persists (Joly et al., 2015). Although it is difficult to pin down the rate of start-up failure, the short history of commercial aquaponics across Europe might well be summed up as 'Small successes and big failures' (Haenen, 2017). It is worth pointing out also, that the pioneers already involved in aquaponics at the moment across Europe are unclear if their technology is bringing about any improvements in sustainability (Villarroel et al., 2016). Recent analysis from König et al., (2018) has shown how the challenges to aquaponics development derive from a host of structural concerns, as well as the technology's inherent complexity. Combined, these factors result in a high-risk environment for entrepreneurs and investors which has produced a situation whereby start up facilities across Europe are forced to focus on production, marketing and market formation over the delivery of sustainability credentials (König et al., 2018). Aside from the claims of great potential, the sombre reality is that it remains to be seen just what impact aquaponics can have on the entrenched food production and consumption regimes operating in contemporary times. The place for aquaponic technology in the transition towards more sustainable food systems, it seems, has no guarantee.

Beyond the speculation of techno-optimism, aquaponics has emerged as a highly complex food production technology that holds potential but is faced with steep challenges. In general, there exists a lack of knowledge about how to direct research activities to develop such technologies in a way that preserves their promise of sustainability and potential solutions to pressing food system concerns (Elzen et al., 2017). A recent survey conducted by Villarroel et al. (2016) found that from 68 responding aquaponic actors spread across 21 European countries, 75% were involved in research activities and 30.8% in production, with only 11.8% of those surveyed actually selling fish or plants in the past 12 months. It is clear that the field of aquaponics in Europe is still mainly shaped by actors from research. In this developmental environment we believe the next phase of aquaponic research will be crucial to developing the future sustainability and food security potential of this technology.

Interviews (König et al., 2018) and the quantitative surveys (Villarroel et al., 2016) of the European aquaponic field have indicated there is mixed opinion regarding the vision, motivations and expectations about the future of aquaponics. In light of this, Konig et al, (2018) have raised concerns that a diversity of visions for aquaponic technology might hinder the coordination between actors and ultimately disrupt the development of 'a realistic corridor of acceptable development paths' for the technology (König et al, 2018). From an innovation systems perspective, emergent innovations that display an unorganised diversity of visions can suffer from 'directionality failure' (Weber and Rohracher, 2012) and ultimately fall short of their perceived potentials. Such perspectives run in line with positions from sustainability science that stress the importance of 'visions' for creating and pursuing desirable futures (Brewer, 2007). In light of this we offer up one such vison for the field of aquaponics. We argue that aquaponics research must refocus on a radical sustainability and food security agenda that is fit for the impending challenges faced in the Anthropocene.

7.7 Towards a 'sustainability first' paradigm

As we saw earlier, it has been stressed that the goal to move toward sustainable Intensification grows from the acknowledgment of the limits of the conventional agricultural development paradigm and its systems of innovation. Acknowledging the need for food system innovations that exceed the traditional paradigm and that can account for the complexity arising from sustainability and food security issues, Fischer et al (2007: 621) have called for no less than 'a new model of sustainability' altogether. Similarly, in their recent plea for global efforts towards sustainable intensification, Rockstrom et al (2017: 7) have pointed out that paradigm shift in our food system entails challenging the dominant research and development patterns that maintain the 'productivity first' focus whilst subordinating sustainability agendas to a secondary, 'mitigating' role. Instead, they call for a reversal of this paradigm so that "sustainable principles become the *entry point* for generating productivity enhancements". Following this, we suggest a *'sustainability first'* vision for aquaponics as one possible orientation that can both offer coherence to the field and guide its development toward the proclaimed goals of sustainability and food security.

As with most calls for sustainability, our '*sustainability first'* proposal might sound rather obvious and unchallenging at first glance, if not completely redundant – surely, we could say, aquaponics is all about sustainability. But history would remind us that making sustainability claims is an agreeable task, whereas securing sustainability outcomes is far less certain (Keil, 2007). As we have argued, the 'sustainability' of aquaponics currently exists as potential. Just how this potential translates into sustainability outcomes must be a concern for our research community.

Our 'sustainability first' proposal is far from straight forward. First and foremost, this proposal demands that, if our field is to justify itself on the grounds of sustainability, we must get to grips with the nature of sustainability itself. In this regard, we feel there is much to be learned from the growing arena of Sustainability Science as well as Science and Technology studies (STS). We will find that maintaining a sustainability focus within aquaponic research represents a potentially huge shift in the direction, composition and ambition of our research community. Such a task is necessary if we are to direct the field towards coherent and realistic goals that remain focussed on sustainability and food security outcomes that are relevant for the Anthropocene.

Taking sustainability seriously is a massive challenge. This is because, at its core, sustainability is fundamentally an *ethical* concept raising questions about the value of nature, social justice, and responsibilities to future generations etc. and encompasses the multidimensional character of human-environment problems (Norton, 2005). As we discussed earlier, the sustainability thresholds that might be drawn up concerning agricultural practices are diverse and often cannot be reconciled in entirety, obligating the need for 'trade-offs' (Funtowicz and Ravetz, 1995). Choices have to be made in the face of these trade-offs and most often criteria upon which such choices are based depend not only upon scientific, technical, or practical concerns, but also on norms and moral values. It goes without saying, there is little consensus on how to make these choices nor is there greater consensus on the norms and moral values themselves. Regardless of this fact, inquiries into values are largely absent from the mainstream sustainability science agenda, yet as Miller et al. (2014) assert, "unless the values [of sustainability] are understood and articulated, the unavoidable political dimensions of sustainability will remain hidden behind scientific assertions." Such situations prevent the coming together of and democratic deliberation between communities – a certain task for achieving more sustainable pathways.

Taking note of the prominent place of values in collective action toward sustainability and food security, scholars from the field of Science and technology studies have highlighted that rather than be treated as an important externality to research processes (often dealt with separately or after the fact), values must be moved upstream in research agendas (Jasanoff, 2007). When values become a central part of sustainability research along comes the acknowledgement that decisions can no longer be based on technical criteria alone. This has potentially huge impacts on the research process, because traditionally what might have been regarded as the sole remit of 'expert knowledge' must now be opened up to other knowledge streams (for instance, 'lay', indigenous, and practitioner knowledges) with all the epistemological difficulty this entails (Lawrence, 2015). In response to these problems, sustainability science has emerged as a field that aims to transcend disciplinary boundaries and seeks to involve non-scientists in solution-oriented, context-determined, research processes that are focused on outcome generation (Miller et al., 2014).

