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CIBR UPDATES FROM THE PROGRAMME MANAGER

Tēnā koutou and welcome to our autumn newsletter.

The last couple of months have been very challenging – adapting to new styles of working and socialising in the wake of COVID-19. Much of our work has been taken online to Teams and Zoom to explore and discuss new opportunities for biowaste research. For up to date relevant information on COVID-19 in wastewater and biosolids, please read New Zealand's Land Treatment Collective's (NZLTCs) latest newsletters – links to the newsletters are posted on the CIBR website: https://cibr.org.nz/newshub/.

Our microbiology scientists have been working over the past 10 years investigating the efficiency of wastewater treatment in to remove pathogens – bacterial and viral. To read more about their work turn to page 2.

We have been working closely with small rural councils from the Lower North Island over the past few years working together to create a regional biosolids strategy (see page 3), trialling alternative reuse options for biosolids that are cost-effective and sustainable. The aim of the project was to create a 'toolbox' that councils can use to compare the different biosolid re-use options and to find one that works for their region.

We also held our annual CIBR workshop in late March, for the first time on a virtual format. Apart from the CIBR team, we enjoyed the participation of three councils and two industry collaborators. To hear about the outcomes of these workshops turn to page 5.

To intensify risk assessments of emerging organic contaminants in New Zealand ecosystems, the ecotoxicology team has expanded their teams and a new PhD student started recently. If you are interested what she is going to study have a look at page 7.

Our soil scientists at Rabbit Island in Nelson have been investigating whether there is accumulation of per- and poly-fluoroalkyl substances (PFAS) compounds in the soil, after land application of biosolids (page 12). These compounds are predominantly found in firefighting foam in New Zealand, and have been shown to contaminate surrounding surface and ground water after use.

For updates on our mānuka research at Lake Wairarapa see page 8, where we have two field sites planted with mānuka and other native plants for improvement in water quality in the catchment. In addition, a lysimeter study at Taupō has been performed over three years to elaborate more on the effect of mānuka on N-removal (page 10).

Te Pā o Rākaihautū (Te Pā) is a special character school based in Christchurch where our social and cultural team have spent the last four years undertaking research learning about the Pā Wānanga (site of educational and community activities) as a culturally grounded model of education (page 14).

Ngā mihi nui,
Maria

Job:982122 ESR Biowaste News Iss 22-June

CIBR ATTACK ON VIRUSES IN WASTEWATER

Louise Weaver

In the current climate of change due to the COVID-19 pandemic we thought it would be of interest to revisit the efficiency of wastewater treatment systems at removing viral pathogens. The CIBR microbiology team have been investigating the effectiveness of wastewater treatment, with a focus on small scale and natural systems on pathogens, including viruses for over ten years. We have had a focus on low cost, sustainable options for wastewater treatment as these are well-used in NZ and overseas but often thought of as inferior to high tech treatments.

There is still a lack of knowledge on the removal and inactivation capacity and current regulations rely on bacterial indicators, which are not suitable for predicting virus removal and inactivation.

Our initial studies focused on holistic removal capacity using large mesocosm scale experiments and oxidation pond wastewater, WSP. We investigated the factors important in virus reduction. Interestingly, although sunlight (UV) demonstrated a primary role in virus reduction in oxidation ponds there were other factors involved and even in systems where light was excluded, virus reduction was achieved. If the pH and dissolved oxygen (DO) levels in the WSP remained elevated, similar levels of removal of indicator organisms and virus (echovirus) were achieved in the presence and absence of direct sunlight (Figure 1).

For summer 2011, MS2 phage die-off rate was calculated at –16.2 (k, ln per day), *E. coli* was –14.0 (k, ln per day), and echovirus –9.5 (k, ln per day). For summer 2012, a similar trend was seen but to a lesser extent, and all die-off rates were lower whether in sunlight or not (Figure 1); die-off rates were –13.8 for MS2 phage, –3.0 for *E. coli*, and –5.5 (k, ln per day) for echovirus. In dark mesocosms the log10 reduction over both summer experiments demonstrated significant reduction in virus could be achieved (Table 1).

Experiments ran over two summers showed variation in reduction in viruses (and indicator organisms) which appeared to be related to differences in temperatures (hotter increased reduction) and UV irradiance (higher increased reduction) (Figure 1). We also found that higher pH and dissolved oxygen (DO) increased virus reduction (Table 1).

Table 1. Overall log10 reduction in dark mesocosms during summer experiments. pH, DO and temperature averages (min and max) are also shown.

	Summer 2011	Summer 2012
E. coli	6	7
MS2 phage	5	6
Echovirus	4	5
pH	10.4 (10.2–10.7)	9.9 (9.4–10.5)
DO (mg/L)	9.1 (6.9–11.1)	11.5 (6.6–14.7)
Temperature (°C)	19.6 (13.4–27.6)	15.4 (6.0–24.5)

We followed on from this by investigating the potential for virus to become attached to solid particles in the wastewater and subsequently settle out. Here we found, consistent with overseas research (Verbeyla et al 2015) that virus particles do not settle with solid particles in wastewater consistently. For all viruses tested (Adenovirus, Echovirus and Rotavirus) there was between 0% and 1.7% attached. After seven days, Echovirus and Rotavirus showed less than 5% settlement and Adenovirus was slightly higher at 9–19.8% settlement. There are mechanisms that may still enhance virus attachment to particulate matter and hence may allow settlement to occur. There is another question, which we are now looking into; if viruses do settle into the sludge would they still be active (infective)?

For small-scale systems, we have been investigating the risk of virus transport from on-site disposal fields into shallow groundwater. Our Masters student, Hazel Clemens, undertook lysimeter experiments to investigate the transport and removal of rotavirus, MS2 bacteriophage (phage) and an inanimate surrogate (DNA-labelled-glycoprotein-coated silica nanoparticles, DGSnp), in free-drain silty and sandy loam overlying sandy gravels, dosed with onsite wastewater (Figure 2).

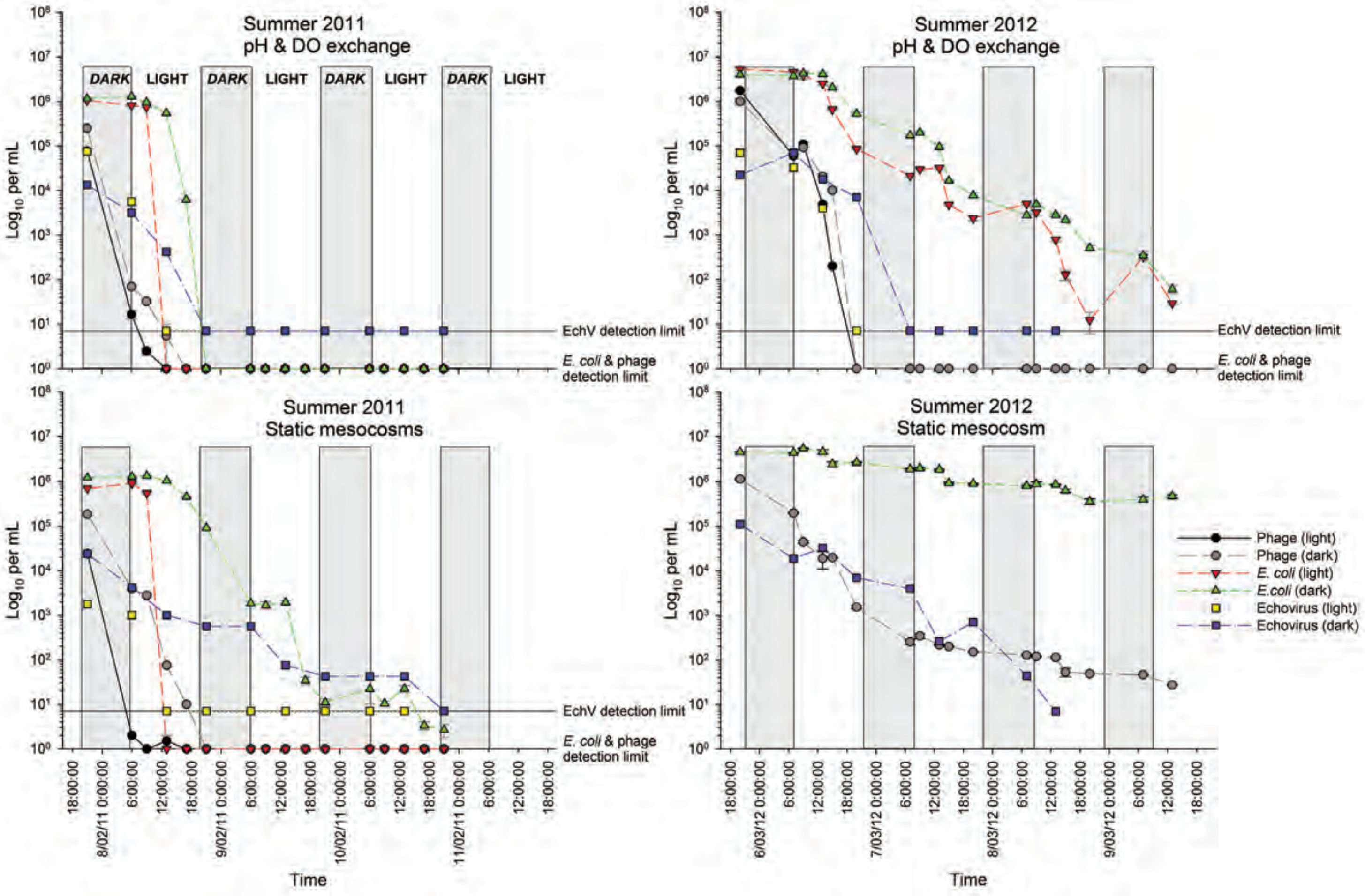

Figure 1. Removal rates of E. coli, MS2 phage and Echovirus during mesocosm experiments.

