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EXPLORING THE COMPLEX ISSUES OF NUTRIENT POLLUTION IN THE DAIRY FARM CONTEXT: A TRANSDISCIPLINARY JOURNEY

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In this article, we illustrate how Nicolescu's (2010) axioms of transdisciplinarity underpinned a pragmatic study (Deane, 2023) conducted by one of the authors (Louise), into the issues of surplus nutrients from dairy farms and food waste and which worked towards a practical resolution to these issues. This article is based on Louise's thesis for the Master of Applied Innovation, and the ongoing projects grounded in recommendations from the thesis. Writing this article in the first person is a choice made by Louise to make the article accessible to stakeholders and those who contributed to the research. Celine and Henk were supervisors on the thesis and have added their commentary. Transdisciplinarity gave us access to knowledge and insights that we could not have gained from a single disciplinary approach.

Literature about the problems of nutrient pollution confirms that they are significant. Nutrient overshoot is a serious issue in New Zealand that needs to be addressed because surplus nutrients generated by dairy farming impose substantial environmental damage on land and waterways and emit greenhouse gases with consequent costs, many of which are not carried by the dairy industry. Economists refer to these costs as externalities. Foote et al. (2015) concluded that the environmental externalities associated with dairy farming may exceed the value of dairy export revenue and its contribution to gross domestic product (GDP), totalling NZ$16.6 billion. The Ministry for Primary Industries (2023, p. 16) estimates the 2023 contribution of dairy farming to GDP to be $25.12 billion. There are multiple perspectives on the causes and effects of this issue, as well as the extent to which environmental considerations should be factored into economic activities. The complexity deepens as we uncover the intricate interrelationships between soil types, soil microbes, plant variety, rainfall, and temperature. These factors collectively influence a farm's ability to utilise nutrients, adding to the challenge of resolving this complex, intransigent problem.

METHODOLOGY

In our globalised, interconnected world, inquiry-based research is reaching across disciplines to bring together the voices of academics, professionals, knowledgeable individuals, and differing world views on pressing issues of lived experience. In this case, the one theoretical framework to achieve this is transdisciplinary research, or simply transdisciplinarity.

Transdisciplinary ontology suggests that there are multiple levels of realities that interact within, and are mediated by, what quantum physicist Nicolescu (2010) calls the Hidden Third (Morin, 2002, cited in McGregor, 2015). This is a place of potential within the consciousness of the researcher/observer where contradictory views and understandings can co-exist, thus enabling the construction of new understandings and insights. The invitation through transdisciplinary theory and methods to engage through the Hidden Third holds opportunities for addressing pressing issues through facilitating new consciousness in the researcher which allows new ways of thinking and being in the world (Rigolot, 2020). Drawing on epistemologies of complexity, integrative transdisciplinarity offers opportunities to "integrate different world views, knowledge sets and mindsets, drawing on creative cognition" (Montuori & Donnelly, 2016, p. 756).

We chose a transdisciplinary research strategy because of the complexity of this problem and the belief that the holistic approach that transdisciplinary research offers would be far more likely to address the root of the problem than a siloed, disciplinary approach alone; a view which is supported by Montuori (2013) and Shrivastava et al. (2022). Nicolescu "believed that transdisciplinarity is about the interaction between humans and the sciences (Subject and Object)" (McGregor, 2015b) and allows for multiple perspectives, at different levels, to be considered, on both the problem and potential solutions (Nicolescu, 2010). Consequently, I sought knowledge from a wide range of stakeholders and experts including dairy farmers, the Thames Food Waste Resource group, AgResearch, black soldier fly larvae farmers, scientists, worm farmers, iwi, and experts in systems dynamics and modelling, considering Rieple and Snijders' (2018) suggestion that using an approach that respects the different realities of stakeholders is necessary to get buy in.

We chose Pragmatic Action Research (PAR) as a methodology because it enables the use of multiple and mixed methods in the research (Feilzer, 2010), encompassing both qualitative and quantitative data collection, to validate and/or help interpret it (Leavy, 2016; Roulston, 2010). Reflection and reflexivity are key processes for PAR as they are in transdisciplinary research (Greenwood, 2007; Lawrence et al., 2022). A pragmatic methodology allowed for changes to be made to the methods in response to insight or as negotiated by stakeholders with their diverse agendas. Significant insights came from informal conversations and from using methods that were not in the original plan but seemed intuitively appropriate.