A key question in these discussions is knowledge. Sustainability problems are often caused by the complex interplay of diverse social–ecological factors, and the knowledge needed for effectively governing these challenges has become progressively more dispersed and specialised (Ansell and Gash 2008). The knowledge required for understanding how sustainability concerns hang together is too complex to be organised by a single body, and results in the need to integrate different types of knowledge in new ways. This is certainly the case for our own field: like other modes of sustainable intensification (Caron et al., 2014) aquaponic systems are characterised by inherent complexity (Junge et al., 2017) which places great emphasis on new forms of knowledge production (FAO, 2013). Complexity of aquaponic systems derives not only from their 'integrated' character, but stems also from the wider economic, institutional, and political structures that impact the delivery of aquaponics and its sustainability potential (Konig et al., 2016). Developing solutions towards sustainable aquaponic food systems may well involve contending with diverse realms of understanding from engineering, horticultural, aquacultural, microbiological, ecological, economic and public health research, to the practical and experiential knowledge concerns of practitioners, retailers and consumers. What this amounts to is not just a grouping together of ideas and positions, but entails that we develop entirely novel modes of knowledge production and appreciation to bridge 'knowledge gaps' (Caron et al., 2014). Abson et al. (2017) have identified three key requirements of new forms of knowledge production that can foster sustainability transformations: (i) the explicit inclusion of values, norms and context characteristics into the research process to produce ''socially robust'' knowledge (Scholz 2011); (ii) mutual learning processes between science and society, involving a re-think of the role of science in society, and (iii) a problem- and solution-oriented research agenda. Drawing upon these three insights can help our field develop what we call a 'critical sustainability knowledge' for aquaponics. Below we discuss three areas our research community can address that we consider crucial to unlocking the sustainability potential of aquaponics, these are: partiality; context; and concern. Developing an understanding of each of these points will help our field pursue a solutions-oriented approach for aquaponic sustainability and food security outcomes.

7.8 'Critical sustainability knowledge' for aquaponics

7.8.1 Partiality

Despite contemporary accounts of sustainability that underline its complex, multidimensional, and contested character, in practice, much of the science that engages with sustainability issues remains fixed to traditional, disciplinary perspectives and actions (Spangenberg 2011). Disciplinary knowledge, it must be said, has obvious value and has delivered huge advances in understanding since antiquity. Nevertheless, the appreciation and application of sustainability issues through traditional disciplinary channels has been characterised by the historic failure to facilitate the deeper societal change needed for issues such as the one we contend here - the sustainable transformation of the food system paradigm (Fischer et al. 2007).

The articulation of sustainability problems through traditional disciplinary channels often leads to 'atomized' conceptualisations that view biophysical, social, and economic dimensions of sustainability as compartmentalised entities, and assume these can be tackled in isolation (e.g. Loos et al. 2014). Instead of viewing sustainability issues as a convergence of interacting components that must be addressed together, disciplinary perspectives often promote 'techno-fixes' to address what are often complex multi-dimensional problems (e.g. Campeanu and Fazey 2014). A common feature of such framings is that they often imply that sustainability problems can be resolved without consideration of the structures, goals and values that underpin complex problems at deeper levels, typically giving little consideration to the ambiguities of human action, institutional dynamics, and more nuanced conceptions of power.

The practice of breaking a problem down into discrete components, analysing these in isolation, and then reconstructing a system from interpretations of the parts, has been a hugely powerful methodological insight that traces its history back to the dawn of modernity with the arrival of Cartesian reductionism (Merchant, 1981). Being a key tenet of the production of objective knowledge, this practice forms the bedrock of most disciplinary effort in the natural sciences. The importance of objective knowledge, of course, is that it provides the research community with 'facts'; precise and reproducible insights about generally dispersed phenomena. The production of facts was the engine room of innovation that propelled the Green revolution. Science fuelled 'expert knowledge' and provided penetrating information about dynamics in our food production systems that remained invariant through change in time, space or social location. Building a catalogue of this kind of knowledge and deploying it as what Latour (1986) calls 'immutable mobiles', formed the basis of the universal systems of mono-cropping, fertilisation, and pest-control that characterise the modern food system (Latour, 1986).

But this form of knowledge production has weaknesses. As any scientist knows, in order to gain significant insights this method must be strictly applied. It has been shown that this knowledge production is "biased toward those elements of nature which yield to its method and toward the selection of problems most tractable to solutions with the knowledge thereby produced" (Kloppenburg, 1991). A clear example of this would be our imbalanced food security research agenda that heavily privileges production over conservation, sustainability or food sovereignty issues (Hunter et al., 2017). Most high-profile work on food security concentrates on production (Foley et al., 2011) emphasising material flows and budgets over deeper issues such as the structures, rules and values that shape food systems. The simple fact is that because we know more about material interventions it is easier to design, model and experiment on these aspects of the food system. As Abson et al (2017: 2) point out: "Much scientific lead sustainability applications assume some of the most challenging drivers of unsustainability can be viewed as ‘fixed system properties’ that can be addressed in isolation”. In pursuing the paths along which experimental success is most often realized, ‘atomized’ disciplinary approaches neglect those areas where other approaches might prove rewarding. Such epistemological ‘blind spots’ mean that sustainability interventions are often geared towards highly tangible aspects that may be simple to envisage and implement, yet have weak potential for ‘leveraging’ sustainable transition or deeper system change (Abson et al., 2017). Getting to grips with the limits and partialities of our disciplinary knowledges is one aspect that we stress when we claim the need to develop a ‘critical sustainability knowledge’ for aquaponics.

Viewed from disciplinary perspectives the sustainability credentials of aquaponic systems can be more or less simple to define (for instance, water consumption, efficiency of nutrient recycling, comparative yields, consumption of non-renewable inputs etc.). Indeed, the more narrowly we define the sustainability criteria the more straightforward it is to test such parameters, and the easier it is to stamp the claim of sustainability on our systems. The problem is that we can engineer our way to a form of sustainability that only a few might regard as sustainable. To paraphrase Klay et al (2014), when we transform our original concern of how to realise a sustainable food system into a ‘‘matter of facts’’ (Latour, 2004b) and limit our research effort to the analysis of these facts, we subtly but profoundly change the problem and direction of research. Such an issue was identified by Churchman (1979:4-5) who found that because science addresses mainly the identification and the solution of problems, and not the systemic and related ethical aspects, there is always the risk that the solutions offered up may even increase the unsustainability of development - what he called the ‘‘environmental fallacy’’ (Churchman, 1979).

We might raise related concerns for our own field. Early research in aquaponics attempted to answer questions concerning the environmental potential of the technology, for instance regarding water discharge, resource inputs and nutrient recycling, with research designed around small-scale aquaponic systems. Although admittedly narrow in its focus this research generally held sustainability concerns in focus. Recently however, we have detected a change in research focus. This is raised in Chapter 1 of this book, whose authors share our own view, observing that research “in recent years has increasingly shifted towards economic feasibility in order to make aquaponics more productive for large-scale farming applications” (p8). Discussions are increasingly concerned with avenues of efficiency and profitability that often fix the potential of aquaponics against its perceived competition with other large-scale production methods (hydroponics and RAS). The argument appears to be that only when issues of system productivity are solved, through efficiency measures and technical solutions such as optimizing growth conditions of plants and fish, then aquaponics becomes economically competitive with other industrial food production technologies and is legitimated as a food production method.