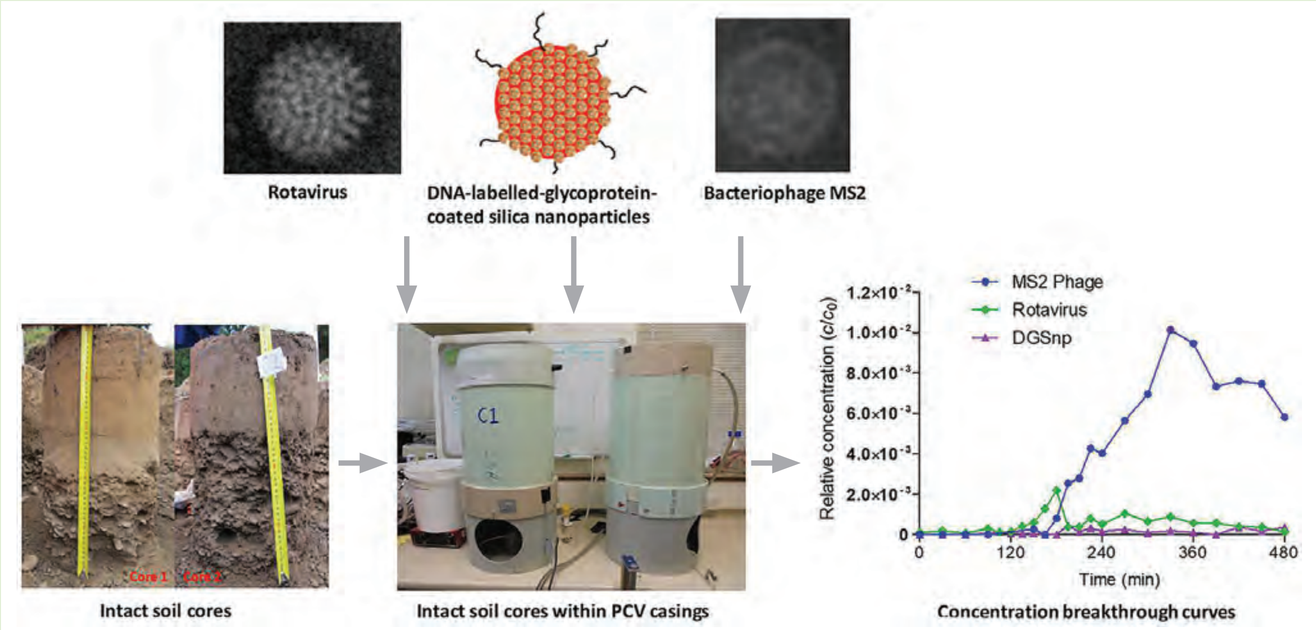

Figure 2. Lysimeter study to monitor virus transport from on-site disposal sites into groundwater.

The estimated removal rate was for rotavirus 3.76–9.23 log/m, surrogate 3.36–8.53 log/m and MS2 phage 1.85–4.99 log/m (Figure 2). Thus, for a 7-log reduction in concentration, it would require a vertical separation distance of rotavirus 0.8–1.9 m, surrogate 0.8–2.1 m and MS2 phage 1.4–3.8 m. The results suggest DGSnp could be used to assess the attenuation capacity of subsurface media to rotavirus. However, DGSnp is not conservative and will underestimate the setback distances required for rotavirus reductions by 3%. On the other hand, separation distances determined using the rotavirus parameters and criteria but based on MS2 attenuation, can be too conservative in some subsurface media (Clemens et al 2020).

We are now in discussions with stakeholders, councils and landowners to take the investigation to the next level by installing a full-scale on-site system that will be monitored in-situ over time.

Our aim here is to improve knowledge of the transport potential for viruses (and other contaminants) at real scale. This is something still lacking in the development of the current setback distance guidelines.

Over the years our research has demonstrated that our low-cost wastewater treatment systems do have the capacity to removal pathogens, including viruses, and continued research will allow us to optimise these systems for future scenarios.

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COLLECTIVE BIOSOLIDS STRATEGY – LOWER NORTH ISLAND

Jennifer Prosser, Hamish Lowe, and Izzie Alderton

Figure 1. Sludge windrows at PNCC facility.

Across the lower North Island there is an estimated 80,000 tonnes of sludge in oxidation ponds that requires management over time. Finding alternatives to landfilling of this sludge is especially difficult for smaller communities where there are limitations of lesser economies of scale to develop sustainable non-landfill options.

Ten councils of the lower Noth Island are involved in a partnership to develop a biosolids strategy, which includes a collective approach for sludge management and the development of a beneficial end-use programme. The *"Collective Biosolids Strategy – Lower North Island"* project funded by the Ministry for Environment Waste Minimisation Fund, and co-funded by CIBR and the partner councils, is led and co-ordinated by Lowe Environmental Impact (LEI) along with partners from The Institute of Environmental Science and Research Ltd (ESR) and Massey University. This project aims to consider economies of scale and alternatives for discharge and beneficial use of biosolids which are affordable, sustainable and provide targeted solutions that are consistent with national waste minimisation strategies. Feasibilities of several alternative end-use options were trialled in this project from greenhouse experiments, to larger scale field trials.

BIOSOLIDS COMPOSTING TRIAL

This trial investigated the practical and/or technical viability of sludge composting by way of a large-scale field trial, to determine if a high-quality compost product could be produced from varying mixtures of contrasting sludge. The field site for this trial was established at the Palmerston North City Council's (PNCC) Awapuni composting facility in early 2019, with 12 windrows of sludges mixed with green waste at a ratio of 1:4 (237 m³ of material forming 12 m long windrows). Three contrasting sludge types were chosen and blended either individually or in combination:

- Palmerston North WWTP digester sludge;
- Palmerston North WWTP alum sludge; and
- Bunnythorpe oxidation pond sludge

The compost windrows were tested at establishment and monthly for an array of parameters to assess the microbial and chemical contaminants presence and the efficacy of the composting process. Incorporated into this trial was a cultural monitoring plan (Rangitāne o Manawatū Cultural Values Assessments and Cultural Monitoring) alongside the Western science that was facilitated by a representative from Tanenuiarangi Manawatū Incorporated.

Figure 2. Field trial set up in May 2019. (A) and (B) sludge application to the plots, (C) Seinalyn Villanueva and Izzie Alderton mixing in the sludge with the soil.

The main findings from the trial were:

- The composting process stabilised the microbial contaminants (*E. coli*) and effectively diluted chemical contaminants (trace metals) to produce a product that met guidelines for composts in NZ (NZS4454, 2005) and 'Grade Aa' and/or 'Grade Ab' biosolids (NZWWA, 2003), within six months of establishment through dilution and composting processes;
- Based on analysis of phosphorus, organic-N, ammonium-N, and nitrate-N it is evident that all 12 sludge composts would provide adequate short-term and long-term nutrition for use as a soil conditioner or plant amendment;
- Elevated trace metals (Zn) in some final composts was a result of reduction in total volume of the product through natural processes, and indicates initial dilution ratios need to take into account when dealing with metal containing sludges;
- Significant insights into local iwi views and the cultural effects of biosolids composting at Awapuni Resource Recovery Centre was gained through the production of a cultural impact assessment (CIA) by Te Ao Turoa Environmental Centre (TATEC) researchers that indicated: Beneficial use of biosolids is viewed positively, but landfilling is not. The application of biosolids should not be near waterways and food-production areas.

Based on the results of this trial it is suggested that commercial composting, under optimal conditions and following recommended procedures, is a viable means of producing a material suitable for a wide range of end uses which might otherwise not be available to un-composted WWTP sludge.

BIOSOLIDS FIELD TRIAL

Biosolids (and sludges) are rich in carbon, nitrogen, phosphorous and essential micronutrients (e.g. zinc) and therefore have the potential to improve crop/ pasture performance. This field trial explored the potential use of sludge as a soil conditioner by assessing the growth response of three grazing crops: Oats, Italian Ryegrass and existing pasture, grown in municipal wastewater treatment sludge amended soil. The crops used were not intended for direct human consumption. The field trial was located at Massey University's Sheep, Beef and Deer Research Unit in Palmerston North, where thirty-six plots each 1 m^2 were established containing the three forage crops grown in four treatments:

- Control (C) – no treatment applied;
- Fresh digested sludge (B);
- Pond sludge (P); and
- Diammonium phosphate fertiliser (F).

The trial was regularly maintained and monitored and ran for five months. At the end of the experiment, soil and herbage was analysed for a variety of chemical and biochemical parameters and biomass production of each crop was quantified.

The results indicated that the application of fresh sludge or pond sludge increased the growth of pasture and ryegrass compared with inorganic fertiliser treatment, particularly toward the end of the trial. This is likely attributed to the increased supply of slow release nitrogen and phosphorous in sludge products. Although trace elements were present in both crops (Zn and Mo), and soils (Cr, Zn, and Pb), the resulting concentrations were within the normal range, and do not present a risk for cattle, sheep or ecological parameters of the soil. The numbers of *E. coli* in the soil after the 6-month period of the experiment were below 100 MPN/g DW and therefore within the limit (<100 MPN/g) considered to be safe for public.

Based on the results of this trial it is suggested that biosolids can be used as a soil conditioner, applied at the appropriate concentration when growing crops for use as animal consumption. Biosolids improves significantly growth of crops for longer periods of time compared with fertilizer, which provides a considerable advantage to traditional fertilizing methods.

Figure 3. Final sampling of soil and herbage for analysis (October 2019).