THE RESEARCH JOURNEY

The research path was a zigzag one, taking full advantage of the flexibility of PAR and transdisciplinary research by following leads and adapting to the limitations encountered. My objectives of reducing nutrient pollution, conserving resources, and mitigating greenhouse gas emissions led me to focus on dairy manure (DM). I needed to identify an innovation with low enough risk to be acceptable to dairy farmers. This led me to explore the potential of using black soldier fly larvae (BSFL) as a means of co-processing DM with food waste. Positioned outside of the usual farming organisations, I chose an enterprise approach and spent time learning about the BSFL, business models and research methods for the Postgraduate Certificate of Innovation. I started the Master of Applied Innovation thesis with the following research question: How might we work with dairy farmers to manage the impacts of surplus nutrients on the environment in such a way as to benefit the dairy farmers and the environment?

A comprehensive, wide ranging literature review, which I revisited throughout the research as part of a reflexive process, had two primary data strands which were essential for my investigation. The first strand was about issues of surplus nutrients for the dairy farmer and the environment. It revealed an industry that is unsustainable in its current form, both financially (Howard, 2022) and environmentally, and one which contributes to New Zealand overshooting its biophysical boundaries. The second strand was around the proposed solution and how to make it work in the New Zealand dairy farm context. I evaluated how BSFL processing of waste would compare to other ways cow manure and food waste could be processed. I considered greenhouse gas (GHG) emissions and other environmental benefits and costs and evaluated income potential and the technology that would be required.

Black soldier fly farming clearly had potential benefits for the environment and the dairy farmer, and additional environmental benefits for other animal farming industries as part of a circular economy. Global demand for insect-based products is accelerating (de Jong, 2021) and making inroads with the BSFL approach might be beneficial in future for the business.

After a low-risk human ethics application was approved (No. WTLR40010921), the next step was pilot interviews. I wanted to explore current solutions to understand how they fitted into the farm context and why they currently did not seem to be solving the problem, despite significant legislative change and farmers' investments of time and money into waste systems. A conversation with the farmer at the first of my two pilot interviews, about how they pay the high costs for their waste systems, totalling over a million dollars, by putting more cows on the farm, yielded the insight that the system could not work, because the waste systems collect only a small proportion of the DM and urine. A serendipitously timed workshop (J. Connolly, personal communication, 2022) directed me to Systems Dynamics, a precursor to transdisciplinarity, to consider what leverage points could be adjusted to help resolve these issues. Further insights came from studying Peter Senge's (1990) system archetypes, a "set of system structures that produce common behavioural patterns across many different fields" (Systems & Us, n.d.).

An online survey, with 10 respondents, gathered quantitative data to support the finding of the price point of an innovation, and to get an idea of the capacity needed to manage the volumes of waste. It also yielded qualitative data, including how farmers felt about their waste systems. Their reported satisfaction with their systems seemed to me at odds with their stated reasons, that they were compliant with legislation. I thought they might have been experiencing similar feelings to those I had had when getting eco buildings signed off as compliant. Before the buildings were signed off, I felt angry and frustrated at the prescriptiveness of the rules and because some were not serving any purpose in my context but were adding significant expense and complication. After the buildings were signed off, I felt relief. I decided to investigate this further with follow-up interviews.

For the two follow-up interviews, both farmers wanted to meet on their farms to ensure I would represent them fairly. I found out that they love their lifestyle, particularly independence, working together with their families and working with machines. They were mostly satisfied with their waste systems at the functional level, particularly with using the wastewater for irrigating pasture and feed crops. Nonetheless, at the big picture level, they felt the costs imposed by the legislation around nutrients, and the stress of compliance, were threatening their lifestyles. Both confirmed that they recover these costs from the sale of milk solids, hence the need for more cows, which is surely counter to the intention of the legislation. They were vocal about lack of government understanding of the farm context and inflexible regulations, "unfit for purpose" and changing too often. One farmer stated, "they (the government) want to replace all cows with trees."