We would certainly agree that economic viability is an important constituent of the long-term resilience and sustainability potential of aquaponics. However, we would caution against too narrowly defining our research ethic - and indeed, the future vision of aquaponics - based on principles of production and profit alone. We worry that when aquaponic research is limited to efficiency, productivity, and market competitiveness, the old logics of the green revolution are repeated and our claims to food security and sustainability becomes shallow. As we saw earlier, productionism has been understood as a process in which a logic of production overdetermines other activities of value within agricultural systems (Lilley and Papadopoulos, 2014). Since sustainability inherently involves a complex diversity of values, these narrow avenues of research, we fear, risk the articulation of aquaponics within a curtailed vision of sustainability. Asking the question 'under what circumstances can aquaponics outcompete traditional large-scale food production methods?' is not the same as asking 'to what extent can aquaponics meet the sustainability and food security demands of the Anthropocene'.

7.8.2 Context

Knowledge production through traditional disciplinary pathways involves a loss of context that can narrow our response to complex sustainability issues. The multidimensional nature of food security implies that 'a single globally valid pathway to sustainable intensification does not exist' (Struik and Kuyper, 2014). The physical, ecological, and human demands placed on our food systems are context bound, and as such, so are the sustainability and food security pressures which flow from these needs. Intensification requires contextualization (Tittonell and Giller, 2013). Sustainability and food security are outcomes of 'situated' practices and cannot be extracted from the idiosyncrasies of context and 'place' that are increasingly seen as important factors in the outcomes of such (Altieri, 1998, Hinrichs, 2003, Reynolds et al., 2014). Added to this, the Anthropocene throws up an added task: localised forms of knowledge must be coupled with 'global' knowledge to produce sustainable solutions. The Anthropocene problematic places a strong need upon us to recognize the interconnectedness of the world food system and our globalised place within it: The particular way sustainable intensification is achieved in one part of the planet is likely to have ramifications elsewhere (Garnett et al., 2013). Developing a 'critical sustainability knowledge' means opening up to the diverse potentials and restraints that flow from contextualised sustainability concerns.

One of the main ruptures proposed by ecological intensification is the movement away from the chemical regulation that marked the driving force of agricultural development during the industrial revolution, and towards biological regulation. Such a move reinforces the importance of local contexts and specificities. Although dealing most often with traditional, small-holder farming practices, agroecological methods have shown how context can be attended to, understood, protected, and celebrated in its own right (Gliessman, 2014). Studies of "real" ecosystems in all their contextual complexity may lead to a "feeling for the ecosystem" - critical to the pursuit of understanding and managing food production processes (Carpenter, 1996). The relevance of agroecological ideas need not be restricted to 'the farm'; the nature of closed loop aquaponics systems demands a 'balancing' of co-dependent ecological agents (fish, plants, microbiome) within the limits and affordances of each particular system. Although the microbiome of aquaponics systems has only just begun to be analysed (Schmautz et al., 2017), complexity and dynamism is expected to exceed Recirculating Aquaculture Systems, whose microbiology is known to be affected by feed type and feeding regime, management routines, fish-associated microflora, make-up water parameters and selection pressure in the biofilters (Blancheton et al., 2013). What might be regarded as 'simple' in comparison to other farming methods, the ecosystem of aquaponics systems is nevertheless dynamic and requires care. Developing an "ecology of place", where context is intentionality and carefully engaged with can serve as a creative force in research, including scientific understanding (Thrift, 1999, Beatley and Manning, 1997).

The biophysical and ecological dynamics of aquaponic systems are central to the whole conception of aquaponics, but sustainability and food security potentials do not derive solely from these parameters. As Konig et al (2016) point out, for aquaponic systems: "different settings potentially affect the delivery of all aspects of sustainability: economic, environmental and social" (Konig et al., 2016). The huge configurational potential of aquaponics - from miniature to hectares, extensive to intensive, basic to high-tech systems - is quite atypical across food production technologies (Rakocy et al., 2006). The integrative character and physical plasticity of aquaponic systems means that the technology can be deployed in a wide variety of applications. This, we feel, is precisely the strength of aquaponic technology. Given the diverse and heterogeneous nature of sustainability and food security concerns in the Anthropocene, the great adaptability, or even 'hackability' (Delfanti, 2013), of aquaponics offers much potential for developing 'custom fit' food production (Reynolds et al., 2014) that is explicitly tailored to the environmental, cultural, and nutritional demands of place. Aquaponic systems promise avenues of food production that might be targeted toward local resource and waste assimilative limits, material and technological availability, market and labour demands. It is for this reason that the pursuit of sustainability outcomes may well involve different technological developmental paths dependent upon locale (Coudel et al., 2013). This is a point that is beginning to receive increasing acknowledgement, with some commentators claiming that the urgency of global sustainability and food security issues in the Anthropocene demand an open and multi-dimensional approach to technological innovation. For instance, Foley et al, (2011:5) state: "The search for agricultural solutions should remain technology neutral. There are multiple paths to improving the production, food security and environmental performance of agriculture, and we should not be locked into a single approach a priori, whether it be conventional agriculture, genetic modification or organic farming" (Foley et al., 2011; 5). We would highlight this point for aquaponics, as Konig et al (2018: 241) have already done: "there are several sustainability problems which aquaponics could address, but which may be impossible to deliver in one system setup. Therefore, future pathways will always need to involve a diversity of approaches."

But the adaptability of aquaponics might be seen as a double-edged sword. Inspiration for specific 'tailor made' sustainability solutions brings with it the difficulty of generalising aquaponic knowledge for larger scale and repeatable purposes. Successful aquaponics systems respond to local specificities in climate, market, knowledge and resources etc. (Villarroel et al., 2016, Love et al., 2015, Laidlaw and Magee, 2016), but this means that changes at scale cannot easily proceed from the fractal replication of non-reproducible local success stories. Taking similar issues as these into account, other branches of ecological intensification research have suggested that the expression 'scaling up' must be questioned (Caron et al., 2014). Instead, Ecological Intensification is beginning to be viewed as a transition of multiscalar processes, all of which follow biological, ecological, managerial and political 'own rules', and generate unique trade-off needs (Gunderson, 2001).

Understanding and intervening in complex systems like this presents huge challenges to our research which is geared toward the production of 'expert knowledge' often crafted in the lab and insulated from wider structures. The complex problem of food security is fraught with uncertainties that cannot be adequately resolved by resorting to the puzzle–solving exercises of Kuhnian 'normal science' (Funtowicz and Ravetz, 1995). The necessity to account for 'specificity' and 'generality' in complex sustainably issues produces great methodological, organisational, and institutional difficulties. The feeling is that to meet contextualised sustainability and food security goals, "universal" knowledge must be connected to "place-based" knowledge (Funtowicz and Ravetz, 1995). For Caron et al (2014) this means that "scientists learn to continually go back and forth..." between these two dimensions, "…both to formulate their research question and capitalize their results… Confrontation and hybridization between heterogeneous sources of knowledge is thus essential" (Caron et al., 2014). Research must be opened up to wider circles of stakeholders, and their knowledge streams.