Centre for Integrated Biowaste Research

CIBR BIOSOLIDS MANAGEMENT VIRTUAL WORKSHOP 30TH MARCH 2020

Maria J. Gutierrez and CIBR Team

Our virtual biosolids workshop was attended by our whole CIBR team, three councils across NZ and two industry partners.

Last year, two workshops were held in Aotearoa – New Zealand (NZ) to improve the engagement and share knowledge and experiences among stakeholders of the biosolids industry [1]. The first workshop organized by WasteMINZ focused on industry was the first attempt to create a collective of biosolids stakeholders. During that workshop the participants started to draw a SWOT analysis about the biosolids management in NZ. A second workshop was held during the Water New Zealand Conference and Expo in Hamilton on the 18th of September 2019 [2], where CIBR members participated. Over 80 participants attended that second workshop which started with presentations explaining the challenges and potential of biosolids management in NZ, as well as some examples of successful beneficial reuse [3,4]. In the end of the session, all the participants openly discussed to extend the SWOT analysis that started in the first workshop. Building on those two workshops, on the 30th of March, the CIBR team met virtually with some councils and operators with the objective of identifying areas of research to enable the beneficial reuse of municipal biosolids that the CIBR team can contribute to in partnership with stakeholders.

> *Biosolids are sewage sludges or sewage sludges mixed with other materials that have been treated and/or stabilised to the extent that they are able to be safely and beneficially applied to land. Biosolids have significant fertilising and soil conditioning properties as a result of the nutrients and organic materials they contain. The term 'biosolids' does not therefore include untreated raw sewage sludges or sludges solely from industrial processes. Neither does it include animal manures, or food processing and abattoir wastes* [5].

The use of biosolids as a fertiliser and soil amendment for improving low fertility soils and degraded land is a common management option in many parts of the world [7–11]. However, 73 % of NZ produced biosolids are underutilized, landfilled or stockpiled [12] (Fig 1). Additionally, four WWTP discharge their sewage sludge into the ocean [12]. The current biosolids management is built on the "take, make and dispose" philosophy of a linear economy, wasting valuable resources. If we transform that amount of biosolids into value for their fertilizer potential, it means that NZ is not using more than $8.8M per year worth of nitrogen and phosphorous. Similar calculations for treated municipal wastewater reveal that about $49 million per year worth of nutrients and irrigation is disposed of in waterbodies. This is despite extensive research in NZ demonstrating beneficial reuse of biosolids [13–23], exemplars of reuse as fertilisers/soil conditioners, indigenous values that are consistent with land reuse [24], and guidelines for land application that minimise risks of application [5, 25]. One of the main reasons biosolids are disposed into landfills or the ocean-disposal is these are currently easy and cheap options, which makes it a default or business as usual option for most councils, particularly smaller councils that cannot afford investigating reuse alternatives. The economics of landfilling biosolids will soon change dramatically with the implementation of the Ministry for the Environment's proposed increase of landfill levy in 2023 [26]. The workshop discussions could be grouped into four main areas:

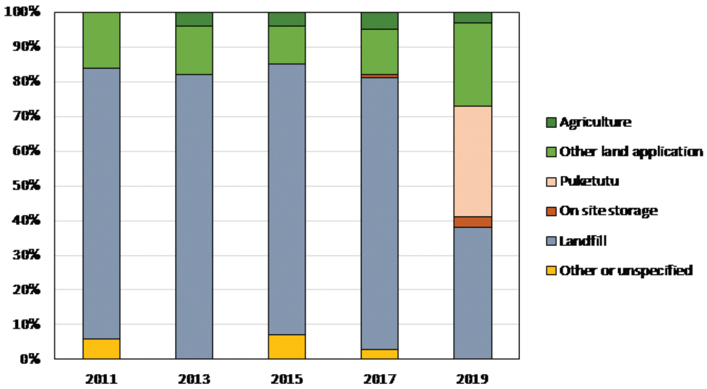

Figure 1. Biosolids enduse in NZ. Data of wastewater treatment plants serving over 25,000 people, which represents about 70% of NZ population (created with data from ANZBP [12]).

1. IMPROVE COMMUNICATION AND COLLABORATION BETWEEN DIFFERENT SECTORS WORKING WITH BIOSOLIDS

Participants in the workshop highlighted the importance of improving communications between councils, WWTP operators, industry, iwi and communities, which can lead to economies of scale, as well as regional and nationwide management strategies that will enable sustainable collaborative solutions, such as certification of products, or facilitate a more enabling regulatory landscape.

The LEI-led MfE-Waste Minimisation Fund project 'Collective Biosolids Strategy in Lower North Island' (see page 4 in this newsletter) intended to address a key challenge for small councils, which is lacking sufficient resources to investigate alternative uses of biosolids, so landfilling is their main option. This project highlighted the potential benefits and strengths of collaborating for developing regional strategies, which enable small councils to work together to provide economies of scale and opportunities for creating high quality biosolid-derived products and beneficially reusing them. This was one of the main results of this project.

This workshop also recognized the disconnection between councils and operators on one hand and researchers in NZ on the other hand. For example, councils and operators considered a barrier was lack of capacity or track record of applying biosolids onto land in NZ compared with other countries, and the need for knowledge specific to NZ. However, much research from the last two decades, including field trials, has demonstrated the advantages and multiple options for beneficially and safely reusing biosolids onto land, confirmed by numerous scientific publications (Figs 2 and 3, and [13–24], as well as popular articles, conference presentations, and newsletters from main industry associations (e.g. NZ Land Treatment Collective [27], Australia and NZ Biosolids Partnership [12], and Water NZ [28]).

Workshops have been an effective means of sharing experiences from both industry and research [1]. They have been a good platform for collectively and collaboratively discussing and analysing the bottle necks for biosolids re-use in NZ. Some of the successful examples discussed were the BioBoost story [3], where biosolids from New Plymouth are heat treated to high standards and sold as fertilizer in garden retailers, and the vermicomposting of biosolids from Taupo used to grow feed crops [4].

2. UNDERSTAND THE SOCIAL AND CULTURAL ISSUES RELATED TO REUSE OF BIOSOLIDS

A common concern expressed by council representatives and WWTP operators in these three recent workshops mentioned above was the negative public perception and cultural sensitivity associated with land application of biosolids in NZ, and the general "not in my backyard" attitude towards the beneficial reuse of biosolids.

Social and cultural drivers for the safe and sustainable reuse options for biosolids have been addressed by CIBR and LEI researchers in the Community Engagement Framework for Biowastes (CEF) [29] and From Tapu to Noa – Māori cultural views on biowastes management [24]. This research supports integrated decision planning to improve science, policy and community engagement for the management of biowastes that provides a pathway to meet the requirements of the Resource Management Act 1991, Local Government Act 2002 and the Treaty of Waitangi 1840.

Engaging with communities and iwi to listen and gain an understanding of these/their concerns, and their preferred treatment and end-use options for biosolids has the potential to improve any negative perceptions and reach an agreement. Addressing community issues much earlier in decision-making can result in cost and time savings, and ensures that services are delivered in a more effective and efficient way for a local community [29]. Linked to this is the need to identify local markets and options for biosolid re-use with local and regional communities so that safe and sustainable long-term local solutions are pursued. Such solutions will remove the need for long distance transportation of biosolids, as is currently the case for some Christchurch City Council and Selwyn District Council biosolids, which are being transported to the West Coast to rehabilitate mined land and degraded soil.

Generally, land application of biosolids that is not associated with agriculture and food production is better accepted by mana whenua, the public and regulators within NZ [30, 31]. However, applying biosolids to forestry or degraded soil can require long transport distances and/or techniques for safe application to slopes in hill country which poses limitations for biosolids application [32]. Hamilton, New Plymouth, Taupō and Tauranga are delivering products derived from biosolids acceptable for re-use as an alternative to chemical fertilisers in people's gardens and feed stock production.

Figure 2. Pot trial with cabbage tree and biosolids. From left to right: soil 1, soil 1 + Biosolids, soil 2, soil 2 + biosolids [19].

Figure 3. Mānuka roots foraging the patch of biosolids at right of the rhizobox [17].

Working with iwi and the broader community it may be possible to understand the appropriate pathways in processing of biosolids. A greater awareness and deeper understanding of social and cultural values and frameworks will help support more respectful and meaningful conversations about how to best design and manage local biosolids production systems and their impacts [24]. Frameworks to guide engagement with iwi and the wider community will support better long-term solutions and co-management approaches for enhanced environmental and biosolid management.

3. DEMONSTRATE THE BENEFITS OF BIOSOLIDS RATHER THAN JUST FOCUSING ON POTENTIAL RISKS

It was recognized that there could be value in establishing demonstration sites to provide real-world examples of beneficial use of biosolids or biosolids-derived products. Relevant demonstration plots exhibiting the benefits of biosolids or biosolid-derived products over fertilizers would provide visual real-world examples to farmers, growers, community and iwi (see page 3 as an example). Expanding on this approach, creating a toolbox of the different experimented options that have been implemented in NZ would highlight the associated benefits, drawbacks, and costs. Such a tool could assist engagement with iwi and communities and underpin decision making processes necessary to increase reuse of biosolids in Aotearoa-NZ. Both the toolbox and experimental demonstration plots would address the two previous concerns (improve communication between sectors and understand social and cultural issues) by improving the communication of science, assessing the benefits and drawbacks of biosolids, while providing real-world examples of beneficial reuse to communities, iwi and stakeholders.

4. IMPROVED UNDERSTANDING OF THE BIOPHYSICAL PROPERTIES OF BIOSOLIDS

The shape of future biosolids research in NZ was also discussed in the workshops. If the future focus of this research is assessing the safe and sustainable benefits of biosolids, further research assessing emerging risks will be expected by end-users and the community. A salient example of such emerging risks include new pathogens like SARS-Cov-2 (the virus of COVID-19), antimicrobial resistance, or new contaminants such as per-fluorinated chemicals, which have recently been the subject of much attention in NZ.