Thematic analysis assisted me to explore the data from the follow-up interviews, to synthesise data from the pilot interviews, questionnaires, and informal conversations with dairy farmers and triangulate my insights with evidence. Braun and Clarke's (2022) suggested process of creating codes enabled me to cluster the data around the relevant code labels, with some data items being clustered in multiple codes, then to re-examine the data to find shared meanings, which were then refined into themes, used to formulate insights and to consider implications.

While exploring the issue I also worked on the proposed solution. In this aspect, the principles of classical science would be beneficial. However, without easy access to laboratory facilities, and initially unable to find a science student to accompany me on the project, I built a semi-controlled environment in a greenhouse, with a breeding cage, setting up my own black soldier fly colony so that I could conduct some basic experiments at home to gather quantitative data that would help answer questions such as:

1. How long does it take BSFL to reach the pre-pupae stage (indicated by self-harvesting from the feed substrate) when fed on different feeds?
2. What is the increase in BSFL biomass over the feeding period from eggs to pre-pupae on different feeds?

Data from the experiments would be compared to results from other studies that investigated similar feed substrates, to determine what environmental conditions would need to be maintained in any BSFL-based adaptation to the dairy farm waste system.

There were several barriers to scientific study, including breeding the black soldier flies. Firstly, I needed to buy black soldier fly eggs to start experiments with batches of larvae of the same age, but these were unavailable in New Zealand. So, I bought mixed-aged larvae, grew them until they were pre-pupae, and bred the flies that emerged from the pupae. This took most of the growing season and since I could only collect three clusters of eggs, there were insufficient larvae to conduct more detailed experiments and test a prototype with farmers.

Secondly, the combination of COVID lockdowns which reduced my access to farmers, and problems with establishing a Black Soldier Fly (BSF) colony meant I needed another way to test the potential of BSFL farming. Henk Roodt proposed system dynamics simulation modelling to explore the proposed alternative. With support from Henk and an AnyLogic computer modelling software expert (C. Dempers, personal communication, 2021), I programmed a computer simulation model of the systems dynamics of the proposed BSFL biodigester on a dairy farm, analysing how the results changed as multiple parameters were adjusted. Through entering parameters from existing scientific studies, combined with the dairy farm information from my survey and literature review, I simulated experiments faster than in real time, and will continue to update the model as I gain more accurate information. This model could be used to inform future development of the technology and processes, and to demonstrate the idea to farmers and other stakeholders.

The potential to sell BSFL for animal feed adds an extra layer of complexity as this requires legislation, which is currently not in place in New Zealand (Bruce Mason, personal communication, 2021) and extra management to ensure the safety of the animal feed produced. Selling the BSFL would also provide additional income.

OUTCOMES

The research processes discussed so far resulted in key insights into the issue of surplus nutrients from dairy farms, and whether and how my proposed black soldier fly larva-based biodigester could be part of a larger movement to "a conservation and rehabilitation approach" to dairy farming (Wikipedia, 2023); in other words, regenerative agriculture.

Senge (1990) states that "today's problems come from yesterday's solutions" (p. 57). The causal loop diagram in Figure 1, drawn as part of a systems analysis of the above pilot interview, illustrates how stricter legislation, a government intervention in response to increasing nutrient pollution from dairy farming, inadvertently causes the nutrient pollution to increase. This is because increasing the herd size has implications beyond the waste systems as they often only capture a small percentage of the waste: 18 percent (Rollo et al., 2017). The increase in dairy cow numbers from 3.4 million in 1990 to 6.3 million in 2019 (StatsNZ, 2021), along with a six-fold increase in fertiliser use in the last 25 years (Pinxterhuis, 2019) and increases in the use of supplementary feed, add validity to the analysis in Figure 1.

My investigation into whether this situation fitted any of Senge's (1990) system archetypes, found that the "Limits to growth" archetype was in play, demonstrated by the environmental degradation and consequent reduction in financial viability currently impacting dairy farming (Howard, 2022). The "Shifting the burden" archetype offered deeper insights into what is driving the unintended consequence of increased nutrient pollution (see Figure 2).