Given the huge challenge on all accounts that such a scheme entails, a tempting resolution might be found in the development of more advanced ‘environment controlled’ aquaponic farming techniques. Such systems work by cutting out external influences in production, maximising efficiency by minimising the influence of suboptimal, location specific variables (Davis, 1985). But we question this approach on a number of accounts. Given that the impulse of such systems lies in buffering food production from ‘localised inconsistencies’ there is always a risk that the localised sustainability and food security needs might also be externalised from system design and management. Cutting out localised anomalies in the search of the ‘perfect system’ must certainly offer tantalizing efficiency potentials on paper, but we fear this type of problem solving bypasses the specificity-generality problematic of sustainability issues in the Anthropocene without confronting them. Rather than a remedy, the result may well be an extension of the dislocated, ‘one size fits all’ approach to food production that marked the green revolution. These directions repeat the knowledge dynamic of modern industrial agriculture that overly concentrated the expertise and power of food production systems into the hands of applied scientists engaged in the development of inputs, equipment, and remote system management. We are unsure of how such technocratic ideals might fit within a research ethic that places sustainability first. This is not an argument against high-tech, closed environment systems, we simply hope to emphasise that within a *sustainability first* paradigm our food production technologies must be justified on the grounds of generating context specific sustainability and food security outcomes.

Understanding that sustainability cannot be removed from the complexities of context or the potentials of place, is to acknowledge that ‘expert knowledge’ alone cannot be held as guarantor of sustainable outcomes. This strikes a challenge to modes of centralized knowledge production based on experiments under controlled conditions and the way science might contribute to the innovation processes (Bäckstrand, 2003). Crucial here is the design of methodological systems that ensure both the robustness and genericity of scientific knowledge is maintained along with its relevance to local conditions. Moving to conceptions like this requires a huge shift in our current knowledge production schemes and implies not only better integration of agronomic with human and political sciences, but suggests a path of knowledge coproduction that goes well beyond ‘inter-disciplinarity’ (Lawrence, 2015).

Here it is important to stress Bäckstrand’s (2004: 24) point, that the incorporation of lay and practical knowledge in scientific processes “does not rest on the assumption that lay knowledge is necessarily ‘truer’, ‘better’ or ‘greener’”. Rather, as Leach et al (2012: 4) point out, it stems from idea that “nurturing more diverse approaches and forms of innovation (social as well as technological) allows us to respond to uncertainty and surprise arising from complex, interacting biophysical and socioeconomic shocks and stresses”. Faced with the uncertainty of future environmental outcomes in the Anthropocene, a multiplicity of perspectives can prevent the narrowing of alternatives. In this regard, the potential wealth of experimentation occurring in ‘backyard’ and community projects across Europe represents an untapped resource which has until now received little attention from research circles. “The small-scale sector…” Konig et al (2018: 241) observe, “…shows optimism and a surprising degree of self-organization over the internet. There might be room for creating additional social innovations.” Given the multidimensional nature of issues in the Anthropocene, grassroots innovations, like that backyard aquaponics sector, draw from local knowledge and experience and work towards social and organizational forms of innovation that are, in the eyes of Leach et al (2012: 4) “at least as crucial as advanced science and technology”. Linking with community aquaponics groups potentially offers access to vibrant local food groups, local government, and local consumers who are often enthusiastic about the prospects of collaborating with researchers. It is worth noting that in an increasingly competitive funding climate, local communities offer a well of resources — intellectual, physical, and monetary— that often get overlooked, but which can supplement more traditional research funding streams (Reynolds et al., 2014).

As we know, currently, large scale commercial projects face high marketing risks, strict financing deadlines, as well as high technological and management complexity that makes collaboration with outside research organisations difficult. Because of this, we would agree with Konig et al (2018) who find advantages for experimentation with smaller systems that have reduced complexity and are tied down by fewer legal regulations. The field must push to integrate these organisations within participatory, citizen-science research frameworks, allowing academic research to more thoroughly mesh with forms of aquaponics working in the world. In the absence of formalised sustainability measures and protocols, aquaponic enterprises risk legitimation issues when their produce is marketed on claims of sustainability. One clear possibility of participatory research collaborations would be the joint production of much needed ‘situation specific sustainability goals’ for facilities that could form the ‘basis for system design’ and bring ‘a clear marketing strategy’ (König et al., 2018). Working toward outcomes like these might also improve the transparency, legitimacy, and relevance of our research endeavours (Bäckstrand, 2003).

The European research funding climate has begun to acknowledge the need to shift research orientation by including the requirement in recent project funding calls of implementing so called ‘living labs’ into research projects (Robles et al., 2015). Starting in June 2018 the Horizon 2020 project proGIreg (H2020-SCC-2016-2017) is going to include a living lab for the exemplarily implementation of so called nature based systems (NBS), one of which will be a community designed, community built and community operated aquaponic system in a passive solar greenhouse. The project with 36 partners in six countries aims to find innovative ways to productively utilize green infrastructure of urban and peri urban environments, building upon the co-production concepts developed in its currently running sibling project CoProGrün.

The researchers' working packages regarding the aquaponic part of the project are going to be threefold. One part will be about raising the so-called technology readiness level (TRL) of aquaponics, a research task without explicit collaboration with laypersons and the community. Resource utilization of current aquaponic concepts and resource optimization potential of additional technical measures are the core objectives of this task. While at first glance this task seems to follow the above criticised paradigm of productivity and yield increase, evaluation criteria for different measures will include more multifaceted aspects such as ease of implementation, understandability, appropriateness and transferability. A second focus will be support of the community planning, building and operational processes, that seeks to integrate objective knowledge and practitioner knowledge generation. A meta objective of this process will be the observation and the moderation of the relevant community collaboration and communication processes. In this approach, moderation is actively expected to alter observation, illustrating a deviation from the traditional research routines of fact building and repeatability. A third package encompasses research on political, administrative, technical and financial obstacles. The intention here is to involve a wider collection of stakeholders, from politicians and decision makers through planners, operators and neighbours, with research structures developed to bring together each of these specific perspectives. Hopefully this more holistic method opens a path to the "sustainability first" approach proposed in this chapter.

7.8.3 Concern

Recognising aquaponics as a multifunctional form of food production faces large challenges. As has been discussed, grasping the notion of 'multifunctional agriculture' is more than just a critical debate on what constitutes 'post-productionism' (Wilson, 2001), this is because it seeks to move understandings of our food system to positions that better encapsulate the diversity, non-linearity and spatial heterogeneity that are acknowledged as key ingredients to a sustainable and just food system. It is important to remember that the very notion of 'multifunctionality' in agriculture arose during the 1990s as 'a consequence of the undesired and largely unforeseen environmental and societal consequences and the limited cost-effectiveness of the European Common Agricultural Policy (CAP), which mainly sought to boost agrarian outputs and the productivity of agriculture' (Cairol et al., 2009; 270). Understanding that our political climates and institutional structures have been unconducive to sustainable change is a point we must not forget. As others have pointed out in adjacent agronomic fields, understanding and unlocking the richness of food production contributions to human welfare and environmental health will necessarily involve a *critical* dimension (Jahn, 2013). This insight, we feel, must feature more strongly in aquaponics research.