Understanding the variability of biosolids quality between different regions in NZ (urban versus rural), and the influence of different treatment processes, may help to the best options for safe and sustainable beneficial re-use. Current evidence suggests the most acceptable biosolid-derived products are produced from blending biosolids with other types of organic waste. Improving our understanding of what influences the quality of different base biosolids will help to optimise and streamline the production of "fit for purpose" blends for specific uses.

Finding new ways of reusing biosolids, or extracting specific components into products with higher value than just compost, will increase the incentives for reusing them and support a transition towards a circular economy. The recovery and reuse of resources in the treatment of wastewater and biosolids can provide nutrients (N, P, K), carbon, and energy (methane), among others. Closing the loop on non-reuse options (landfill) is a future opportunity for biosolids where its reuse is safe and sustainable (e.g. Terax TM [33]).

Another final potential research opportunity is associated with "carbon credits". Currently there is a significant knowledge gap with respect to the potential advantages and disadvantages associated with the production and emission of climate change gases, and carbon sequestration, resulting from landfilling versus land application of biosolids (which stimulates plant growth, especially in nutrient-stressed soils), and how to use biosolids to help mitigate climate change [34] and contribute to zero carbon emissions [35]. As NZ moves towards a future zero net-carbon economy there is a driver and opportunity to explore both the economic and ecological benefits of land filling versus land application and other re-use options of biosolids.

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ECOTOX NEWS UP-DATE

Grant Northcott and Louis Tremblay

Grant Northcott and Louis Tremblay participated to a workshop coordinated by Geoffroy Lamarche (Chief Adviser Science) and Bella Whittle (Senior Advisor) from the Parliamentary Commissioner for the Environment (PCE) office. There were 20 participants with expertise in environmental chemistry, ecotoxicology, ecology and regulations that contributed to identify representative chemical contaminants with potential environmental risk to New Zealand. This was part of a wide-scope PCE investigation, to identify a short list of representative chemical contaminants that would best enable a discussion on their different physical pathways, effects in the environment and current regulatory settings including those under the Hazardous Substances and New Organisms Act (HSNO) and the Resource Management Act (RMA).

A NEW PHD CANDIDATE JOINED THE ECOTOX TEAM

My name is Camille Baettig, I am a first year PhD student at the University of Auckland and a recent addition to Dr. Louis Tremblay's ecotoxicology lab at the Cawthron Institute. I completed my BSc in ecology and evolution at the University of California, Santa Cruz. There I worked as a volunteer lab assistant in Dr. Rita Mehta's comparative vertebrate anatomy lab where I developed an undergraduate research project investigating the feeding kinematics of the sarcastic fringehead (*Neoclinus blanchardi*). My project resulted in a poster that I presented at the Society for Integrative and Comparative Biology in San Francisco, CA (2013). In addition to laboratory experience, I worked as Dr. Mehta's field technician at the USC Wrigley Institute for Environmental Studies on Catalina Island, CA for five years (Summer 2012–16). As part of a long-term study trapping and tagging California moray eels (*Gymnothorax mordax*), I anesthetized specimens, took morphological measurements, PIT-tagged specimens, operated small boats as well as managed a team of students. My MSc was completed at Ludwig Maximilians University of Munich where I spent 1.5 years gaining experience in Prof. Dr. Herwig Stibor's aquatic ecology lab. As part of a long-term monitoring project with the Bavarian Government, I was investigating the effects of nutrients and zooplankton composition on the size and abundance of lake whitefish (*Coregonus sp.*) with smaller mesocosm experiments to validate whether species zooplankton abundance or species composition was the limiting factor on larval fish growth.

For my PhD, I will assess whether emerging organic contaminants (EOCs) pose a risk to New Zealand's unique aquatic ecosystems. Research conducted thus far demonstrated that various EOCs are detectable in New Zealand (aquatic) ecosystems and concentrations are found to be similar to what is reported overseas. Within my PhD project, I will focus on three chemicals corresponding to main families of pollutants and I will test the hypothesis whether these chemicals can alter the modulation of gene expression patterns at concentrations commonly found in the New Zealand freshwater and coastal environments. I will use the common bully (*Gobiomorphus cotidianus*) and the triplefin (*Forsterygion capito*) as bioindicators of environmental health for New Zealand freshwater and coastal aquatic ecosystems, respectively. My project will consist of both field-based and laboratory experiments. The information of expression patterns should contribute to the establishment of adverse outcome pathways specific to native fish species and could be tested against other species. The overall outcome of this project will provide important information and knowledge to better characterize the impacts of EOCs on unique New Zealand aquatic ecosystems.

UPDATES FROM MĀNUKA-DOMINATED ECOSYSTEM RESEARCH AT LAKE WAIRARAPA

Maria J. Gutierrez, Izzie Alderton and Kristin Bohm

Figure 1. People who attended the Hui at Masterton. From left to right: Kristin Bohm (ESR), Ra Smith (Ngāti Kahungunu ki Wairarapa), Maria J. Gutierrez-Gines (ESR) holding her Science Award, Sky Halford (ESR, Victoria University), Kolja Schaller (GRWC).

HUI AT MASTERTON

On 12 November 2019, Greater Wellington Regional Council (GWRC) invited Ngāti Kahungunu ki Wairarapa and ESR (Maria J. Gutierrez-Gines, Richard Dean and Kristin Bohm) for a hui in Masterton. One component of the hui was Sky Halfords presentation of her master's thesis "An ecosystem service perspective of Lake Wairarapa: Insights from the past, present and toward the future" which she accomplished with Maria as a co-supervisor. Sky gave a nice overview about the different parts of her thesis. For example, she performed paleo-environmental reconstruction by analysing lake sediments and could show how human activity (removal of mānuka -dominated native forest around the lake and farming intensification) affected ecosystem service effectiveness of the lake that led to a transition into an entirely new environmental state at Lake Wairarapa. Furthermore, Sky presented the results of her small-scale field trial using mānuka which is part of a riparian planting established earlier by CIBR in cooperation with GWRC (CIBR Newsletter issue 17 - Feb 2018, https://www.cibr.org.nz/assets/CIBR/Reports-papers/Newsletters/Feb-2018_Issue-17.pdf). She treated mānuka or livestock-excluded pasture (as control) with a solution of urea and *E. coli* to assess the ability of mānuka to reduce nitrogen leaching and *E. coli* spread in soil. Results indicated that the mānuka seedlings significantly reduced conversion of ammonium to nitrate that can be potentially linked to a decrease in nitrogen leaching.

After Sky's presentation, the group moved on to talk about the future of the established field trials and explore different paths to collaborate.

FIELD SITE AT WAIRARAPA

After the hui on 12 November 2019, the ESR team visited one of our experimental plots. At this field site, which was established in 2018, approx. 650 trees were planted in experimental 6 plots supported by GWRC and Ngati Kahungunu ki Wairarapa (Figures 2 and 3). After initial establishment no further treatment was given to the weeds.

Since beginning of November, the farmer begun irrigation of his paddocks including the experimental plot with water drawn from the lake. Irrigation of the plot had led to increased growth of the pasture, overtaking our natives. Finding the planted trees was like an Easter

Figure 2. Location of the field site, indicated by "Mānuka Trial Area – Phase 2".

egg hunt! However, on closer inspection we found many plants happily growing and flowering such as mānuka (Figure 4).

An intensive monitoring of plant survival was performed on 10 January 2020. Due to the hot, dry summer the pasture had turned brown (Figure 5). The pasture was above 110 cm high while height of planted trees that survived ranged from 55 to 75 cm for mānuka, kānuka, horopito, black beech and matai and 90 to 105 cm for cabbage tree and flax, respectively.

Overall, survival rates for mānuka, cabbage tree and flax were highest (Figure 6). Hence, for some of the planted trees the pasture might function as shelter to withstand usual strong winds. This would suggest that a cost-effective and environmentally friendly way to manage native planting is to promote pasture growth, eliminating growth of other weeds and giving shelter to planted tree seedlings. However, the survival rate for rātā tree, black beech and matai was very low indicating that those trees were not able to cope with local climate, soil conditions and/ or increased pasture coverage (Figure 6).

Most mānuka and some kānuka carried seeds. Furthermore, comparing the results of last plant monitoring performed in March 2019, it seemed that height increase for mānuka was strongest for first three plots when growing in a mixture with five other native trees (native tree mixture 1), or alone 1 m or 2 m apart (Figure 6). This trend might be correlated with an apparent decline in soil moisture from plot 1 (native tree mixture 1) to plot 6 as the irrigation system did not cover those plots.

Future research at the experimental field sites at Lake Wairarapa will be intensified on data collection belowground to monitoring fluxes of water and nutrients in soil.