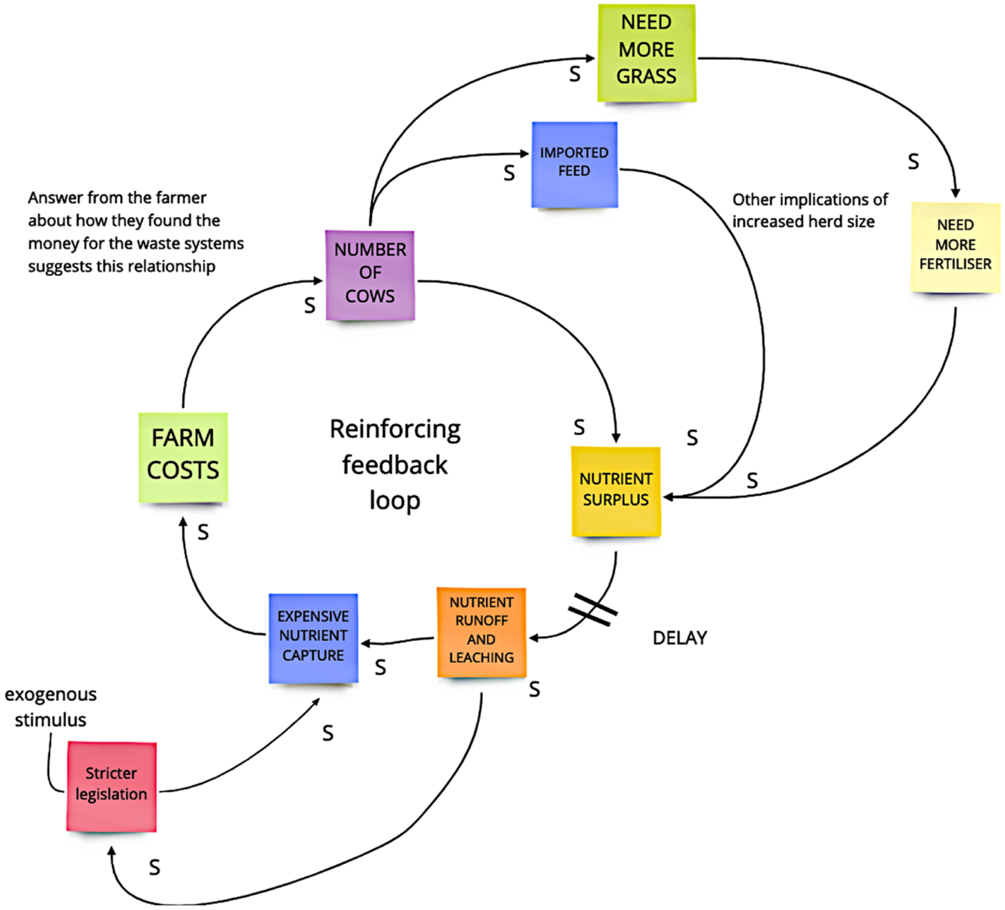

Figure 1. Causal loop diagram to show relationship between higher costs and herd size. The S next to the arrowheads indicates a 'same' relationship; in other words, that the impacted factor moves in the same direction as the causal factor. Diagram by the first author.

