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THEMATIC COLLECTION: MAINTENANCE & ITS KNOWLEDGES ORIGINAL RESEARCH ARTICLE

Knowing *with* Microalgae: On the Maintenance of a Wastewater Treatment Prototype in an Ecovillage

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Abstract

In this article, we present a case study of an experimental set up of a microalgae-based wastewater treatment prototype in an ecovillage requiring many maintenance operations to function. Taking our cue from maintenance and repair studies, we focus on the embodied engagements by which caring for wastewater unfolds. We examine how aquatic ecologists, environmental engineers and villagers use their senses as instruments of inquiry when handling wastewater, as they observe its colour and smell its occupants, and manually check the connections between tubes and pumps. A multispecies body of microbial wastewater figures prominently, as the metabolism of three species of microalgae dwelling in the wastewater is key to the functioning of the prototype. Turning to insights from multispecies ethnographies of laboratory studies, we expand our focus on embodied engagements across the species barrier while maintenance unfolds. We show how ecologists, engineers and villagers engage in 'knowing *with* microalgae' as the algal community invokes and adapts its metabolism in surprising ways to the interferences stirred by their human caretakers. By juxtaposing three ethnographic stories about knowing (1) *with* hungry, (2) *with* stressed, and (3) *with* dying microalgae, we show how algal bodies are both object and instrument of inquiry. Unexpectedly, they also become, tools of repair, liaising *with* their human caretakers, *with* other microorganisms and *with* added chemicals in the wastewater, as well as natural forces such as heat, sunshine, and frost. Considering the maintenance of and by living matter such as microalgae, we raise questions about life and death as the object of maintenance shifts. In so doing, we urge for a multispecies perspective on maintenance that acknowledges that 'the inclusion of nonhuman others from the animal/organic world produces a different set of ethical concerns than the engagement with technological entities' (Puig de la Bellacasa 2010, 159). This is needed as societies advance towards ecologically sustainable modes of living in which humans will progressively cohabitate with a wide variety of species as well as the technologies that house and facilitate them.

Keywords

maintenance; knowing *with*; multispecies; ethnography; microalgae; wastewater; treatment

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Introduction

How may we care for household wastewater in ways that disrupt the environment less than we currently do? This is a question to which environmental engineers have sought an answer for decades. One possible solution involves microalgae. Using microalgae in wastewater treatment appears to enable a shift from linear sanitation systems to circular ones that close nutrient cycles (Silva et al. 2019). In research laboratories across the globe, scientists experiment with microalgae species to learn about these microorganisms in their various, specific biotechnological figurations (Kiesenhofer and Fluch 2018). In this article, we describe one such experiment, namely a wastewater treatment prototype that aquatic ecologists and environmental engineers developed in the Netherlands Institute of Ecology (NIOO) laboratory. Key to the functioning of this prototype are three species of microalgae – *Scenedesmus obliquus, Chlorella sorokiniana and Chlorococcum sp* (hereafter: microalgae) – which are well-known for their use in wastewater treatment. Microalgae-based treatment methods make use of algal metabolism: the biochemical processes by which microalgae take up nutrients and convert these into resources needed for growth and reproduction (Beardal and Raven 2021). The algal community in our experiment had to recover nutrients (such as phosphorous and nitrogen) from the wastewater for re-use as biofertiliser. Also, the microalgae had to remove micropollutants (such as pharmaceuticals) from the wastewater to render it clean enough to infiltrate into the soil. An innovative ambition and an intricate task.

The prototype was taken out of the laboratory setting and experimentally put to use in ecovillage Lommel in the southern region of The Netherlands. The ecovillage, a small, experimental circular housing project, had just been founded and consisted of seventeen adults and nine children who at the time lived on a plot of land in ten provisional houses. The villagers were keen to find out if the prototype could be adapted for daily use as the objective of the ecovillage was to develop ecologically sustainable ways of living. This enabled the engineers to explore, in-situ, under which living conditions the microalgae would want to feed off the wastewater. 'If you know how the algae act, you can act on that', an engineer explained the effort to finetune the prototype. When the prototype functioned, that is, when a 'continuous flow' of wastewater ran through its tubes and pumps, 'reliable data' about algal metabolism could be produced. Only then could the experiment produce 'matters of fact' (Latour 2004) about how this microalgal community recovered nutrients and removed micropollutants from the wastewater. But while the prototype was in use, interferences occurred constantly: the quality of wastewater varied; the tubes and pumps carrying the wastewater proved brittle; and the amount of chemicals added to the wastewater in order to harvest the algae was either too high or too low. Rather than operating in a 'steady state', the prototype formed a fragile assemblage of tubes, pumps, chemicals, and microorganisms (see figure 1), and it required many *maintenance* operations in order to function.