Considerations such as these make up a third aspect of what we mean when we call for a *'Critical sustainability knowledge'* for aquaponics. As a research community it is crucial that we develop an understanding of the structural factors which impinge upon and restrict the effective social, political and technological innovation of aquaponics. Technical change relies upon infrastructure, financing capacities, market organizations as well as labour and land rights conditions (Röling, 2009). When the role of this wider framing is assumed only as an 'enabling environment', often the result is that such considerations are left outside of the research effort. This is a point which serves to easily justify the failure of technology-based, top-down development drives (Caron, 2000). In this regard, the techno-optimistic discourse of contemporary aquaponics, in its failure to apprehend wider structural resistance to the development of sustainable innovation, would serve as a case example.

As an important potential form of sustainable intensification, aquaponics needs to be recognised as being embedded in and linked to different social, economic and organizational forms at various scales potentially from household, value chain, food system, and beyond including also other political levels. Thankfully, moves towards attending to the wider structural difficulties that aquaponic technology faces have recently been made, with Konig et al. (2018) offering a view of aquaponics through an 'emerging technological innovation system' lens. König et al., (2018) have shown how the challenges to aquaponics development derive from: 1) system complexity, 2) the institutional setting, and 3) the sustainability paradigm it attempts to impact. The aquaponic research field needs to respond to this diagnosis.

The slow uptake and high chance of failure that aquaponics technology currently exhibits is an expression of the wider societal resistance that makes sustainable innovation such a challenge, as well as our inability to effectively organise against such forces. As Konig et al (2018) note, the high risk environment that currently exists for aquaponic entrepreneurs and investors forces start up facilities across Europe to focus on production, marketing and market formation, over the delivery of sustainability credentials. Along these lines, Alkemade and Suurs', (2012) remind us, "market forces alone cannot be relied upon to realize desired sustainability transitions" rather, they point out, insight in to the dynamics of innovation processes is needed if technological change can be guided along more sustainable trajectories (Alkemade and Suurs, 2012).

The difficulties aquaponic businesses face in Europe suggest the field currently lacks the necessary market conditions, with 'consumer acceptance' - an important factor enabling the success of novel food-system technologies - acknowledged as a possible problem area. From this diagnosis there has been raised the problem of 'consumer education' (Miličić et al., 2017). Along with this we would stress that collective education is a key concern for questions of food-system sustainability. But accounts like these come with risks. It is easy to fall back on traditional modernist conceptions regarding the role of science in society, assuming that 'if only the public understood the facts' about our technology they would choose aquaponics over other food production methods. Accounts like these assume too much, both about the needs of 'consumers', as well as the value and universal applicability of expert knowledge and technological innovation. There is a need to seek finer grain and more nuanced accounts of the struggle for sustainable futures that move beyond the dynamic of consumption (Gunderson, 2014) and have greater sensitivity to the diverse barriers communities face in accessing food security and implementing sustainable action (Carolan, 2016, Wall, 2007).

Gaining insight into innovation processes puts great emphasis upon our knowledge generating institutions. As we have discussed above, sustainability issues demand that science opens up to public and private participatory approaches entailing knowledge coproduction. But in terms of this point, it's worth noting that huge challenges lay in store. As Jasanoff (2009: 33) puts it: "Even when scientists recognize the limits of their own inquiries, as they often do, the policy world, implicitly encouraged by scientists, asks for more research." The widely held assumption that - *more* objective knowledge is the key to bolstering action toward sustainability, runs contrary to the findings of sustainability science. Sustainability outcomes are actually more closely tied to deliberative knowledge processes: building greater awareness of the ways in which experts and practitioners frame sustainability issues; the values that are included as well as excluded; as well as effective ways of facilitating communication of diverse knowledges and dealing with conflict if and when it arises (Smith and Stirling, 2007, Healey, 2006, Miller and Neff, 2013, Wiek et al., 2012). As Miller et al. (2014) point out, the continuing dependence upon objective knowledge to adjudicate sustainability issues represents the persistence of the modernist belief in rationality and progress that underwrites almost all knowledge-generating institutions (Horkheimer and Adorno, 2002, Marcuse, 2013).

It is here where developing a critical sustainability knowledge for aquaponics shifts our attention to our own research environments. Our increasingly 'neoliberalised' research institutions exhibit a worrying trend: The rollback of public funding for universities; the increasing pressure to get short-term results, the separation of research and teaching missions, the dissolution of the scientific author; the contraction of research agendas to focus on the needs of commercial actors; an increasing reliance on market take-up to adjudicate intellectual disputes; and the intense fortification of intellectual property in the drive to commercialize knowledge, all of which have been shown to impact on the production and dissemination of our research, indeed all are factors that impact the nature of our science (Lave et al., 2010). One question that must be confronted is whether our current research environments are fit for the examination of complex sustainability and long term food security targets that must be part of aquaponic research. This is key point we would like to stress - If sustainability is an outcome of multidimensional collective deliberation and action, our own research endeavours - thoroughly part of the process - must be viewed as something that can be innovated towards sustainability outcomes also. The above mentioned Horizon 2020 project proGIreg may be an example of some ambitious first steps towards crafting new research environments, but we must work hard to keep the research process itself from slipping out of view. Questions might be raised about how these potentially revolutionary measures of 'living labs' might be implemented from within traditional funding logics. For instance, such calls foreground the conceptual importance of open ended outcomes when pursuing participatory approaches, while at the same time requiring the intended spending of such living labs to be pre-defined. Finding productive ways out of traditional institutional barriers is an ever present concern.

Our modern research environments can no longer be regarded as having a privileged isolation from the wider issues of society. More than ever our innovation-driven biosciences are implicated in the agrarian concerns of the Anthropocene (Braun and Whatmore, 2010). The field of Science and Technology Studies teaches us that technoscientific innovations come with serious ethico-political implication. A 30 year long discussion in this field has moved well beyond the idea that technologies are simply 'used' or 'misused' by different socio-political interests after the hardware has been 'stabilized' or legitimated through objective experimentation in neutral lab spaces (Latour, 1987, Pickering, 1992). The 'constructivist' insight in STS analyses goes beyond the identification of politics inside labs (Law and Williams, 1982, Latour and Woolgar, 1986 [1979]) to show that the technologies we produce are not 'neutral' objects, but are in fact infused with 'world making' capacities and political consequence. The aquaponics systems we help to innovate are filled with future making capacity, but the consequences of technological innovation are seldom a focus of study. To paraphrase Winner (1993), what the introduction of new artefacts means for people's sense of self, for the texture of human/nonhuman communities, for qualities of everyday living within the dynamic of sustainability, and for the broader distribution of power in society - these have not traditionally been matters of explicit concern. When classic studies (Winner, 1986) ask the question 'Do artefacts have politics?', this is not only a call to produce more accurate examinations of technology by including politics in accounts of the networks of users and stakeholders –though this is certainly needed; it also concerns us researchers, our modes of thought and ethos, that affect the politics (or not) we attribute to our objects (de la

Bellacasa, 2011, Arboleda, 2016). Feminist scholars have highlighted how power relations are inscribed into the very fabric of modern scientific knowledge and its technologies. Against alienated and abstract forms of knowledge, they have innovated key theoretical and methodological approaches that seek to bring together objective and subjective views of the world, and to theorize about technology from the starting point of practice (Haraway, 1997, Harding, 2004). Aware of these points, Jasanoff (2007) calls for the development of what she calls 'technologies of humility': "Humility instructs us to think harder about how to reframe problems so that their ethical dimensions are brought to light, which new facts to seek and when to resist asking science for clarification. Humility directs us to alleviate known causes of people's vulnerability to harm, to pay attention to the distribution of risks and benefits, and to reflect on the social factors that promote or discourage learning."