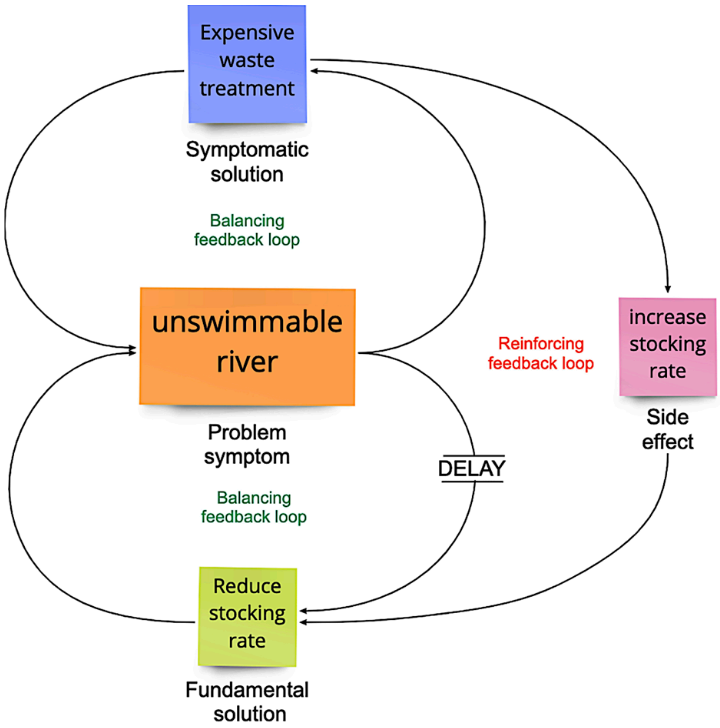

Figure 2. "Shifting the burden" story for the situation in Figure 2. Diagram adapted from the archetype of Senge (1990, p. 112).

The expensive waste capture and treatment systems are one area of the symptomatic solutions that were instigated with the aim of reducing nutrient and pathogen pollution of rivers. The diagram shows how a side effect of the solution, that of increasing the number of cows to provide more income to pay for the waste system, defeats the fundamental solution that would solve the problem.

Another feature which Senge (1990) explains about this archetype, which is at play in the situation of unswimmable rivers caused by nutrient pollution, is that of "eroding goals" (p. 108), which happens when solutions do not work. This is illustrated through the 2017 National government's attempt to change the water quality standard of "swimmability" for bodies of freshwater from 260 E. coli to 540 E. coli per 100 mls water (Ministry for the Environment, 2017). In 2017, this became an election issue with significant push back (Baisden, 2019). The "Shifting the burden" system archetype can also result in "unintended shifts in strategic direction." An example of this, which came up later in my conversation with the farmer, was the observation that the gradual push in New Zealand dairy farming from pasture-based dairy farming to a more industrial, off-pasture system, with more time spent on feed pads or in herd homes as a way of reducing the nutrient load on paddocks, was contrary to the key marketing message about New Zealand dairy products being pasture-based and natural. From my youth in the United Kingdom, I remember the 1989 Anchor butter advert jingle, "We are lucky cows, we chew the cud and browse. / 'Cause we're eating up our greens, it makes our butter taste supreme" (Animal Ad Stars, 2013). If we keep heading towards a more intensive dairy farming model, our point of difference could be lost.

The implication of this system analysis for a possible solution is that cost is likely a leverage point. Through either reducing the cost of the waste system, or gaining an income from it, farmers might be able to reduce stocking rates, thereby reducing the nutrient surplus which can leach from the paddock. Another potential leverage point is increasing the capacity of the system to use more nutrients. This would involve increasing the complexity of the system. Natural ecosystems are generally much more complex than human-made systems which tend towards being monocultures. In a complex ecosystem such as a rainforest, excess nutrients provide niches for other living things. Regenerative farming techniques may also be part of this more fundamental solution to the problem, as they tend to increase the capacity of the farm to use excess nutrients by increasing soil life and varying pasture species or introducing more trees. Increased natural processes, for example processing of manures by insects, also help make natural nutrients more available to plants thereby reducing the need for synthetic fertilisers. A BSFL-based waste system would work on both leverage points.

Thematic analysis gave me insights into farmers' feelings about their lifestyle and the threats they perceive to it. Some of the themes were interesting, although less relevant to my particular purpose with my ongoing project, or provided insights about areas that I have little control over, such as legislation and government. Nevertheless, when synthesised with other information, or considering parallel situations, they have offered some insights.

The thematic analysis showed that farmers are open to a circular economy and have been open to new ideas, yet they are overwhelmed with the perceived constant changes to legislation, which they feel is unfair. They have spent a lot of time and effort on their waste systems and feel that their efforts to reduce nutrient pollution are not recognised and that the government wants to get rid of all dairy farms. They pay for their waste systems using income from milk solids. They do not like being told what to do by people who they consider do not understand their context. The implication of these insights are: the proposed BSFL system needs to reduce costs and/or generate income, which needs to be used to reduce the number of cows whilst retaining the lifestyle farmers love; the importance of establishing a trusting relationship with the farmers and including them in designing the enterprise and the biodigester; the need to work with the government to get appropriate legislation in place for insect farming; and the need to create a positive narrative about BSFL farming.