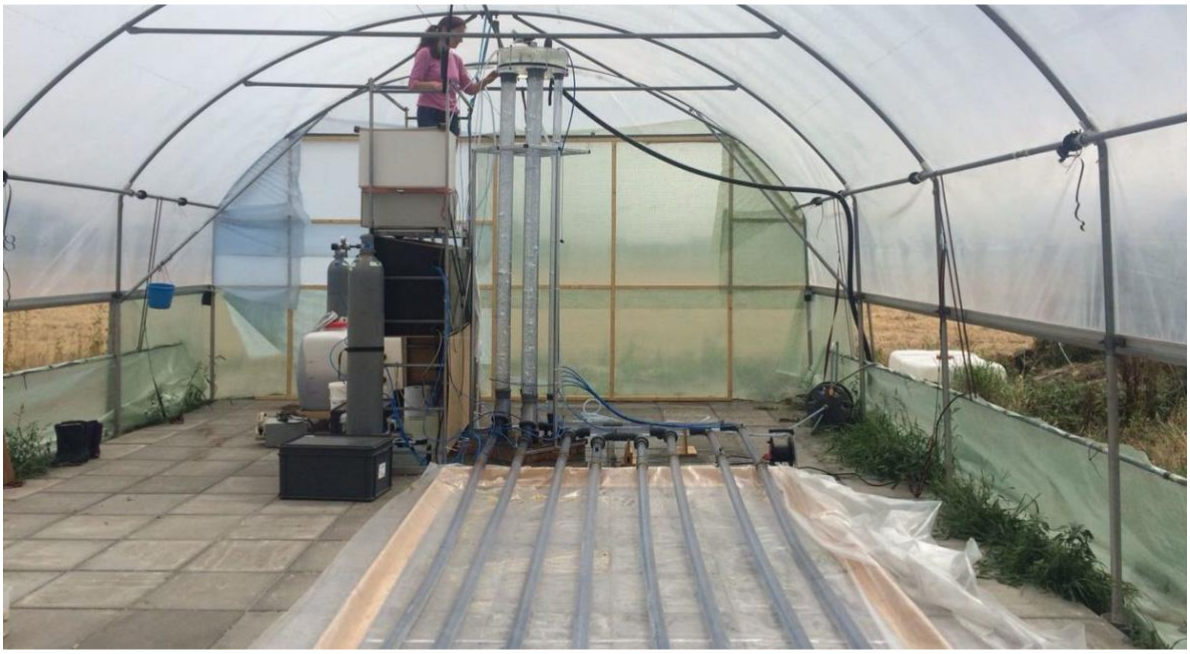

Figure 1. The wastewater treatment prototype installed in a makeshift greenhouse in the ecovillage. (Source NIOO-KNAW, 2018)

Classic laboratory studies (Latour and Woolgar 1979; Latour 1987) show that maintenance work forms a crucial part of scientific knowledge production. On a daily basis, objects such as glassware, flasks, and test tubes must be cleaned, sterilised, and stored to prevent malfunctioning. Studying knowledge production in molecular biology, Karin Knorr Cetina (1999, 111–159) foregrounds researchers in their role as caretakers of *living matter*, of the mice and microorganisms prepared for experimental manipulation. In the experimental setting of our ecovillage, the microalgae also formed an enduring concern for their human caretakers. Do they eat from the wastewater? Are they stressed? How can they be killed properly? These were some of the questions the ecologists, environmental engineers, and inhabitants of the ecovillage sought to answer in their efforts to finetune the prototype. To answer them, to *know about* microbial interferences, the engineers and villagers observed, smelled, and handled the wastewater-with-algae. They learned about the preferences and whims of the microalgal community by engaging their senses. The sight of green wastewater flowing through the tubes of the prototype, for instance, was a sign of vital algae, because the microalgae inoculated in the wastewater contain chlorophyll, a green-coloured pigment, within their cells. This was a good sign, at least when it concerned algal wellbeing. It was a bad sign, though, when the time came to harvest – and kill – the microalgae. Then, repair work to the prototype was needed to facilitate the harvesting of the microalgae in the service of the scientific experiment. Just like Knorr Cetina's (1999) biologists who manually engaged living matter while conducting scientific experiments, the bodies of our interlocutors turned into information-processing tools to make microalgae speak.

Working in the tradition of classic laboratory studies, maintenance and repair studies taught us a great deal about 'mak[ing] matters speak' (Sanne 2010). Understanding objects as fragile assemblages of matter in need of constant care in order to function or to last, Jérôme Denis and David Pontille (2015, 19) argue that 'maintenance draws on a certain engagement with matter and objects, a bodily commitment, which is at the centre of taking care of things'. And so, these studies focus on *embodied engagements* as a key aspect of diagnosing, that is, knowing whether a thing is broken and in need of repair: 'something looks wrong, smells bad, feels too hot or cold, or does not sound right' (Henke 2019, 262). In-depth ethnographies highlight how people 'sense matter' (Callén and Sánchez Criado 2015, 23–26) to learn if energy technologies still work properly (de Wilde 2021), if walls of city buildings need cleaning (Denis and Pontille 2018), or if art works require restoration (Domínguez Rubio 2014). These are stories of technicians listening to devices, cleaners touching the graffitied surface of walls, and museum restorers scratching and observing the colours that emerge from underneath a scratch. By highlighting fragility as a property that materials possess, these studies elicit the agency of nonhuman matter such as stones, metal, or paint in relation to manipulation by humans' sensory gestures. Our prototype, by contrast, does not solely consist of minerals, metals, or chemicals. It is also home to a multispecies body of wastewater-with-algae. It thus requires a focus on embodied engagements *across* the species barrier, while maintenance unfolds.

To explore the embodied engagements in our wastewater treatment prototype, we turn to insights from multispecies ethnographies of laboratory studies with animals, plants, and microorganisms. These studies explore an interspecies ethic of 'response-ability' (Haraway 2008) to bring attention to how humans and nonhumans *mutually* constitute worlds, and thus knowledges. A recurring topic is how scientists make their embodied selves available to notice and respond to the agency of the corals (Hayward 2010), orchids (Hustak and Myers 2012), or beagles (Giraud and Hollin 2016) with which they work. Multispecies ethnographers focussing specifically on microorganisms emphasise the activity of 'wit(h)nessing' (cf. Boscacci 2018): which constitutes knowing as an embodied, interspecies encounter where natural scientists *affectively* engage with marine microbes (Helmreich 2009) or brewer's yeast (Calvert and Szymanski 2020). The species turn in the social sciences, thus, urges us to appreciate microbes as 'partners in inquiry' (Szymanski, Smith, and Calvert 2021, 263; cf. Haraway 1997). Multispecies theorists such as Vinciane Despret (2004, 2013) and Matei Candea (2010) have demonstrated that scientists who commit to engage intimately with nonhumans as partners when inquiring, inquire more openly. They attempt to generate shared concerns with these nonhumans by 'learn[ing] to be affected' by them (Despret 2004, 131).