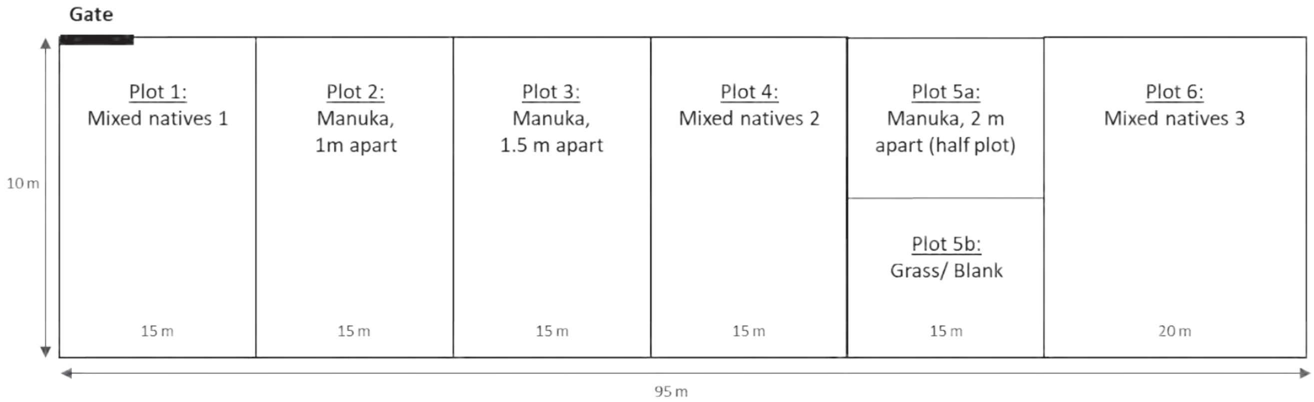

Figure 3. Planting scheme of experimental field site ("Mānuka Trial Area – Phase 2"). Mixed natives 1: mānuka, kānuka, black beech, northern rātā, horopito, and matai; Mixed natives 2: mānuka and kānuka; Mixed native 3: mānuka, flax, and cabbage tree.

Figure 4. Experimental plot with knee-high pasture and happily growing mānuka in between, 12th November 2019.

Figure 5. Plant monitoring at one of the field sites at lake Wairarapa on 10 January 2020. Inset: Izzie Alderton measures height of one of the planted flax trees.

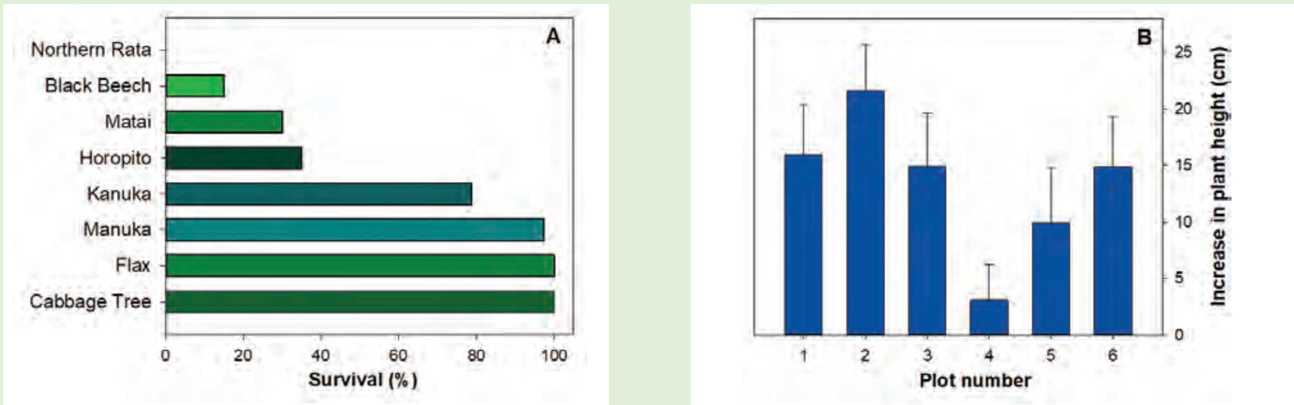

Figure 6. Survival rate (A) of natives planted in May 2018 and increase in height of mānuka (B) planted per plot measured in January 2020. Survival rate was calculated according to number of initially planted trees in 2018. Increase in plant height of mānuka was calculated as difference from plant heights measured in March 2019. Plot 1: mixed natives 1 (mānuka, kānuka, black beech, rātā tree, horopito and matai); Plot 2: mānuka 1m apart; Plot 3: mānuka 1.5 m apart; Plot 4: mixed natives 2 (mānuka and kānuka); Plot 5: mānuka 2 m apart; Plot 6: mixed natives 3 (mānuka, flax and cabbage tree).

N-LEACHING UNDER MĀNUKA: TIHOI LYSIMETER STUDY

Robyn Simcock and Jo Cavanagh

INTRODUCTION

Nitrogen leaching from root zones can degrade surface- and groundwater in farmed areas. In highly-N-sensitive areas, such as the Lake Taupō catchment, significant areas of grazed pasture are being retired and planted in mānuka to generate income from mānuka honey and as a low-nitrogen-leaching land use. Nationally, such planting is mainly restricted to riparian areas adjacent to grazed paddocks, but there is also interest in grazing within low-density mānuka (ca. 1000–1200 stems/ha) as mānuka is not palatable to most stock. Once established, grazing can be managed to minimise damage to mānuka (along with kānuka and totara) and this approach could augment honey production while also enhancing stability of areas vulnerable to shallow erosion. In such areas, the reduction in nitrogen leaching is currently linked to pasture 'retirement', i.e. removal of grazing stock and any fertiliser applications.

Nitrogen is important for healthy plants as it is major component of chlorophyll and proteins; leaves contain more nitrogen than any other nutrient; typically 1 to 4% w/w. Plant roots influence soil nitrogen levels by extracting nitrogen from the soil (mostly as NO_3-), however, some plants may also affect soil nitrogen by influencing soil microbial activity as nitrification by autotrophic bacteria is the primary way NO_3- is produced in most studied ecosystems (Ross et al 2009). Recent in vitro, and lysimeter studies have shown mānuka root extracts and roots inhibit nitrification processes in soil, potentially reducing NO_3- (Downward, 2013, Esperschuetz et al., 2017), thereby potentially enhancing protection of surface- and groundwater. Further, trials in rhizoboxes have shown mānuka roots preferentially seek such enriched areas (Reis et al., 2017; Gutiérrez-Ginés et al., 2019) so might 'target' subsurface urine patches. Mānuka root extracts have also been found to inhibit harmful bacteria *Escherichia coli* and *Salmonella sp*. (Prosser et al., 2014).

This article reports the effect of mānuka planting (with simulated grazing) on nitrogen leaching, compared with pasture, in a lysimeter trial established on part of a working pastoral farm about 6 km south-east of Tihoi in the Taupō Lake Catchment.

METHODS

Large lysimeters (1.5 m deep and 0.9 m diameter) were cut into a Typic Orthic Pumice Soil (Figure 1). After the lysimeters were collected, and placed into the facility, all lysimeters were irrigated to prevent any cattle urine that was already entrained in the lysimeters influencing results. The pasture was sprayed with glyphosate and once the pasture was dead, soils in all lysimeters were ripped to 50 cm depth and cultivated to 15 cm depth, simulating the process for renovating pasture or establishing a crop. Plants were established in each lysimeter in November; ryegrass by seed (2.8 g m^{-2}) with crop-specific fertiliser application and mānuka, using 7 nursery-grown seedlings per lysimeter, equivalent to about 110,000 stems/ha. This high density was selected to achieve a high mānuka cover within the life of the experiment. Thereafter, a single, annual application of cow urine was applied to each lysimeter in autumn (mid-April) to enable comparison of the movement of a concentrated nitrogen pulse through each lysimeter at the time of the year when leaching is highest. Figure 2 shows the planted lysimeter facility.

Figure 2. Lysimeter setup as installed, with mānuka on right hand side (2018).

Table 1. Total N in cow urine and loading rate applied to lysimeters in each year: 1, 2 and 3.

	Total N in cow urine (g L^{-1})	Loading rate of cow urine (kg N ha^{-1})
Year 1	5.89	515
Year 2	7.05	617
Year 3	5.73	501

From January 2017, until completion of the experiment in November 2019, leachate was collected from the base of each lysimeter, piped to a central underground facility and captured in 80 L collection barrels. Depending on leachate volume, but at approximately monthly intervals, leachate volume was measured, and a sub-sample analysed for Total N, ammonium N (NH_4-N) and nitrate-N + nitrite-N (NO_x-N). Only total N results are presented here (Table 1 and 3) because nitrate was the dominant form of nitrogen leached in all leachate samples; ammonium was often below the detection limit.

Figure 1. Collecting undisturbed soil lysimeters in a nearby paddock. Note the pale, pumiceous soil material overlying the darker, finer ash and unused rejected areas that had large holes in the subsoil.

RESULTS AND CONCLUSION

Rainfall varied between years, influencing leachate volumes (Table 2). Beyond the first year, leachate volume from mānuka was less than that for pasture. This was probably due to differences in leaf cover and density. Pasture had high cover in the first year but by the third year mānuka developed a much taller, dense canopy which resulted in greater interception of rainfall. However, the average annual nitrogen concentration in the leachate from mānuka was consistently higher than for pasture in all three years (Table 2). This leads to a higher total N-leaching from mānuka (Figure 3), although this difference diminishes with time as the mānuka grows. The markedly higher leaching that occurred in the first year is attributed to three factors: (1) residual fertiliser in potting mix of the planted mānuka, (2) additional cultivation effects associated with the planting of the seedlings – as compared to sowing of ryegrass seeds, and (3) a longer lag in time for full root exploration (and uptake) by the very small mānuka in the year of establishment compared to the pasture. The markedly higher

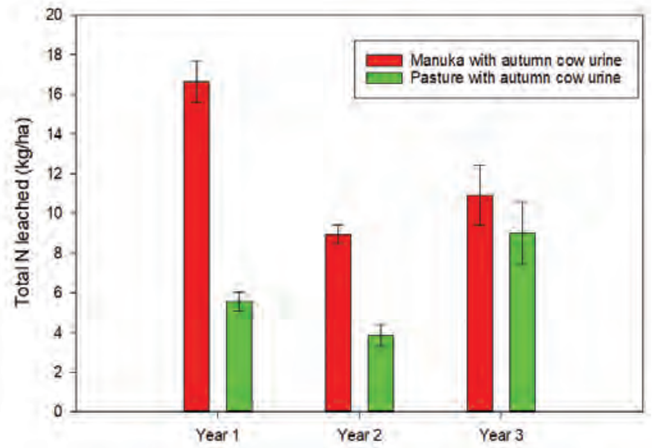

Figure 3. Estimate of total N leached per grazed paddock assuming 20% coverage of cow urine spots per year, for mānuka and grass established at the same time, using blanket herbicide and cultivation.