The computer simulation model of a BSFL-based bioreactor on a dairy farm suggests that it could provide income for the dairy farmer from the sale of BSFL and frass (insect manure and cast-off exoskeletons), while reducing the mass and volume of the dairy manure, preserving many of the nutrients that would otherwise be lost as GHGs, or potentially leached onto land or water (see Figures 3 to 5 below). I will continue to update the model; initially by adding a chart of nutrient capture and GHG reduction based on data from new research. The model provided part of the evidence for the potential of scenario 1 (see conclusion).

Although my efforts to grow a colony were only partially successful, the process illuminated some of the barriers to establishing BSFL farming in a field-based setting in New Zealand. These include the need for a controlled environment for black soldier flies and larvae to breed and grow in colder locations and seasons; protection from pests such as rats and ants and the need to pre-process the feed substrate. All these have implications for the next steps.

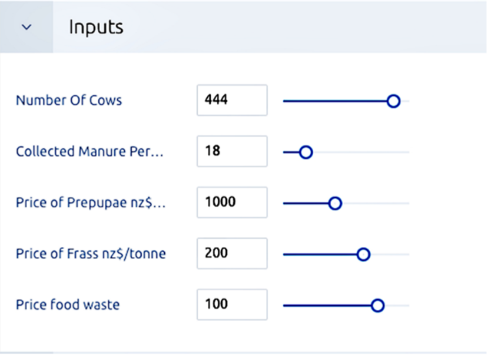

Figure 3. Inputs into the AnyLogic model yearlong simulation of the BSFL based waste system. The inputs were set on the experiment to reflect realistic figures. The number of cows and the collected manure percentage are the average for dairy farms in 2021. The price of pre-pupae reflects the price for fishmeal and the price of food waste is an estimate of what people pay to dispose of food waste. Extract from my model BSFL Unit 2, Version 13, Experiment 2.

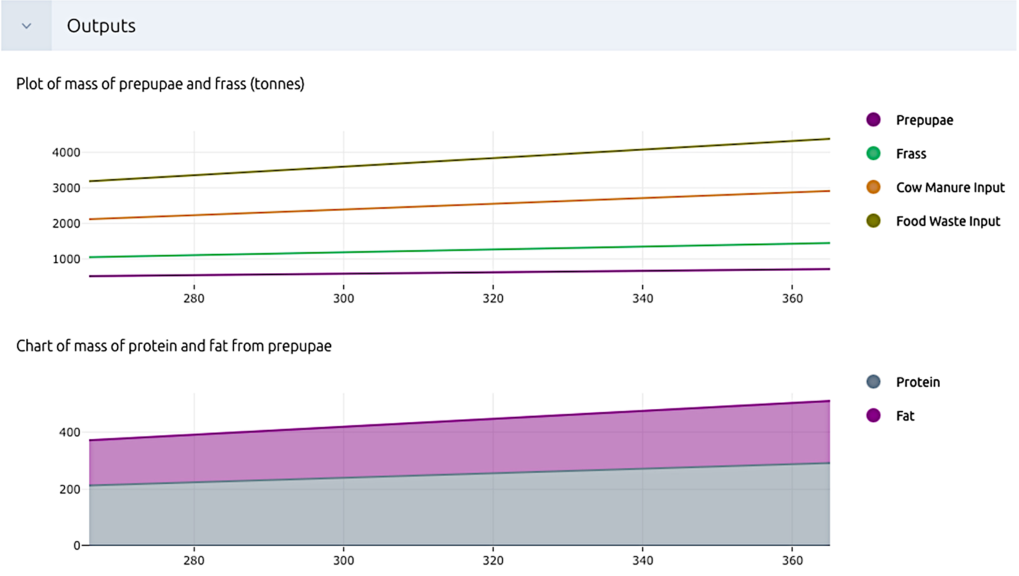

Figure 4. Mass of inputs and outputs from the BSFL waste system in the above simulation. The unit on the y axis is tonnes. Cow manure and food waste input masses are shown to illustrate how much the volume of these waste streams can be reduced by BSFL processing. Protein and fat are shown as BSF pre-pupae are often processed into these components for sale as ingredients. Extract from my model BSFL Unit 2, Version 13, Experiment 2.