But if knowing happens as part of a transmission *between* living and sensing bodies, how does this unfold with 'awkward creatures' (Ginn, Beisel, and Barua 2014; Lorimer 2014) such as microalgae? These aquatic, photosynthetic microorganisms are strange corporeal creatures to humans and live in non-mammalian ecologies, namely microbial wastewater that is potentially lethal to humans. Developing a feeling for them proved challenging to our human interlocutors. To even perceive an algal presence or acquire a sense of their vulnerability presented a constant challenge: 'You cannot know for sure how healthy they are, but you can guess from what you see', an aquatic ecologist explained while peering through a microscope at a wastewater sample. To highlight these kinds of complexities and uncertainties when natural scientists engage with microbial bodies, Claire Waterton (2017) uses the term 'indeterminate'. In a case study of a research project on the polluting effects of cyanobacteria – a microalgae species – in a British Lake, she shows how scientists and local inhabitants started to question the nature and boundaries of cyanobacterial bodies within the lake:

> [i]t soon became clear that these microscopic organisms and their relations were elusive in both physical and conceptual terms (one could not often 'see' them; they were multiple, consisting of many different species; they had complex life cycles; they were ephemeral and not always present). Even for ecologists, cyanobacteria were, in many senses, intangible, indeterminate and difficult to make into research objects (Waterton 2017, 107)

Waterton (2017) shows how scientists and locals explore these indeterminate bodies by learning to identify the limits of their routine modes of knowing and engage openly and experimentally with cyanobacteria and their ecologies. In this paper, we explore how such an openly embodied engagement unfolds with microalgae who live in wastewater that flows through an experimental prototype. We argue that generating shared concerns with microalgae, hinges on 'maintaining [a species]' ability to respond to their experimental probings' (Schrader 2010, 277 with emphasis added by de Wilde and Smits). In the case of the wastewater treatment prototype in our ecovillage this implies caring for wastewater to make microalgae speak.

As an approach for analysing and engaging with the challenges and transformations associated with the world's ecological crises, we learn from Maria Puig de la Bellacasa (2017, 1) that thinking with care is a 'disruptive thought' that allows for speculating on how we can live differently. Following this line, we present a multispecies perspective (cf. Haraway 2003) on maintenance that acknowledges that 'the inclusion of nonhuman others from the animal/organic world produces a different set of ethical concerns than the engagement with technological entities' (Puig de la Bellacasa 2010, 159). We do not, however, subscribe to a popular understanding of caring, as an inherently benevolent act. Rather, we explore caring as a situated practice (Mol, Moser, and Pols 2010) where shifting normative engagements may emerge. Caring forms a discriminatory mode of engagement: it involves choosing which matters come to form a concern, to whom, and for whom and who or what may flourish or wither in the process.

In this article we focus how those choices are distributed across the species barrier. We focus on how 'knowing *with* microalgae' unfolds while our ecologists, engineers, and villagers care for a continuous flow of wastewater through the prototype. In so doing, we present three ethnographic stories about knowing (1) *with* hungry, (2) *with* stressed, and (3) *with* dying microalgae. We illustrate how various stakeholders invoke and adjust their bodies, attuning their embodied selves to each other as they generate shared as well as diverging concerns and care for those concerns. By juxtaposing these stories, we raise questions about life and death as the object of maintenance shifts and urge for a multispecies-inspired ethic of care in maintenance and repair studies.

Case Study and Methods

In recent decades, macro- and micro-algae have been lauded as the green gold of the bio-based economy, and algal metabolism and other vital processes are used in science and industry: to make biofuels and biofertilisers and produce nutraceuticals and food supplements (Kiesenhofer and Fluch 2018). Wastewater treatment is one area in which microalgae has great potential. Sewage and wastewater treatment systems overuse potable water, allow valuable resources, such as phosphorus, to go to waste, and fail to prevent chemical contamination (Vasconcelos Fernandes et al. 2015).

Our research project focuses on environmental engineers and ecologists from the 'Netherlands Institute of Ecology' (NIOO) who designed a wastewater treatment method to treat domestic wastewater using microalgae living in a photobioreactor (see figure 2). The goals were to recover nutrients, such as phosphorus, nitrogen, potassium, as well as microelements such as cobalt and iron on the one hand; and to remove micropollutants such as pharmaceuticals and hormones, as well as human pathogens such as bacteria and viruses, on the other. To develop the prototype, the engineers and ecologists used three species of microalgae – *Scenedesmus obliquus, Chlorella sorokiniana and Chlorococcum sp*. They mobilised knowledge from microbial biology to address the bacteria and microalgae, biochemistry to develop retrieval processes and discern the characteristics of various molecules and their internal conversions, and environmental technology to ensure the efficiency of the bioreactors. At the institute, the treatment method was partly operational, but its design was still in the pilot phase. A further step in its development was to take the prototype out of the laboratory and put it to work in the 'real-life setting', as the environmental engineers called it, of an ecovillage. This was a necessary step to fine-tune the prototype. The adaptations and recalibrations it required are the focus of our ethnographic fieldwork.

As social scientists, we had a stake in this project. We collaborated with the inhabitants of Ecovillage Lommel, engineers and ecologists from the NIOO, and three regional water authorities of The Netherlands, with the aim of studying the design and implementation of the prototype. Our role was to discover efficacious solutions to the various interferences to making the prototype work in the 'real-life-setting' of the ecovillage, so it fulfilled its biotechnological promises. Jointly, we aimed to design, implement, evaluate, and adapt the prototype for suitable use in the ecovillage and later in other settings including on agricultural land. Over the course of a year, from July 2018 to July 2019, we conducted ethnographic fieldwork both in the institute and the ecovillage during implementation and adaptation of the wastewater prototype. We observed ecologists, environmental engineers, and their students working on the prototype, taking samples from the ecovillage site, and testing those samples in the laboratory. We participated in volunteer labour days in the ecovillage, conducted informal interviews when the villagers performed check-ups on the prototype, and conducted a focus group interview with villagers about their engagement with the microalgae and the wastewater.

Knowing *with* Microalgae

In this section, we present three stories about maintenance operations that ecologists, engineers, villagers, and microorganisms performed while caring for a continuous flow of wastewater in the prototype. We illustrate how humans know (1) *with* hungry microalgae, (2) *with* stressed microalgae, and (3) *with* dying microalgae as their object of maintenance shifts from (1) the algal community to (2) the tubes and pumps, and, ultimately, (3) the scientific experiment.