Figure 4. Above: aerial view of the lysimeter site at Tihoi, 2018. Mānuka lysimeters and guard crop are to the right of the compound adjacent to the shed; lucerne lysimeters and guard crops are generally adjacent to the mānuka. The collecting facility is at the centre. Right: rooting pattern of ryegrass/pasture in a nearby paddock showing the young pumice layer overlying the darker, finer allophanic material at about 90 cm depth.

N-concentration in the leachate from mānuka was surprising, given previous studies showing lower leaching under mānuka (Esperschuetz et al., 2017). However, these previous studies had used biowastes with a high proportion of organic-bound nitrogen (e.g., sewage sludge or dairy shed effluent), and/or markedly lower application rates (e.g. 50–150 kg N/ha compared with 500 kg N/ha in this study). Organic bound-N needs to be mineralised to NOx before nitrogen can be leached or taken up by plants, resulting in a 'flattened' pulse of NOx in leachate. In contrast, nitrogen in cow urine is predominantly present as ammonium (NH_4^+) which is converted by soil bacteria to NOx.

Table 2. Total leachate volume from grass and mānuka lysimeters and rainfall.

Total leachate	Mānuka		Pasture		Rainfall
(L)	Average	SD	Average	SD	(mm)
Year 1	771	21	717	51	1720
Year 2	309	42	383	30	1145
Year 3	176	35	288	73	860
Total	1256	88	1388	136	3725

Table 3. Nitrogen concentration in leachates from grass and mānuka lysimeters (average and standard deviation, SD).

Total N concentration	Mānuka		Pasture	
(mg/L)	Average	SD	Average	SD
Year 1	139	28	50	10
Year 2	84	17	40	8
Year 3	127	25	76	15

Overall, nitrogen leaching under mānuka is controlled by:

- The volume of leachate, which for mānuka is expected to reduce over time compared to pasture, because as mānuka grows it is taller and has higher rainfall interception than pasture therefore less rain enters the soil. Mānuka is also likely to root more deeply than pasture, providing a deeper zone (greater opportunity) from which to extract nitrate.
- The nitrogen concentration of that leachate, which is influenced by soil microbial processes and plant uptake or release. In this experiment a drought resulted in pasture dying back. The death and decomposition of roots following the drought probably contributed to the increased nitrogen leached from pasture in the final year.
- The form, total amount, and distribution of nitrogen applied to the soil. Cow urine is much more readily leached than forms of N with a significant organic component, such as biosolids or dairy shed effluent. Further, it is deposited all at one time in concentrated patches (500 to 1000 kg/ha), rather than irrigated at lower (e.g. 50 kg/ha) N loadings.

Thus, further research is required to understand the processes resulting in the elevated nitrogen concentration in leachate under mānuka grazed by cattle, and the impact of increasing mānuka canopy, to determine under what conditions reduced nitrogen leaching does occur.

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REPEATED APPLICATIONS OF BIOSOLIDS HAD NO SIGNIFICANT IMPACT ON RESIDUAL PFAS (PER- AND POLY-FLUOROALKYL SUBSTANCES) LEVELS IN THE TOP SOIL AT RABBIT ISLAND

Dr Jianming Xue

LAND APPLICATION OF BIOSOLIDS

The usef of biosolids as a fertiliser and soil amendment for improvement of low fertility soils, and reclamation of degraded land, is common in many parts of the world. Land application of biosolids can enhance carbon (C) sequestration in soils, provide nutrients to plants, and improve overall soil fertility.

In New Zealand, application of biosolids onto forest land is often preferred over agricultural application. Forests are typically planted on low fertility or degraded soils where biosolids can measurably increase tree growth and subsequent economic returns without risk of contaminants entering the human food chain. Despite this, it is still essential to closely monitor the quality of soil receiving biosolid application to ensure thresholds for contamination of heavy metals and other potentially toxic compounds.

EMERGING ORGANIC CONTAMINANTS IN BIOSOLIDS

Research on organic contaminants (OC's) in biosolids has been undertaken worldwide for over thirty years. The body of evidence demonstrates that most compounds studied do not place human health at risk when biosolids are recycled to farmland (Clarke and Smith, 2011). The Ecotox Team in CIBR has been studying the impact of these contaminants in NZ for over two decades (Stewart et al, 2016, Stewart and Tremblay, 2020). However, there are 143,000 chemicals registered in the European Union for industrial use, all of which could be potentially be found in biosolids. The risk profile of OC's (the range of potential compounds, with unique chemistries, lack of empirical knowledge on their immediate and long-term persistence and toxicology) is immense, and this is causing significant uncertainty to the ongoing use of biosolid application. Currently, CIBR is undertaking a MBIE research programme to identify which contaminants are predominant nowadays in our aquatic environments and their risk (Tremblay, 2018). There has been recent prioritisation of research needs and monitoring of emerging organic contaminants (EOCs) for soils receiving biosolids (Clarke and Smith, 2011; Rigby et al., 2015). Give the importance of this issue, considerable efforts have been made to prioritise ecotoxicological investigation of EOCs based on the risk profile and potential for human impact (Clarke and Smith, 2011).

The identified chemicals of concern are ranked in decreasing order of priority (reference):

(1) perfluorinated chemicals (e.g. PFOS, PFOA)
(2) polychlorinated alkanes (PCAs), polychlorinated naphthalenes (PCNs)
(3) organotins (OTs), polybrominated diphenyl ethers (PBDEs), triclosan (TCS), triclocarban (TCC);
(4) benzothiazoles;
(5) antibiotics and pharmaceuticals;
(6) synthetic musks;
(7) bisphenol A, quaternary ammonium compounds (QACs), steroids;
(8) phthalate acid esters (PAEs) and polydimethylsiloxanes (PDMSs).

In Aoteaora, CIBR has also undertaken a similar assessment, and now there is a new list of priority and indicator EOCs that will have to be monitored in biosolids if these are aimed to be applied to land (Table 1, WaterNZ, 2017).

ENVIRONMENTAL CONTAMINATION WITH PER- AND POLY-FLUOROALKYL SUBSTANCES

There has been increasing media attention in New Zealand on per- and poly-fluoroalkyl substances (PFAS) contamination in soil and groundwater systems, as well as in biosolids, as it was highlighted in the last Biosolids Conference organized by the Australia and New Zealand Biosolids Partnership celebrated in Brisbane in 2019 (Seberry et al. 2019). Currently, there are no data for PFAS levels in NZ biosolids. But CIBR is now assessing their inclusion in the Draft Organic Materials Guidelines (WaterNZ, 2017). PFAS are a class of manufactured chemicals that have been used since the 1950s to make products that resist heat, stains, grease and water. There are over 6,000 individual PFAS identified to date. Of these, two are commonly referred to as high risk: perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA).

Table 1: List of EOCs that will be required to be monitored if biosolids or organic materials intended to be used in land, and concentration limit (mg/kg dry weight) (Water NZ, 2017)

Emerging Organic Contaminant	Concentration Limit (mg/kg)
Nonyl phenol and ethoxylates (NP/NPE) *Comprising the sum of technical nonylphenol, NPE10 and NPE20 equivalents*	50
Phthalate (DEHP)	100
Linear alkydbenzene sulphonates (LAS) *Comprising the sum of technical C11-C13 homologues and corresponding mixtures of isomers*	2600
Musks – Tonalide	15
Musks – Galaxolid	50

Perhaps the most prominent application of PFAS are those used in Class B firefighting foams (Fig. 1). The historic use of PFAS-containing firefighting foams has resulted in the areas becoming contaminated with PFOS and PFOA. Over the past five decades, these chemicals have worked their way through the soil to contaminate surface and ground water (Fig. 2) and have also migrated into adjoining land areas. In addition, PFAS have had many uses in common household and industrial applications. These include stain resistant applications for furniture and carpets, fast food or packaged food containers, make up, personal care products and cleaning products. The biggest environmental concern about PFOS and PFOA is that they do not breakdown in the environment and accumulate over time and can travel long distances in water and air currents. There is evidence that exposure to PFAS can lead to adverse human health effects (Fig. 3). Now, PFOS and PFOA have become widespread global contaminants and many countries are now monitoring and restricting their use.

HOW DO PFAS COMPOUNDS GET INTO BIOSOLIDS?

PFAS may enter the environment via several point and nonpoint sources including domestic, commercial and industrial activities, wastewater treatment plants (WWTPs), and other similar points of origin. To date, many studies have reported the detection of PFAS in influent, effluent and sludge at WWTPs. Typical wastewater treatment processes do not remove PFAS compounds and, consequently, PFOS-containing wastewater was discharged to the municipal treatment plant. WWTPs can therefore be considered as one of the hot spots of pollution, as their significant contribution towards environmental contamination with PFAS.

Figure 1. The source of environmental contamination with PFAS (Source: United States Environmental Protection Agency).