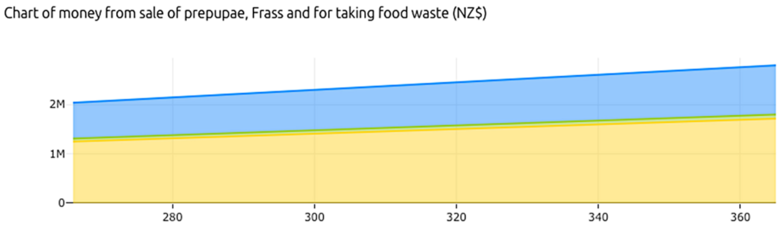

Figure 5. Projected income from taking food waste, and sale of prepupae and frass in the above simulation. Yellow = income from sale of prepupae, green = income from sale of frass and blue = income from taking food waste as a service to councils or other food waste generating industries. Extract from my model BSFL Unit 2, Version 13, Experiment 2.

CONCLUSION AND WAY FORWARD

The issue of surplus nutrients from dairy farming is a significant and highly complex problem with many contradictory viewpoints. BSFL based dairy farm waste systems could be one of several ways of making dairy farming more environmentally regenerative and economically viable. They would diversify farm income streams, use more of the nutrients in dairy manure, and replace chemical fertilisers with frass, which soaks up surplus nutrients and improves the soil in the long term. Significantly, the main environmental benefits would only eventuate if the number of dairy cows were reduced. There could be environmental benefits in other industries by making more of the surplus nutrients from food waste, while getting it out of the waste stream. Benefits potentially include providing an alternative protein and fat source for animal-feed to replace environmentally damaging fishmeal and soy, providing a source of biodiesel, and making frass available as a soil conditioner.

The regulatory environment is not yet in place for BSFL farming on manures and post-consumer food waste, and the technology is not yet consistent enough to reliably grow BSFL in New Zealand, although it is getting very close. At this stage, it may be more effective to bring in the technology from companies that are further ahead in trialling, and to start BSFL farming on easier waste streams such as pre-consumer food waste.

Since the completion of the thesis, I have been working to develop a collaborative group to further BSFL/invertebrate farming in New Zealand. We now have scientists, entrepreneurs and potential customers on board and are looking at regulation. I am also working with a local resource recovery social enterprise to get a BSFL-based food waste biodigester trial started, using imported technology. My BSFL-based dairy farm waste system may happen in the future when the regulations and technology are in place.

Although not directly relevant to my proposed solution, I also aim to communicate my analysis to appropriate people, particularly government and dairy farming organisations, about how current expensive waste systems and regulations are having the unintended consequences of increasing the number of dairy cows and that they are also affecting the relationship between farmers and the government.

LOUISE'S REFLECTION ON THE LEARNING JOURNEY

Through my research, I explored diverse methods, gaining skills from various academic disciplines and learning from both academic and non-academic participants. Embracing a transdisciplinary approach which emphasised the importance of respecting and listening to all participants, exposed me to valuable knowledge beyond my limited perspective.

This approach aligned well with my dyslexic, big-picture thinking style. I tend to absorb knowledge through insights rather than relying solely on explicit sources, and this approach catered to my intuitive way of learning. While intuition and insights may not conform to the traditional academic norm of falsifiability rooted in classical science, my personal experience suggests they still contribute legitimate knowledge. They may not adhere to universal laws or be easily replicated, but their non-provability and the complex amalgamation of multiple sources in the subconscious mind should not discount their legitimacy. In my experience, insights often provide crucial missing pieces that explain why things do not work as expected. This resonates with Nicolescu's concept of the Hidden Third, where insights offer glimpses into knowledge that remains inaccessible from our own perspective. I have gained confidence in the validity of my insights, which have guided me towards solutions in Nicolescu's (2010) "included middle," a place where different and contradictory realities can exist at the same time. I think I would have had a lesser understanding of the problem had I stayed with one or two methods and would argue that transdisciplinarity has a place in bridging the gap between science/academia and lived world practice.