Knowing *with* Hungry Microalgae

While the microalgae's metabolic potential to feed off household wastewater was key, whetting the microalgae's appetite in a *controlled* manner proved difficult. The faeces and urine the villagers' bodies discharged, rich in nutrients such as phosphate, nitrogen, and potassium, comprised a potential banquet for the microalgae. However, this wastewater was also rich in suspended solids, which posed a problem. For a maximum amount of light to penetrate the water, the quantity of solids in it needed to be kept at a minimum. Light provides energy needed for photosynthesis, a vital process for microalgae, which, just like plants, have chlorophyl. Asking villagers to produce different faeces (or rather, to eat differently) in order to solve this problem was, obviously, not an option. However, pre-treating the villagers' bodily waste was a suitable solution.

The situation called for help from anaerobic bacteria. The scientists piped the household wastewater into a septic tank where anaerobic bacteria ate the solid waste. This microbial activity helped decompose the suspended solids. Eventually, liquidised waste floated to the top of the septic tank and formed a thin layer of scum. The scum acted as a seal, keeping oxygen out – anaerobic bacteria neither live nor grow in its presence – and thus was vital to the filtering work of the bacteria. However, anaerobic life in the septic tank was sensitive to certain chemicals. In their efforts to maintain microbial life in the septic tank, the environmental engineers urged villagers to abstain from using chlorinated cleaning products: 'We can't use chlorine in any of the toilets because it kills life in the septic tank', one of the villagers explained. Chlorine does not biodegrade or dissolve in water. Instead, it accumulates in the scum in the septic tank and risks spoiling its necessary ecological conditions.

As the villagers' hygiene routine became entangled with the metabolisms of both the anaerobic bacteria in the septic tank and the microalgae in the tubes and pumps, the villagers learned to care for the wastewater. Villagers became aware of what they flushed in consideration of what they affectionately referred to as "our pet" or "the algae filter". They would only clean with plant-based, biodegradable products. 'If it's known to be ecological, it's fine', one inhabitant explained. This made it somewhat difficult to maintain hygienic norms because in the ecovillage the treated wastewater was re-used to flush. It had a 'yellowish' colour and stuck to the toilet bowl, leaving dark yellow stains. All in all, villagers accepted a less clean, 'smelly' toilet as the only option. Dealing with these sensory discomforts constituted the villagers' embodied mode of knowing *with* hungry microalgae. It enabled them to produce and ensure good-quality wastewater with few suspended solids.

Ensuring good quality wastewater was, however, not enough to feed the microalgae. The scientists strove 'to assure a stream' of wastewater, because then the prototype would be 'in need of less maintenance'. But during most of its experimental run, the prototype operated in a fed-batch process. This means the wastewater was manually fed to the microalgae. Every week, the ecologists and environmental engineers travelled to the ecovillage, fetched ten to twenty litres of wastewater from the septic tank, and slowly poured it into the tubes and pumps (see figure 2). 'Then the algae will have lots of food, that's nice', one of the students shared enthusiastically while filling the pipes.

Figure 2. The tubes of the bioreactor turn green, an indication of vital microalgae. (Source De Wilde and Smits, 2019)

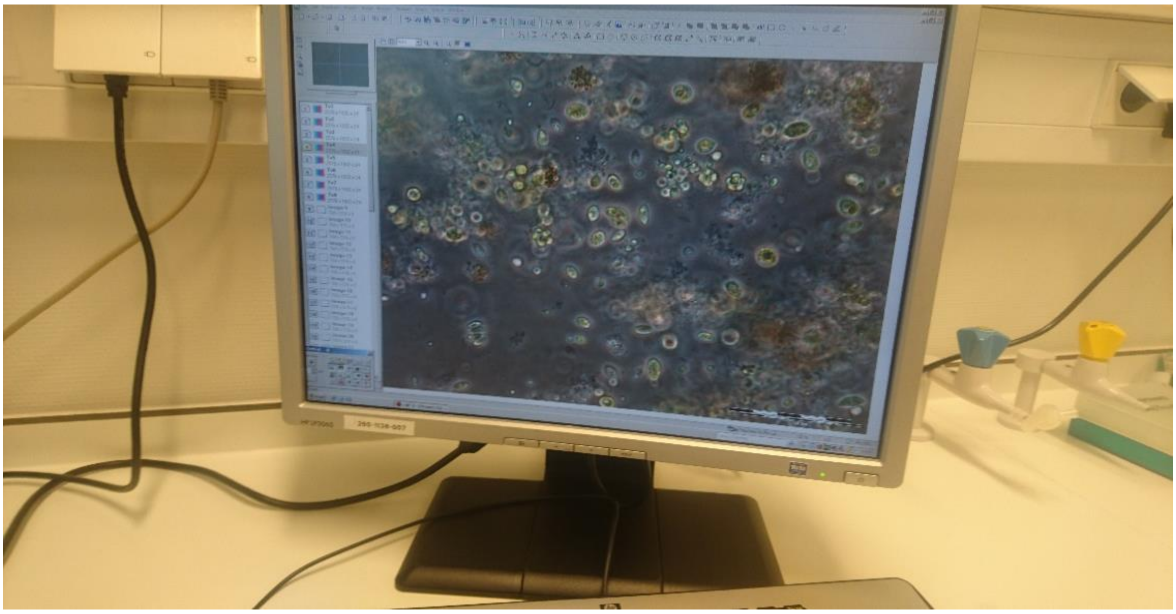

Figure 3. Wastewater sample of the microalgal community visualised in the lab. (Source De Wilde and Smits, 2019)

Less nice and rather unexpected was the engineers' inability 'to control the amount of nutrient intake' by the algal community. In analysing samples of the wastewater-*with*-algae, they noticed that for each fed-batch, the microalgae would grow exponentially at the beginning of the batch period when all nutrients were in excess. The algal growth rate would then decrease over the week until the next batch was fed to them. This puzzled the engineers. But at the end of the pilot project, they explained:

> It's like getting hungry just before dinner. The algae get moody and grumpy. If you feed in batches, you have 'this' amount of phosphate. The algae just take up everything. When it's gone, it's gone. And then they enter a static phase.