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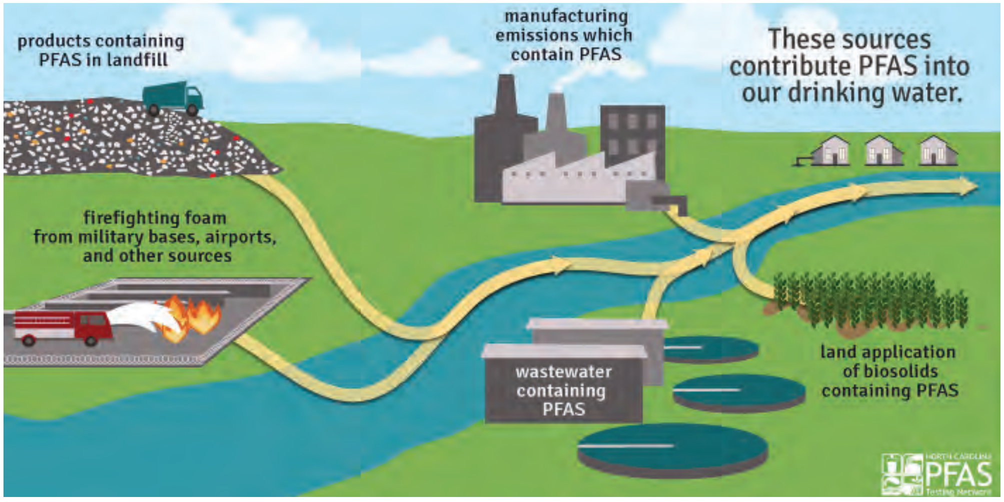

Figure 2. Sources of PFAS in drinking water (Source: North Carolina PFAS Testing Network).

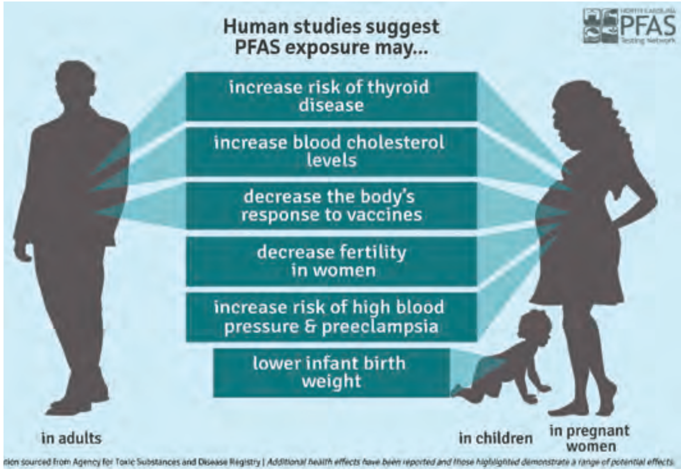

Figure 3. Adverse effects of PFAS on human health (Source: North Carolina PFAS Testing Network).

Various contamination levels have been observed in effluent samples collected from WWTPs located in different cities or countries, with PFOS and PFOA concentrations ranging from <0.06 to 461.7 ng/L, and from <0.5 to 1057.1 ng/L, respectively (Guo et al., 2010; Ahrens et al., 2009; Yu et al., 2009; Lin et al., 2010). It has been reported that the fates of perfluoroalkyl compounds in the WWTPs were related with the functional groups. The PFOS concentrations tended to decrease after treatment in most WWTPs, whereas PFOA increased. The different fates of PFOA and PFOS in WWTPs were attributed to the higher organic carbon-normalized distribution coefficient of PFAS compounds than that of the carboxylate analogue, indicating the preference of PFAS to partition to sludge. It appears that concentrations of PFAS in samples from WWTPs vary significantly with sources of influent and wastewater treatment techniques. The discharge of effluent waste, either as liquid or treated biosolid material may therefore lead to a distribution of PFAS in the environment, especially in groundwater (Fig. 4).

FOREST LAND APPLICATION OF BIOSOLIDS AT RABBIT ISLAND

Class A biosolids, obtained through auto thermal thermophilic aerobic digestion (ATAD), have been applied to a 1000-ha Pinus radiata D. Don forest plantation at Rabbit Island near Nelson City since 1996. Repeated applications to individual forest stands within the plantation have been made approximately every 3 years (Xue et al., 2015).

A research trial was established on the site in 1997 to investigate the ecological and environmental impacts of long-term application of biosolids on pine plantation forests. Tree growth and nutrition have been monitored, along with environmental variables such as soil and groundwater quality. To date, the experimental results of biosolids application to Rabbit Island indicate a low level of risk for tree crops (Xue et al., 2015). However, little is known about the ecological impacts of non-regulated contaminants (e.g. PFOS, PFOA, triclosan, antibiotics) found in biosolids.

Despite the increasing quantities of organic wastes being applied to land, there are few studies that assess the ecotoxicological risks of this practice. Investigation of the long-term effects of biosolids on the accumulation of PFAS in the soil will lead to a better understanding of ecosystem-level effects and the sustainability of long-term application of biosolids to land.

The objective of this study was to investigate the accumulation of PFAS in the top soil after long-term repeated biosolids application onto poor-quality plantation forest soil at Rabbit Island.

EFFECT OF BIOSOLIDS APPLICATION ON ACCUMULATION OF PFOS AND PFOA IN THE TOP SOIL AT RABBIT ISLAND

The levels of PFAS compounds were negligible (i.e. below the Limit of Reporting (LOR) for PFAS compounds) in any of 12 soil samples collected. These results indicate that the long-term repeated applications of biosolids didn't cause any accumulation of PFOS and PFOA in the top soil (Table 2). In consideration of high permeability of the soil at Rabbit Island, however, we can't totally exclude that leaching of these two perfluorochemicals has occurred into the subsoil or groundwater. This needs to be further verified by analysing the PFAS concentrations in the subsoils and groundwater in the future.

Table 2. Concentrations of PFOS and PFOA (µg/g dry weight) in the soil.

Treatment (kg N/ha)	Total PFOS	PFOA
0	<0.0010 a	<0.0010 a
300	<0.0010 a	<0.0010 a
600	<0.0010 a	<0.0010 a

Total PFOS = The numerical sum of di-PFOS, mono-PFOS, and L-PFOS
di-PFOS: Total perfluorodimethylhexane sulfonic acids
mono-PFOS: Total perfluoromethylheptane sulfonic acids
L-PFOS: Linear perfluorooctanesulfonic acid
PFOA: Perfluoro-n-octanoic acid

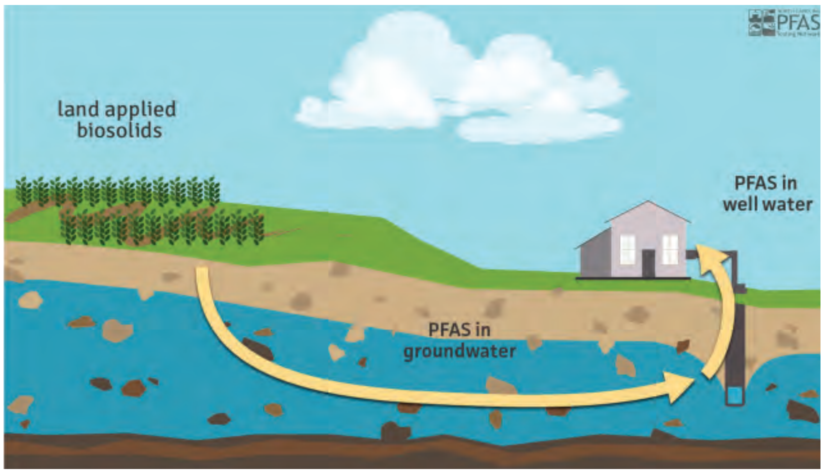

Figure 4. Potential PFAS contamination of groundwater related to land application of biosolids (Source: North Carolina PFAS Testing Network).

Many studies have reported PFAS levels in agricultural soils following the land application of municipal biosolids (e.g. Sepulvado et al., 2011), WWTP and landfills as sources of PFAS to the atmosphere (e.g. Ahrens et al., 2011), and contamination of PFAS in surface and well water resulting from application of WWTP biosolids (Lindstrom et al., 2011). Sepulvado et al. (2011) first reported levels of two perfluorochemicals (PFCs) in agricultural soils amended with typical municipal biosolids and found that PFOS was the dominant PFCs in both biosolids (80-219 ng/g) and biosolids-amended soil (2-483 ng/g). Concentrations of all PFOS and PFOA in soil increased linearly with increasing biosolids loading rate.

The findings from this study is different from the previous studies above. We assume the PFAS concentrations in the biosolids from the WWTP at Bell Island, Nelson are much lower due no significant industrial inputs of PFAS compounds into the waste stream. However, this needs to be confirmed by further testing PFAS levels in the biosolids.

CONCLUSION

This study has found no evidence for long-term repeated applications of biosolids to result in accumulation of PFOS and PFOA in the surface soil (0–25 cm) at Rabbit Island.

It is important to note that deeper soils and groundwater were not tested in this study. Although unlikely, we cannot totally exclude potential leaching of these two perfluorochemicals to the subsoil or to groundwater.

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FOUR YEARS CIBR RESEARCH WITH TE PĀ O RĀKAIHAUTŪ

Alan Leckie, Lisa Langer, Jamie Ataria, Joanna Goven, Jinny Baker

From left to right: The Social and Cultural Team with Jacqui Horswell (Former Programme Manager CIBR, now MPI), Alan Leckie, Lisa Langer, Jamie Ataria, Jacqui Horswell, Jinny Baker.

Te Pā o Rākaihautū (Te Pā) is a designated special character school based in Ōtautahi/Christchurch that is committed to educational success by capturing the whole whānau in the education experience. Underpinning this philosophy is the pā wānanga, or learning village that encompasses early childhood, primary and secondary schooling to sub-degree tertiary education. Te Pā also strives to implement environmental sustainability through their unique kaitiakitanga perspective that incorporates local-cultural narratives, concepts and language.

The CIBR Social and Cultural team of five researchers have had a positive working relationship with the pā wānanga since it opened in 2015 and it has been the focus of their social and cultural research for the last four years. Team members have been involved in a collaborative research at Te Pā that has involved participation in Te Tautarinui o Matariki (Board of Trustees) meetings, interviews, mahi (work), manning stands at two Te Pā gala days, celebrations, prize giving ceremonies, and with on-going research kōrero (discussion). This article looks back over these years and documents some of the activities that have defined the special relationship that has developed.