An important first step for our field to take towards understanding better the political potentials of our technology would be to encourage the expansion of the field out into critical research areas that are currently underrepresented. Across the Atlantic in the US and Canada similar moves like this have already been made, where an interdisciplinary approach has progressively developed into the critical field of political ecology (Allen, 1993). Such projects not only aim to combine agriculture and land use patterns with technology and ecology, but furthermore, also emphasise the integration of socioeconomic and political factors (Caron et al., 2014). The aquaponics research community in America has begun to acknowledge the expanding resources of food sovereignty research, exploring how urban communities can be reengaged with the principles of sustainability, whilst taking more control over their food production and distribution (Laidlaw and Magee, 2016). Food sovereignty has become a huge topic that precisely seeks to intervene into food systems that are overdetermined by disempowering capitalist relations. From food sovereignty perspectives the corporate control of the food system and the commodification of food are seen as predominant threats to food security and the natural environment (Nally, 2011). We would follow Laidlow and Magee's (2016: 1) view that community-based aquaponics enterprises "represent a new model for how to blend local agency with scientific innovation to deliver food sovereignty in cities."

Developing a *'critical sustainability knowledge'* for aquaponics means resisting the view that society and its institutions are simply neutral domains that facilitate the linear progression towards sustainable innovation. Society is infused with asymmetric power relations and is a site of contestation and struggle. One such struggle concerns the very meaning and nature of sustainability. Critical viewpoints from wider fields would underline that aquaponics is a technology ripe with both political potential and limitation. If we are serious about the sustainability and food security credentials of aquaponics, it becomes crucial that we examine more thoroughly how our expectations of this technology relate to on-the-ground experience, and in turn, find ways of integrating this back into research processes. We follow Leach et al (2012) here who insist on the need for finer grained considerations regarding the performance of sustainable innovations. Apart from the claims, just who or what stands to benefit from such interventions must take up a central place in the aquaponic innovation process. Lastly, as the authors of chapter 1 have made clear, the search for a lasting paradigm shift will require the ability to place our research into policy circuits that make legislative environments more conducive to aquaponics development and enable larger-scale change. Influencing policy requires an understanding of the power dynamics and political systems that both enable and undermine the shift to sustainable solutions.

7.9 Conclusion: Aquaponic research into the Anthropocene.

The social–biophysical pressures *of* and *on* our food system converge in the Anthropocene towards what becomes seen as an unprecedented task for the global community, requiring "nothing less than a planetary food revolution." (Rockström et al., 2017). The Anthropocene requires food production innovations that exceed traditional paradigms, whilst at the same time are able to acknowledge the complexity arising from the sustainability and food security issues that mark our times. Aquaponics is one technological innovation that promises to contribute much toward these imperatives. But this emergent field is in an early stage that is characterised by limited resources, market uncertainty, institutional resistance and high risks of failure – an innovation environment where hype prevails over demonstrated outcomes. The aquaponics research community potentially holds an important place in the development path of this technology. As an aquaponics research community we need to craft viable visions for the future.

We propose one such vison when we call for a 'sustainability first' research programme. Our vision follows Rockstrom et al's (2017) diagnosis that paradigm change requires shifting the research ethic away from traditional productivist avenues so that sustainability becomes the central locus of the innovation process. This task is massive because the multidimensional and context bound nature of sustainability and food security issues is such that they cannot be resolved solely through technical means. The ethical and value laden dimensions of sustainability require a commitment to confront the complexities, uncertainty, ignorance and contestation that ensue with such issues. All this places great demands on the knowledge we produce; not only how we distribute and exchange it, but also its very nature.

We propose the aquaponic field needs to pursue a 'critical sustainability knowledge'. When Konig et al (2018: 242) ask what sustainability experimentation settings would be needed to enable science, business, policy and consumers to '*answer sustainability questions without repeating the development path of either [RAS or hydroponics]*', the point is clear - we need to learn from the failures of the past. The current neoliberal climate is one that consistently opens 'sustainability' discussion up to (mis)appropriation as 'agribusiness mobilizes its resources in an attempt to dominate discourse and to make its meaning of "alternative agriculture" the universal meaning' (Kloppenburg, 2009: 256). We need to build a critical sustainability knowledge that is wise to the limits of technocratic routes to sustainability, and is sensitive to the political potential of our technologies and the structural forms of resistance that limit their development.

A critical sustainability knowledge builds awareness of the limits of its own knowledge pathways and opens up to those other knowledge streams that are often pushed aside in attempts to expand scientific understanding and technological capacity. This is a call for inter-disciplinarity and the depth this brings, but it goes further than this. Sustainability and food security outcomes have little impact if they can only be generated in the lab. Research must be contextualised: we need "to produce and embed scientific knowledge into local innovation systems" (Caron et al., 2014; 51). Building co-productive links with aquaponics communities already existing in society means forging the social and institutional structures that can enable our communities to continually learn and adapt to new knowledge, values, technologies and environmental change. Together, we need to deliberate on the visions and the values of our communities and explore the potential sociotechnical pathways that might realize such visions. Central to this, we need systems of organising and testing the sustainability and food security claims that are made of this technology (Pearson et al., 2010, Nugent, 1999) so that greater transparency and legitimation might be brought to the entire field: entrepreneurs, enterprises, researchers, and activists alike.

If all this seems like a tall order, that's because it is. The Anthropocene calls for a huge rethink in how we organise society, and our food system is central to this. There is chance, we believe, that aquaponics has a part to play in this. But if our hopes are not to get lost in the hype bubble of hollow sustainability chatter that marks our neoliberal times, we have to demonstrate aquaponics offers something different. As a final remark, we revisit de la Bellacasa's (2015: 699) point, that: "agricultural intensification is not only a quantitative orientation (yield increase), but entails a 'way of life'". If this is the case, then the pursuit of *sustainable intensification* demands that we find a new way of living. We need sustainability solutions that acknowledge this fact and research communities that are responsive to it.