The microalgae responded to the intermittent feeding routine by adjusting their metabolic activity: they ate voraciously and grew exponentially when nutrients were in excess. As a result, their enlarged bodies affected other microorganisms living in the wastewater. When microscopically examining samples of the wastewater-*with*-algae over the course of the week, the engineers saw it's full of all sorts of microorganisms. One of the engineers turned on the computer screen to share the image with one of the authors (see figure 3). On the screen appeared bright spots, in different shapes, of greenish, yellowish colour, as well as some spots turned light blue and some bigger spots with a greyish colour. They constantly vibrated and some spots even moved in a rapid speed. Most spots of similar colour and substance clustered together in little groups that formed a larger spot on the screen. The engineer explained that the spots represented different microorganisms:

> Look, you see that one, of a green substance, with a little yellow-like transparent circle inside? That's the *Chlorella*! This one is quite easy to recognise. And this one, with a blueish shadow, do you see that? This might be the *Scenedesmus*, but it can also be the other blue-green algae, the *Chlorococcum*. . . . You can't say for certain if you use the microscope, you'll have to look at indications, such as substance, colour, clusters, form. . . . What we do see is that over the course of the week the variety of colours and shapes, which is an indication of the diversity of the wastewater sample, disappear very fast.

The fading variety of shapes and colours indicated the wastewater held ciliates, a plankton species known from other laboratory studies to feed on microalgae. However, in the ecovillage wastewater, the ciliates instead seemed to feed off the bacteria also present in the wastewater, causing their swift disappearance. Thus, in the wastewater ecology of the prototype, the ciliates shifted to feeding off other microorganisms, as one of the engineers explained somewhat hesitantly:

> It probably means that the algae have become too big for the ciliates to eat.

To conclude, maintaining algal appetite entailed 'composing with material modulations' (Denis and Pontille 2021, 21), or composing with embodied adjustments, to be precise. Villagers adjusted their household cleaning techniques to accommodate the conditions for anaerobic bacteria's viability so as to create good quality wastewater. The microalgae adapted their metabolism to the engineers' weekly feeding routine. Other microorganisms in the wastewater known to prey on microalgae started consuming bacteria. The algae's appetite, thus, became an adaptive practice. That microalgae adjust their metabolism to changing circumstances did not surprise the ecologists and environmental engineers, but the rate and extent at which they do, did. Microbial bodies thus became diagnostic tools – just as they should be in a biotechnological experiment. Following up on the maintenance and repair studies insight that repair occurs when a body senses something out of order, microbial adaptations also became *tools for repair*. The algal community sensed an interference and immediately acted on it. By adjusting its metabolism to a fed-batch mode in an unexpected manner, the algal community did not starve and ensured a functioning prototype.

Knowing *with* Stressed Microalgae

Ecologists invoke the term *stress* when microalgae respond to changes in their environment with biochemical and metabolic adjustments (Borowitzka 2018). In some biotechnological experiments, they strain microalgal bodies to induce stress and stir the growth of metabolites, which can for instance be used as vitamin supplements for humans. In our experiment though, they pampered the microalgae to explore the ideal operating conditions for the prototype, under which the microalgae could attain optimal growth. They therefore aimed to avoid algal stress. However, once they installed the prototype in the ecovillage, the microalgal community was constantly at the mercy of local weather conditions. Outside the laboratory an engineer explained:

> . . . we cannot protect the algae too well. So, we're really dependent on the weather.

When weather forecasts proved daunting, the engineers and villagers did not stand idly by. Instead, they tinkered with the tubes and pumps of the bioreactor in an effort to mitigate weather-induced stress effects.

They established minimal temperature control by refurbishing a second-hand greenhouse frame with a single wall of sheet plastic and placing it over the tubes and pumps (see figure 1). This protected the wastewater-*with*-algae from wind and severe rain. But when winter came, the wastewater was at the risk of freezing, which could break the bioreactor tubes in which the microalgae dwelled and kill off the algal community simultaneously. To prevent this from happening, the engineers removed the algal community from the tubes and stored them in dark barrels with nutrient-rich wastewater. In early spring, the engineers transferred the stored wastewater-*with*-algae back to the bioreactor with the help of a set of tubes and a small pump. As the engineers walked around the tubes to observe its flow, they constantly warned each other 'don't step on the tubes!' Their mutual warnings did not prevent stepping on the tubes and each time it resulted in a firm gush of microbial wastewater with dying microalgae on the floor. While handling this transfer, the big questions were whether the microalgae had survived and how to be certain they did. While filling the tubes with wastewater, one engineer pointed out that the tubes were turning green:

> Look at the tubes. They turn dark green immediately.

Not only was this a sign of microalgae, but it was also a sign of vital microalgae. The dark green colour indicated a large quantity of chlorophyll in the algae, which allows them to photosynthesise, a process necessary to their survival.

When one of the engineers took a sample from the wastewater, she slowly spun the cup and inhaled a deep breath with her nose above it, she mumbled to herself:

> I wonder how this will work out?

Asked why she smelled the wastewater, she explained she could smell that the wintering community of microalgae belonged to 'an old culture', as they have a different scent to freshly-cultivated microalgae. This also led her to conclude that the mature algal community must be 'very resilient', as it had been stored in dark barrels with hardly any sunshine for over a month and, surprisingly, had survived. An analysis of the sample provided clues: the microalgae seemed to have entered a sort of hibernation. During this period, their bodies had not grown. Nor had the algae multiplied. But, surprisingly, they had endured the unfavourable conditions again by lowering their metabolic rate.

Summer, though, brought problems of a different kind. During a summer heat wave, the engineers and villagers sprayed cold water on the walls of the greenhouse and submerged the horizontal tubes in which the microalgae dwelled in a cold-water bath (see figure 4). Both activities had a cooling effect on the wastewater, and, indirectly, a calming effect on the microalgae. However, during one of the hottest days in The Netherlands' meteorological history, the situation became crucial. The thermometer in the greenhouse indicated that the temperature had risen to 40 degrees Celsius, which was above the maximum temperature the chosen species of microalgae were known to survive. One of the engineers explained:

> All species have a curve with an optimum temperature for growth and a maximum temperature for survival. When the temperature exceeds the maximum temperature, we know that they die.

Concerned, the engineers decided to visit that evening—

> . . . to check how the algae are doing.

They took samples from the wastewater—

> . . . to have a look at the algae and check how vital they are [in the laboratory].