CELINE'S REFLECTION ON THE LEARNING JOURNEY

Working in a transdisciplinary team with scientists it was my role, as an applied linguist, to assist Louise to tell the narrative of the research in all its twists and turns, and also, to encourage her to write herself into the narrative, with a critical and analytical lens. For inquiry-based research addressing complex issues, which in this case entailed high financial stakes for individual farming businesses, a transdisciplinary research framework offers researchers and mentors the opportunity to engage multiple methods to explore the issues and work towards a proposed solution. It invites the humane values of searching out and listening to people across a wide spectrum of experiences and beliefs, disciplines, and worldviews, encompassing a range of perspectives, including that of the natural world, to inform a response. The requirement to seek out respectfully, to try to take account of differing views and lived experiences, and to be aware that there is still more to understand, as acknowledged in Nicolescu's Hidden Third or included middle, requires the researcher to be open to stepping beyond the initial framing and parameters of the inquiry. This response requires an understanding of the connectedness of multiple factors and allows the potential for creative and often unexpected solutions.

In responding to the challenges and unexpected outcomes researchers and mentors can encounter in the process of inquiry, transdisciplinary research can accommodate the personal strengths of the researchers, such as a dyslexic thinking-style, as in this research project. Bringing together mentors from across disciplines can provide its own challenges given that disciplinary understandings and mindsets are extended in the process of the inquiry.

HENK'S REFLECTION ON THE LEARNING JOURNEY

As the journey unfolded and the global COVID-19 pandemic disrupted our lives, the research project was threatened significantly. Limited or no access to laboratories, and no physical access to fellow research participants and collaborators, forced Louise and the facilitators as a team to consider innovative ways to continue the work. Modern computing technology, mixed with ingenuity driven by 'making do with what we have where we are,' opened other opportunities: the BSF plant, built on Louise's own property, the use and adaptation of simulation models to progress concepts, and long sessions in video calls discussing options became the new normal.

We embraced modelling to explore ideas to make best use of time talking to other actors and stakeholders. As Celine points out, we were forced to dig deep to understand people's motivations. It meant that we were ready to review and validate concepts when limited regional travel became possible. Perhaps because of the significant social distancing during lockdowns, people were keen to have discussions in person. It allowed for longer and more engaging meetings that highlighted deeper emotional drivers of the dilemma that this research addressed.

Above all, the entrepreneurial spirit and willingness to be agile in adversity delivered an ongoing enterprise that operates quite comfortably in an increasingly brittle and uncertain world. When we started to focus on the dilemma we faced, we realised that our different world views could be used quite productively to synthesise a new reality. Similarly, in this new reality farmers, environmental activists, researchers and the community are all heard and can see a way to achieve outcomes for the common good.

Environmental educator, eco-builder and social entrepreneur, **Louise Deane** has been a long time community and environmental volunteer in practical projects and on various boards of trustees. Her current work is in establishing a collaborative group for scientists, entrepreneurs and potential customers, to progress insect farming in Aotearoa, and in working with a local social enterprise to trial using black soldier fly larvae to process food waste.

Celine Kearney PhD, Doctor of Philosophy, teaches English language to learners from migrant, refugee, and international backgrounds, and supervises postgraduate students in Transdisciplinary methods at Wintec | Te Pūkenga. An applied linguist, her research interests include language acquisition, culture, and identity. A former journalist and teacher of journalism, her most recently published book is *Southern Celts: Stories from people of Irish and Scottish descent in Aotearoa*.

Jan Hendrik Roodt PhD EngSc is an experienced practitioner and academic at the New Zealand Institute of Skills & Technology, Te Pūkenga. He specialises in business innovation and professional practice development. Affiliated with professional organisations including the IEEE Systems Council, International Council on Systems Engineering, and Academy of Management, he serves as a project and publication reviewer, as well as a journal editor.

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