Chapter 8: **Conclusion**

I began this thesis by locating this work inside the disturbing and disorienting situation that has come to be called the Anthropocene. A controversial and differentially understood phenomenon, the Anthropocene has become for some the ''most important question of our age—scientifically, socially and politically" (Zalasiewicz et al, 2011b; 838), a 'master narrative' that calls for humanity to reassess its distorted and disastrous relation to the world. Within this frame, prominent voices across geography and beyond are calling for greater engagement with science and its productions (Castree, 2015, Latour, 2016, Haraway, 2016b). This thesis responds to this call, identifying 'aquaponics' as an opportunity to engage with science operating in the Anthropocene.

Through a suit of qualitative methodological tools the thesis focuses on how humans and nonhumans are gathered around sites of aquaponic interest, producing multi-species and multi-practice ecologies. Working in the field alongside researchers, practitioners, and innovators this thesis explores aquaponic research spaces (laboratories, universities and conferences) through an embodied, performative methodology that aims to get at what comes to matter in the European field of aquaponics. The contributions made by this thesis flow from bringing aquaponic science in uneasy relation with MTH geographies and STS. Three interconnected contributions can be identified:

1)

Whilst aquacultural practices are exploding on to the global scene, contemporary geographic scholarship is scarcely keeping up (Belton and Bush, 2014). This thesis offers an interdisciplinary autoethnographic study of aquaponic research in practice, contributing to the urgent analytic task of bringing forth a documentation of an 'everyday aquaculture'.

Aquaponics is a food system innovation that is gaining increased attention across Europe and is beginning to become enrolled into the task of meeting humanity's global appetite for fish. Through literature review the thesis shows how aquaponics is increasingly articulated within the 'water−food−energy nexus' discourse that frames global food production within a finite planet. More specifically, Aquaponic research communities suggest the innovation has potential to intervene in a number of interconnected issues: distorted planetary nitrogen and phosphorus cycles, efficient food production for an increasingly crowded and urban planet, water scarcity and desertification, the collapse of global fisheries and global demand of aquaculture, and climate change inducing anthropogenic emissions.

Through ethnographic exploration, this thesis highlights the way 'ecology' acts as an area of shared concern for aquaponic researchers, practitioners and innovators. Ecology drives the concept of aquaponics acting as an attractor for both questions and answers, opportunities and challenges, hopes and fears. At the heart of aquaponic research is the inspiration that novel ecosystems comprised of fish/plants/bacteria offer tantalizing potential to respond to the impending pressures facing food production in the Anthropocene. The aquaponic community recognises the need to respond to the wasteful and destructive materialities enacted by modern agricultural practices with a shared commitment to 'Closing the loop'. As such, Nitrogen, Phosphorus, and other trace elements become objects of concern for an aquaponic science responding to planetary boundaries discourse. Research focuses upon how particular biological configurations of fish/plants/bacteria might offer opportunities to intervene in wider anthropogenic shifts in planetary material. As such, the 'model ecosystems' (Paxson and Helmreich, 2014) gathered in aquaponic research become the petri dishes of agronomic ecologies yet to come, providing an opportunity to experiment with the way food production might be (re)organised to meet the needs of a finite planet.

The 'ecologies' of aquaponics, however, extend well beyond the dynamic biological and chemical interactions occurring within aquaponic systems. Utilising ethnographic techniques over a prolonged integration within the field this thesis shows how 'ecology' in aquaponics takes on wider concerns and logics, coming to serve as a set of mapping techniques for organising connectivities in the field – between materials, organisms, technologies, people, practices, disciplines, concerns. The aquaponic system becomes an experimental device/arena to test how issues across a number of interlinking scales (distorted nutrient cycles, aquacultural pollution, food sovereignty, resource recycling etc.) condense within grounded and localised action. The malleability of aquaponic systems allow a great number of biological, technological, and operational agents to be juxtaposed towards different needs and purposes. Which formations of aquaponics will become prevalent is an ongoing process of experimentation that enrols increasing numbers of research communities, entrepreneurs and activists alike. Treating aquaponics as a field-in-the-making, chapter 6 documents the shifting commitments of this emergent field, allowing this thesis to explore the textures and paradoxes of research realities that are too often ironed out of official publications.

This thesis asks how an understanding of aquaponics might relate to wider issues for science in the Anthropocene. Considering the complex, persistent, and far reaching nature of issues such as sustainability, food security, food sovereignty, and ecological intervention, the challenges facing aquaponics speak to wider issues regarding the application of science in the Anthropocene. As aquaponics research pushes on, it moves towards a clustering of objects, an expanding catchment of expertise, and a facing up with serious contextual challenges. Due to the complex, multidimensional nature of the aquaponic problem, the question of inter/multi/transdisciplinarity became a focus of chapter 7. The natural sciences dominate current aquaponic research, and articulate particular manifestations of aquaponics that are crucial for developing more just and sustainable food systems. However, every discipline pays some price in partiality, and it is clear the Aquaponic problem requires more than the natural sciences. Other lines of enquiry are required to think with these complex multispecies worlds, and the more-than-human realities that they draw from and feed into. This is where the tools of ethnography, philosophy, history, artistic, and activist practice, amongst others, are surely required to develop a fuller picture of the entangled potential and significance of aquaponics, to learn and develop its myriad meanings and the diverse ways in which it can matter.

2)

Following the above analytic task, this thesis contributes methodologically by offering the first steps toward applying autoethnographic methods to aquaponic science. Taking up the hybrid role of ethnographer-scientist, this thesis provides a rare example of an alternate way to bring together the ideas, practices, and energies of disparate fields and disciplines within knowledge making practices. Deliberately aiming to work outside those institutionalised and often tired forms of "collaboration" or "interdisciplinarity", this thesis takes a 'fugitive' approach to ethnographic study (Berry et al., 2017) and shows how it can provide fertile ground for scholarly activity within technoscientific networks. Doing so, the thesis importantly expands Berry et al's (2017) formulation of a fugitive practice beyond the registers of gender, race, and violence to incorporate the commitments, questions, and imperatives of posthuman STS and speculative MTH geographies.

By taking a view of interdisciplinarity as an emergent, speculative task, this thesis experiments with alternatives to the prescribed knowledge ways that dominate contemporary research activity. By focusing on the co-production of research agendas not fixed in advance but emerging in dialogue with other fields and more-than-human participants, this thesis challenges the fields of MTH Geography and STS to reconsider what counts as data, who produces knowledge, and how we as researchers should conceptualise the perennial issues involved in qualitative research such as rigour, evaluation, analysis, authorship, and attribution (Henwood et al., 2019).

Through its embodied and performance-based approach to ethnography, the thesis forwards multimodal methods as a way of developing posthuman ethnographic sensitives that are of heightened relevance in our time of the Anthropocene. Through careful examination of knowledge-production outside of verbal language (affective, multisensory, non-representational) this thesis is able to chart “the emotional and affective forms of embodiment that are formed and re-formed within the materiality of hybrid [technoscientific] forums” (Probyn, 2011; 99), contributing not only an important example of life within an aquaponic experiment (Chapter 5) but also how, in our time of the Anthropocene, the body can become a ‘site of scholarly awareness and corporeal literacy’ (Spry, 2001) in understanding what matters in technoscientific production.