Here's one of the engineers attentively seeking signs of stress:

> I see that the algae are a little stressed. I can see it from their pigmentation. The algae should be green. But when they are stressed, they can become more, like, orange. I also look at the shape of the cells. When their cells look disintegrated, it can also be a sign of stress.

Using the microscope to visually assess the condition of the microalgae did not establish certainty about their wellbeing. It only provided clues from microalgae who change colour, cell structure, or shape in response to changes in temperature. As the engineer explained:

> You cannot know for sure how healthy they are, but you can guess from what you see.

The engineers could still see physical traces of the three species of microalgae. This indicated their presence – and continued existence – because dead microalgae "just disappear" from the wastewater ecology altogether. They don't leave a bodily trace as they are eaten by other creatures in the wastewater. The engineers' hunch to refresh the water bath with cool water in an attempt to save the microalgae from dying had been the correct one. The work of the villagers and the engineers paid off and the microalgal community survived the sweltering heat on that exceptional summer day. This was an unexpected outcome.

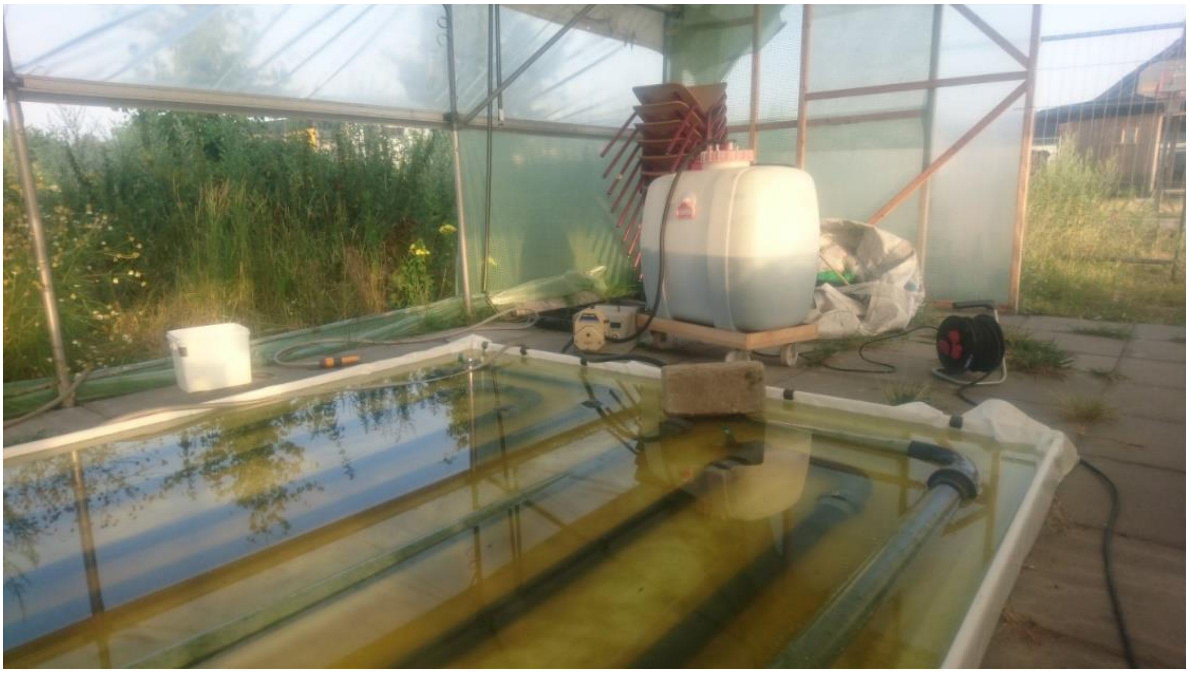

Figure 4. The tubes of the bioreactor are submerged in cold water. (Source De Wilde and Smits, 2019)

To conclude, knowing *with* stressed microalgae entailed improvisations to the tubes and pumps of the prototype. Engineers and villagers alike performed these actions. The microalgae, the engineers learned, improvised in response to the improvisations of their human caretakers. This is very much in line with a key insight of maintenance and repair studies, namely that maintenance work entails continuously coming up with provisional solutions within the triangular relationship of technician, user, and device. In pioneering studies on the reliability of prototypes, Lucy Suchman, Jeanette Blomberg, Julian Orr, and Randall Trigg (1999, 395) describe 'collaborative sensemaking' as something which characterises interactions among designers working on and users working with prototypes in-situ (see also Suchman, Trigg, and Blomberg 2002). But studying our wastewater treatment system in-situ shows that, when it concerns multispecies prototypes, the improvisatory agency of nonhumans should be included in this sensemaking process. Precisely because microorganisms have no fixed shapes and yield to attentive experimentation, much is possible in terms of the provisional solutions they help enact.

Knowing *with* Dying Microalgae

The microalgae, having been fed wastewater and sheltered from harsh weather, were eventually harvested to become biomass. This step was necessary for the prototype to function because a well-fed and happy microalgal community will multiply and thus incrementally increase in volume, to a point that the microalgal community becomes too large for the tubes and pumps to contain. The harvested microalgae were intended to be used as biofertiliser. Harvesting microalgae was also necessary in order for the engineers to sample the microalgal body. After all, in the development of this prototype, the microalgae played a biotechnological role and their growth and wellbeing were at the service of scientific knowledge production. Harvesting, though, was a process that eventually killed them off (see figure 5).

> Harvesting microalgae proved to be a cumbersome task. The engineers used bulk harvesting, a technique that aimed to separate the microalgae from their lifeline, the wastewater, by adding a mix of chemicals called 'flocculant' to clump suspended microalgae into large clusters. These clusters were easier to harvest than an individual microalga. Then the engineers collected the clumped microalgae through gravity sedimentation, allowing time and gravity to bring the clumps to the bottom of the wastewater tank.