TE PĀ O RĀKAIHAUTŪ

Te Pā, as it is more commonly known, set out to redefine how, where and when the best learning happens for their whanau using a pā wānanga approach. To quote the vision of the pā wānanga "Te Pā does this by restoring culture, connection and identity as a foundation to educational success; reconnecting our whanau with place, our communities; our whakapapa and our stories; reigniting a passion for learning; and pushing the reset button on Māori educational achievement." (https://hail.to/rakaihautu/publication/UOTqgq0/article/IaQKGoA). Kaitiakitanga or guardianship around environmental sustainability is a Māori worldview expressed and defined by their beliefs at Te Pā. Cultural sustainability ethos is practiced, and this forms a part of Te Pā's management of organic wastes and environmental education.

GOING BACK TO 'SCHOOL' – INITIAL ENGAGEMENT

In July 2016, the CIBR Social and cultural team was invited to Te Pā to obtain an overview of its concepts of environmental education. The purpose was to assess whether assisting Te Pā to document and develop thinking and tools that they could use to collect data and information. The team looked over the whole pa wānanga and took part in a discussion on the educational and environmental principles that they provide in terms of early childhood education. A follow-up meeting was held with Board of Trustees who stated that they want "better data – this is the key".

CONTRIBUTION TO TE PĀ ACTIVITIES

This research relationship is also predicated on a 'kanohi ki te kanohi' (the seen face) approach where the whole team has engaged and has been active on-site involving themselves in numerous aspects of Te Pā life. Activities outside of the research included taking part in an ohu or working bee at Te Pā alongside many whānau from Te Pā. There we participated and collectively dug, mulched and prepared the māra kai (veggie garden) and erected a whare whakaata (greenhouse). The pononga (students) sowed seeds in preparation for spring planting. This kai (food) supplements other food that goes into prepared and healthy breakfasts and lunches where only healthy kai is supplied and sugar banned.

The production of kai and the composting of green and other carbon wastes underpins a 'closing the loop' ethic which is very important to the future of place-based learning which has become part of Te Pā's identity and cultures. Students see that the buildings and grounds of their pa wānanga are their place and care for them accordingly.

CO-CREATED RESEARCH FOCUS

After discussions, a number of complementary social and cultural research areas have been found. These are the development of eco-friendly cleaners, organic waste recycling, kaitiakitanga or sustainable guardianship and exploring the Te Pā model.

ECOFRIENDLY CLEANING PRODUCTS

Staff at Te Pā are interested in the impact of the use of cleaning products on young children and teenagers. These included cleaning of classrooms, whare paku (toilets/washrooms), and the kīhini (kitchen) and whare kai (dining room). The focus on food preparation and cleaning of the māra kai led staff to restrict current chemical-based cleaning products where kai was prepared and eaten and where plates, cups and utensils are cleaned and stored.

The pā wānanga moved away mainstream school cleaning products and changed their cleaning contract to one that only uses Environmental Choice NZ approved cleaning products. Using knowledge and with approval of the kaitunu kai (chef), Te Pā developed an eco-friendly cleaner using safe, natural products and non-toxic ingredients. Citrus peels from on-site school lunches were a part of the cleaner. ESR CIBR microbiologists have tested the efficacy of the cleaning products in both the māra kai and the whare kai under strict protocols (https://www.cibr.org.nz/assets/CIBR/Reports-papers/Newsletters/Biowaste-News_June-2019.pdf, page 4).

VERMICOMPOSTING AND INVOLVEMENT IN TE PĀ GALA DAY

Engagement with staff in the whare kai (kitchen), cleaning and janitor staff in discussions assisted in initiating a vermicomposting system to augment the current open-air composting of organic wastes from the kitchen.

A series of one-on-one questionnaires were conducted with key non-teaching staff highlighting organic kitchen waste, paper recycling and waste reduction options. Suggested opportunities were: a shredder/chipper to make a compostable mulch, reuse of paper, better food preparation management to bring food waste down to zero, and the use of eco-friendly cleaning products in the pa wānanga.

A novel circular bio-economy approach to vermicomposting was developed by Jamie Ataria, inspired by the Large Hadron Collider in Switzerland. Aptly named, the WERM (Waste Elimination and Recycling Mihini) was a talking point at the Kai Hua Kai Gala Day in terms of how best to recycle daily organic kitchen and paper waste by vermicomposting. Vermicomposted wastes are returned to the māra kai as organic based fertilisers, form the basis to making Te Pā more sustainable and have become an important learning beyond the Te Pā gate.

Also, on sale at the Gala Day and supported by CIBR staff, were about 150 individual seedlings grown on site in recyclable pots made from both recycled newspaper and writing/printing paper by Te Pā staff and pononga.

THE TE PĀ MODEL

Over the last two years the Social and cultural research team have focused on how the Te Pā model has developed over the years in their educational success of teaching whānau, from early childhood, primary and secondary schooling to tertiary education.

One-on-one interviews with a range of Board of Trustees and staff at Te Pā were undertaken in December 2018 and January 2019. The 15 semi-structured interviews covered the same set of questions and transcribed interview conversations have been analysed using a software package called Dedoose. Although interviews are a snapshot in time, they are providing both the CIBR research team and the Board of Trustees with vital data on the development of pedagogical tools to enable Māori placed-based education, based on sustainability to develop into the future. The concept of kanohi ki te kanohi (face to face) is critical to a number of Māori cultural constructs. The relationship between Te Pā staff and pononga is built on knowledge, presence and trust.

Initial feedback has commenced with the Board of Trustees using video conferencing during the COVID-19 lockdown. We hope to feedback and discuss results around the Te Pā model, how it is working, any barriers and enablers or issues and how successful the research on the Te Pā model has been with the Board of Trustees and interviewed staff as soon as the lifted lockdown allows.

APPLICATION FOR MARSDEN FUNDED RESEARCH

In December 2017, CIBR's Social & Cultural team, University of Canterbury Māori Research and Te Pā received scoping research funding from Ngā Pae o Te Māramtanga (Centre of Research Excellence) to develop a Marsden Fund application and to explore research opportunities with the National Science Challenge. Subsequently a Marsden Application led by Dr Richard Manning, Prof. Angus Macfarlane and Mārie McCarthy in collaboration with the Social and cultural team was lodged. The application was well received

with positive feedback and passed successfully through the first round. Unfortunately, the submission of the full application was not successful, but a revised application is being considered when the Marsden funding round opens later this year.

CONCLUSION – THE ON-GOING RELATIONSHIP AND RESEARCH

The Social and Cultural team has formed a very strong relationship with Te Pā since 2016. Our research is nested within a culture of reciprocity and it has shaped positive outcomes for Te Pā and Te Pā has shaped positive learnings for the Social and Cultural team. For example, a successful collaboration in this project is built around mutual listening and learning that provided focus for the research and ultimately ensured that value was created for each party. Ensuring that expectations of each party are recognised and acknowledged is a critical component of value and was foremost in our commitment to communication and the broad engagement that we have had with Te Pā. We have learned important culturally responsive pedagogies that are recognised in Aotearoa-New Zealand research and policy communities as being fundamental in guiding and shaping good social and cultural practice. We can better understand and support Te Pā as a kaitiakitanga-centred learning village appreciate the value that independent research and objective research methodology can bring to assist cultural initiatives, like Te Pā, if they are embedded within an appropriate collaborative framework.

We have collaborated with Te Pā and Te Ru Rāngahau: The Maori Research Laboratory (University of Canterbury) to investigate kaitiakitanga/environmental stewardship as a critical driver to advance the Te Pā community and by having structured uiuinga (interviews) with staff and board. We have assisted Te Pā to track its model of education and to identify the barriers they were confronted with as well as the enablers that have been important in overcoming these barriers. This provides useful input to Te Pā as they continue to develop their long-term vision for the pā wānanga.

The Social and Cultural Team's work with Te Pā is the culmination of a journey that began in 2003 with Waste to Resource, when we faced an expectation that we would work with the community to provide a "social license to operate" for those who wished to apply biosolids to land. From the early days of our Christchurch Scenario Workshops and our Wairewa Little River mārae-based Community Dialogue, we have striven to shift those with whom we work away from the assumption that questions of waste disposal and reuse are best decided by scientific and technical experts, and that the role of the Social and Cultural Team should be to secure community acceptance of expert technical solutions by assisting the community to learn from the experts and overcome "irrational" fears. Through our Tapu to Noa work and Kaikōura Biowaste Hui we emphasised the fundamental role of Te Tiriti partnerships in decision-making as well as consultation, a role that also requires an understanding of, and ability to work with, Māori cultural frameworks. Indeed, Te Tiriti requires that we move well beyond "consultation" to decision-making partnerships and transdisciplinary research that shares power with Māori partners at all stages of the process. At Te Pā we have endeavoured to implement these insights through the co-production of research to ensure that the research would, above all, meet the needs of our research partners. In turn, the knowledge produced would be more comprehensive and robust. This is the model the Social and Cultural Team has worked to promote within CIBR. We are pleased to see this approach now being applied in the Emerging Contaminants and Microplastics projects.

The Social and Cultural team thanks all members of the Te Pā whānau for their aroha and support over the last four years. Kia ora!

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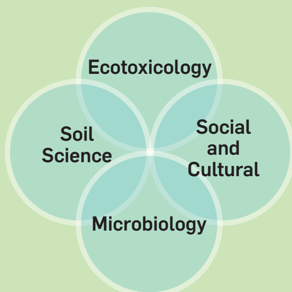

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