3)

Lastly, this thesis contributes theoretically. From an embodied intervention within an experimental apparatus the thesis offers an important case concerning the role of care within technoscience that moves the discussion beyond one-to-one accounts founded within a situated ethics of entanglement, towards broader ‘objects’ of care and processes of intimacy within experimental apparatuses.

In recent work on matters of care in technoscience researchers have stressed two interconnected dimensions (Atkinson-Graham et al., 2015, Kerr and Garforth, 2015, Martin et al., 2015, de la Bellacasa, 2017). First, care has been framed as something that is both mundane and tacit; an inevitable part of scientific research which nonetheless requires constant negotiation, or ‘tinkering’ (Mol et al., 2015), in order to be accommodated by the systems/processes/infrastructures within which care lies in uneasy relationship. A second dimension of care are its affective qualities. Authors have shown how good care cannot assume a prescriptive format, and as such it relies on researchers being open to affective encounters. For instance, Haraway’s (2008) core argument regarding the replacement of traditional ethical frameworks is founded upon an idea of care generated from entangled and embodied encounters. This thesis holds these conceptualisations of care relations very close in both the methodology and analysis of aquaponic research, yet the results of my experimentation in aquaponic intervention raises problems with such conceptions, especially regarding the efficacy of situated ethics borne from entangled relations.

Although entering the experimental space of the PAFF box with some ideas of conducting a ‘symmetrical’ analysis of ‘science in action’ (Latour, 1987), I soon found myself implicated in an aquaponic ecology brimming with ‘ethico-political obligation’ (Puig de la Bellacasa, 2011: 90). Living the PAFF box experiment, pulled me into unexpected modes of experimentation, what Haraway (1997; 36) describes as ‘casting our lot with some ways of life and not others’. Yet the results were not wholly positive; aspects of my intervention perpetuated forms of care based upon ignorance, epistemological obedience, and exclusion. Maintaining accountability to the politics, power, and privilege that come with Haraway’s proviso proved challenging in the intimate-yet-insula aquaponic world of the PAFF box. This thesis evidences the limitations of accounts of care that over-valorise the importance of situated ethics drawn too narrowly from methodologies of embodied practice, as well as the perceived potential of such ethics to bring about epistemological and ontological change within experimental settings.

Chapter 5 highlights how dissenting-within networks of scientific production opens up the research process – and the researcher - to vulnerability (de la Bellacasa, 2017). Posthuman ethnographic analysis allows this thesis to explore the way bodies imbricate into the 'objects', 'things' and processes of technoscience, and the way ontological and ethical questions arise that concern our own bodies 'power to surprise, to perform, or to be functionalized' (Bensaude-Vincent et al., 2011). Assimilation occurs even as our research practices persistently omit the traces of our bodies. Becoming aware of the more-than-human forces that shape how our bodies react and respond in fields of technoscience allows this thesis to cast Downy and Dumit's (1997) point of 'co-optation' through a posthuman lens. The affective tonalities that resonated between and across actors in the PAFF box express how technoscientific assemblages generate indeterminate experiences that are not solely the result of human planning or intent, nor can they be planned for. This thesis thus describes how multispecies experiments become spaces imbued with particular striations of demands and affordances for bodies, and furthermore, these affordances give rise to consequences not only for particular non-humans but also those of the scientists/researchers involved, having the ability to induce or deny care relations within certain experimental contexts (Greenhough and Roe, 2011). Chapter 5 described the way that certain responsibilities and manifestations of agency may already be foreclosed in the gathering of experimental situations around particular forms of research processes and infrastructures. As such, the thesis documents how affective investments within the scientific productions that we co-create carry very real scholarly dangers, especially regarding the work of good care.

There is a tendency in much work on care to establish a situated, relational ethics upon concepts of entanglement and co-becoming without the consideration of issues of exclusion. Such approaches may uncritically celebrate relationality and hybridity that implicate the researcher without due reflection about the alternative worlds lost during processes of emergence (Hollin et al., 2017). This thesis shows the need to move toward more complex account of care. Chapter 5 of this thesis is an important example of the way care can highlight exclusions (Puig de la Bellacasa, 2011) yet at the same time foster them (Giraud and Hollin, 2016). Greater awareness is required, and this thesis suggests researchers' ethical obligations move beyond immediate somatic relations within experimental contexts, to take into account those disparate agents that are affected (or excluded) in the wider processes of technoscience research. Work in related fields has shown how attention should be paid to the contexts (Johnson, 2015), histories (Greenhough and Roe, 2011), and exclusions (Puig de la Bellacasa, 2011) that (often silently) contribute to caring encounters. This thesis extends these discussions towards broader 'objects' of care.

This thesis highlights the importance of not only of paying attention to the acts of care but also to "the very conditions of possibility for care" (Martin et al 2015, 635). In response, the thesis attempts to acknowledge the potential of exclusion enacted in scientific knowledge ways, using the conceptualisation of *apparatus* (Barad, 2007) as one possible heuristic to consider how the gathering of particular aquaponic research spaces impacts the potential of care relations in aquaponic systems and resultant aquaponic futures. The *apparatus* is an expansive move that looks beyond the immediacy of entanglement to consider the way 'cuts' in technoscientific knowledge practices are made, and the ethical implications that are involved. Focus upon the apparatus does not jettison entangled, affective relations in the study of scientific research, but rather attempts to set them within wider frames of research activity. With this refocus on the distribution of care in technoscience, what becomes important is the possibility of efficacy within the research milieu (Stengers, 2018). This thesis explores such considerations in Chapter 6, where documenting aquaponics as a 'field-in-the-making' (Swanson et al., 2015) allows this thesis to develop an appreciation of knowledge politics involved in the emergent field of aquaponics, particularly the way that wider milieus of research effort become responsible for gathering particular apparatuses, and how these come to matter for the field of aquaponics. Building on this, Chapter 7 grows into a different sort of intervention to the experimental performance of Chapter 5, turning attention towards the wider processes of care within the aquaponic milieu. Such work adds to the growing interest in 'cosmopolitical' ethics in science, predicated as it is upon devising research processes that can create room for nonhumans to impose their own 'requirements' on humans (Stengers, 2015).

As a parting word, if the Anthropocene presents an impending challenge to reimagine our relationship with the more-than-human others that populate the increasingly doom-laden planet, crafting spaces and opportunities for epistemological and ontological change is an important step towards bringing about more flourishing patterns of existence. With aquaponics as the testing ground for speculative intervention, this thesis shows that attempts toward more care-full technoscience must not only consider the ambivalent role of care, the centrality of affect, non-representational practice and the limits of (post)human action within experimental apparatuses, but must also attend to the milieu as a site for crafting more complex notions of ethical responsibility, even as it perpetuates processes of exclusion in the production of new realities.

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