However, the composition of the chemicals comprising the flocculant was by no means a given. The responsible engineer tried to develop the right composition on the basis of her knowledge of the individual microalgae species chosen for this experiment. However, since these species formed a community in a natural, *dynamic* ecology, she also tested different sorts of flocculants on collected wastewater samples from the ecovillage. Finally, she determined which flocculant to use to harvest the microalgae. Then, the next uncertainty occurred: finding the correct concentration of flocculant. The engineer shared her worries, which she came to by engaging in trial-and-error experiments on a regular basis:

> . . . there is no principal way to know [how much flocculant should be added to the wastewater to make the microalgae clump. It is] an informed estimate.

Because she was only able to visit the ecovillage once a week, she mobilised some villagers to assist her in monitoring the testing. She requested detailed pictures of the tubes that connect the harvesting device to the pump that pushes flocculant into the system, along with a video to determine the pace of flow. She also taught the villagers how to replace the bottle containing flocculant. She used their WhatsApp® group to inform them how much flocculant to add each day, depending on the environmental conditions in the ecovillage.

On the same day that the engineers installed the harvesting technology, the prototype broke down. Late that evening, one of the villagers delivered the bad news and sent pictures and videos of "a big mess": a green substance of dying microalgae and flocculant, merged into a liquid, was pouring onto the ground. The engineers asked a villager to switch off the pump. The mess should ideally be cleaned up, but it was too hazardous for the villagers to do so as there is always the risk of infection when working with wastewater. The engineers came the day after to clean up, wearing protective gloves and carefully engaging with the wastewater-*with*-algae. When their hands or face accidentally came into direct contact with the wastewater, they cleaned themselves with ethanol, a disinfectant. The encounters with the algae-*with*-wastewater were dangerously close that day. Not only was microalgal life at stake, but also the health of their human caretakers.

The prototype was eventually re-installed and, one hot summer's day, an engineer worked on-site, tinkering with the quantity of flocculant. The microalgae seemed to be doing well that day, which was not surprising considering that in high temperatures, microalgae grow at a fast pace. But when harvesting microalgae is at stake, they can also grow too quickly. The engineer adapted the amount of flocculant accordingly by increasing the pace at which the pump pushed flocculant from a barrel into the pipes with wastewater. However, rising temperatures also “make the algae unpredictable”. The engineer pointed towards the pipes with green flows of microalgae, she said,

> . . . because of them there, I have to adjust things in response to them.

Before leaving, the engineer observed and touched the connections between the devices and pumps once more, as well as checking the acidity of the wastewater. With a sigh of relief, she said:

> It’s great now. It’s perfect. [See figure 6 for what the engineer was showing us]

Figure 5. Harvested microalgae from the wastewater prototype are left to dry (Source De Wilde and Smits, 2019).

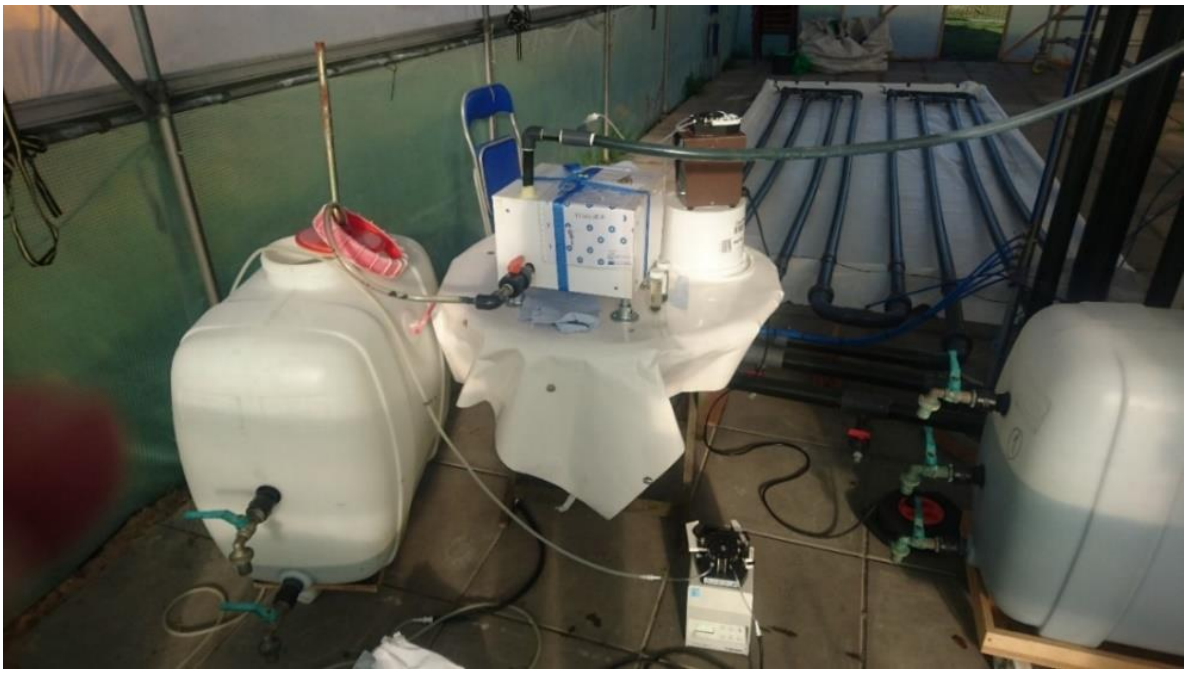

Figure 6. The connection between the harvesting system and bioreactor is fragile and the connecting tubes require constant monitoring. (Source De Wilde and Smits, 2019)

To conclude, harvesting microalgal biomass entailed an ultimate sacrifice from the microalgae, namely their death. While microalgae may prove surprisingly resilient to changing circumstances, when a controlled vulnerability is required, that resilience is not desired by their human caretakers. This is a particular form of vulnerability, an ultimate embodied engagement, namely *life beyond repair*. Only when the scientists could harvest algal biomass, and only when they could dry and analyse the non-living body of microalgae, would the experiment produce scientific knowledge, and thus achieve success. Thus, the object of maintenance shifted from microalgal wellbeing to safeguarding the scientific experiment. Vulnerability, however, was not easy to identify: it emerged through practical manipulation. The engineers engaged in what Blanca Callèn and Tomas Sánchez Criado (2015) call 'vulnerability tests': there may be a blockage or leakage of the wastewater, but it may not necessarily be an interference which requires repair. In the process, whose vulnerability is at stake shifts: the engineers seek microalgal death when they harvest microalgae, but this is intimately entangled with human health as the risk of bodily exposure to wastewater attests.

A Call for a Species Turn in Maintenance Studies

In this paper, we presented a case study of an experimental set up of an microalgae-based wastewater treatment prototype requiring many maintenance operations to function. Taking our cue from maintenance and repair studies, we focused on the *embodied engagements* by which caring for a continuous flow of wastewater through the prototype unfolded. The bodies that figure in maintenance and repair ethnographies are primarily those of humans. Concierges, cleaners, and mechanics are examined while observing, smelling, or touching materials in order to know if something may be off, and if so, how it may be fixed. In the stories we presented here, we examined how aquatic ecologists, environmental engineers and villagers used their senses as instruments of inquiry when handling wastewater, as they observed its colour and smelled its occupants, and as they manually checked the connections between tubes and pumps.

In our stories, however, a multispecies body of microbial wastewater likewise figured prominently, as the metabolism of three species of microalgae dwelling in the wastewater was key to the functioning of the prototype. We showed how engineers and villagers engaged in 'knowing *with* microalgae' as the microalgal community invoked and adapted its metabolism in surprising ways to the interferences stirred by their human caretakers. While caring for wastewater, knowing unfolded across the species barrier. Our empirical insight conforms to a pivotal finding of multispecies laboratory ethnographies of animals, plants, or microorganisms, which explore how humans and nonhumans co-create worlds, and thus knowledges (cf. Despret 2004, 2013; Helmreich 2009; Candea 2010; Giraud and Hollin 2016). In our case study, the algal bodies, both object and instrument of inquiry, also became, unexpectedly, *tools of repair*, liaising with other microorganisms and added chemicals in the wastewater, as well as natural forces such as heat, sunshine, and frost. By sensing interferences and adapting their metabolism accordingly, the microalgae's corporal improvisations sometimes ensured a functioning prototype and sometimes caused its dysfunction. Considering the maintenance of and by *living matter* helps us to rethink two issues concerning maintenance work and its knowledges from a multispecies perspective.

First, the notion of 'the networked body' (Henke 2000; 2019, 262) has been invoked in maintenance and repair studies to emphasise that knowledge that emerges *for*, *around*, and *as* maintenance is located 'not just in the body but distributed through the stuff of particular machines and systems'. This insight is helpful for specifying that the ontology of maintenance is relational. But, the majority of maintenance and repair ethnographies are case studies of information and communications technologies (Jackson 2014; Crooks 2019), energy systems, and transport vehicles (Dant 2010; Tironi 2019). Thus, the bodily engagements foregrounded are often those of humans with mechanical or electronic equipment. Our case study differs from these aforementioned studies. Our engineers and villagers were in a setting with similar equipment (such as pumps, computers, and microscopes), but also with microorganisms, and equipment of a biochemical nature.

This has implications for rethinking the 'triangular relationship' (Suchman, Blomberg, Orr, and Trigg 1999, 396; Orr 1996, 7) of use – between object, user, and designer/technician – the holy trinity of maintenance and repair studies. If microorganisms become 'partners in inquiry' (Szymanski, Smith, and Calvert 2021, 263), as well as tools of repair, one way to acknowledge their agency is to appraise them as maintenance workers, too. The species turn in the social sciences shows us how to acknowledge nonhuman agencies in knowledge production. But this pertains mostly to scientific knowledge production. Precisely because maintenance and repair studies engage with the *democratisation* of knowledge production (Denis and Pontille 2015; Sormani, Bovet, and Strebel 2019) by focussing on invisible, practical improvisations, it offers a suitable subfield within STS for foregrounding the improvisatory agency of living matter. This is our call for a species turn in maintenance studies, and more specifically, for updating Christopher Henke's notion of the networked body as a 'multispecies body of use'.

Yet, this should not only be in the form of a nuisance, of 'matter . . . which resists' (Denis and Pontille 2020, 284), aiding neither maintenance nor repair (see Edensor 2011). Living matter, in its unruly form, can also collaborate. In the ecovillage microalgae engaged as 'inventive practitioners who experiment'

(Hustak and Myers 2012, 106) as, together with their human caretakers, they sensed if something was off and in need of repair. Paraphrasing Henke (2019, 262), by knowing *with* their human caretakers, microalgae were sometimes able to repair an issue, unexpectedly. They adapted the biochemical processes by which they took up nutrients, but they also engaged differently with other microorganisms in the wastewater. For instance, by turning them into food. As societies advance towards ecologically sustainable modes of living, people will progressively cohabitate with a wide variety of microbes (see Brives, Rest, and Sariola 2021) and other species, and the technologies that house and facilitate them are worthy of the scrutiny of maintenance and repair studies (see Smits and de Wilde 2023).

Second, the stakes of embodied engagements changed when the object of maintenance shifted from algal appetite to the tubes and pumps, and, ultimately, the scientific experiment. As caring is a discriminatory mode of engagement, this raises the question who safeguards whom, who decides if, how, and when the object of maintenance shifts. As the object of maintenance shifted while caring for wastewater unfolded, 'cross-species sensations are . . . mediated by power that leaves impressions, which leaves bodies imprinted and furrowed with consequences' (Hayward 2010, 592). Coming into direct contact with wastewater was potentially harmful for engineers and villagers, but this bodily frailty differs from the vulnerability endured by the microalgae. Green and Ginn (2014), studying the maintenance of bee pollinator populations, call this a 'sharing [of] unequal vulnerabilities' (151). In the ecovillage, preventing accidental death or harm to microalgae formed a constant concern. However, controlled death also comprised the gateway to scientific knowledge. Our third story shows that microalgae need to go *beyond repair* – they need to mutate from living into non-living matter – to become biomass, which can then be dried, sampled, analysed, and turned into reliable data. This, with a touch of drama, we may say is their ultimate act of embodied engagement. Considering a multispecies-inspired ethics of care in techno-scientifically-focussed maintenance and repair studies entails articulating these shifting, at times conflicting, normative engagements 'within the very life of things' (Puig de la Bellacasa 2011, 87).

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