THE INFLUENCE OF RECYCLED FIBRES ON WATER QUALITY INDICATORS

MATTER OF TRUST & THE PHYTO LAB

2023 RESEARCH SYNTHESIS

1. RESEARCH SUMMARY

This research was made possible due to funding provided by the Ecological Public Charity Matter of Trust - MatterofTrust.org. Scientific facilities were provided by the University of Technology Sydney (UTS) and expertise by The Phyto Lab at UTS.

This research project encompasses a series of pilot tests on a diverse selection of sustainable-origin fiber materials, including dyed and natural human hair collected from salon wastes, dog fur from different breeds, llama wool, alpaca hair, and felted hair mats.

The key aim was to determine whether sustainable-origin sorbent materials influence key water quality parameters, informing the design and application of further ecological studies.

The laboratory investigation involved:

- A series of standardised microcosm experiments designed to replicate marine and freshwater environments, as well as municipal drinking water.

Water quality parameters of interest included:

- Heavy metal content (i.e., Cadmium, Chromium, Copper, Iron, Lead, Manganese, Nickel and Zinc)
- pH
- Dissolved oxygen (i.e., DO % saturation)
- Water colour
- Turbidity (i.e., NTU)
- Ammonia and Total Nitrogen Concentration (i.e., µg L-1)

All sorbents did not alter water chemistry to levels of ecological concern, though lower dilution factors may make certain chemical changes more evident.

2. RECYCLED FIBRES

Recycling waste and reducing environmental pollution are key goals of sustainable development. Global nations are exploring optimisations and innovations in technologies, processes, and materials to decrease landfill contributions and waste volume overall.

One important direction within the overall sustainability strategy is to explore the utility of existing waste-stream materials to identify new value and options compared to conventional materials which do not readily degrade, including many plastics. Given the socially progressive nature of many communities, there is also particular interest in these materials to offer other benefits for local communities, including affordability, accessibility, lower supply-chain emissions, and ethical sourcing.

Compared with the synthetic fibre materials, natural fibres have demonstrated many advantages due to their abundance, availability and low cost (Arpitha *et al.* 2017, Madhu *et al.* 2019).

Among natural fibre resources, keratinous materials can be used as biosorbents with important environmental applications, including crude oil decontamination from surface water and terrestrial environments (Pagnucco and Phillips 2018, *Murray et al.* 2020). Keratin is an abundant non-food protein and is the major component of human hair and many other animal fibre products.

Keratin wastes including salon hair wastes, feathers from agricultural production, horns, nails from butchery, poor quality raw wools from sheep breeding and some by-products from the textile industry amount globally to more than four millions tonnes per year, with one recent waste impact report estimating hair salons may generate as much as 397 kg of waste per minute globally (Green Circle 2023).

3. MICROCOSM EXPERIMENTS

Use of new and innovative materials in environmental applications requires an understanding of their chemical and physical properties and how these may change, or remain the same, under real-world environmental conditions. Microcosm experiments are an important approach whereby specific environmental conditions are simulated within contained and controlled experiments, presenting no risk of harm to ecological communities. These experiments also provide a valuable opportunity for experimental replication to understand variation, or consistent responses, within and across experimental treatments.

A series of microcosm experiments were performed at UTS to determine whether sustainable-origin fibres altered the water chemistry of the aquatic environments they were placed in.

Sustainable fibres in this experiment were provided by a range of international donors, organised and facilitated by Matter of Trust (Table 1).

Table 1. Summary of sustainable fibres in microcosm experiment.

SAMPLE TYPE	ORIGIN
ALPACA HAIR	AGRICULTURE
HUSKY FUR	DOMESTIC PETS
LABRADOR FUR	DOMESTIC PETS
LLAMA HAIR	AGRICULTURE
POODLE FUR	DOMESTIC PETS
DYED HAIR: COPPER, BLONDE, BROWN, PURPLE	SALON WASTE
NATURAL DYED HAIR: BROWN, GOLD, RED	SALON WASTE
UNDYED HAIR	SALON WASTE
MATTER OF TRUST FELTED HAIR MATS	MATTER OF TRUST

4. WATER QUALITY INDICATORS

Ecosystem health indicators assess how an ecosystem functions. Environmental indicators have been defined as physical, chemical, biological (or socio-economic) measures that best represent the key elements of a complex ecosystem or environmental issue. An indicator is embedded in a well-developed interpretative framework and has meaning beyond the measure it represents.

Physico-chemical indicators are the traditional water quality indicators that are used consistently by different global communities. These include dissolved oxygen, pH, temperature, salinity, and nutrients. They also include measures of toxicants such as insecticides, herbicides, and heavy metals. Physico-chemical indicators provide diagnostic information on ecosystem impacts. For example, is it a build-up of organic wastes that is affecting dissolved oxygen, or some type of toxicant?

For any environmental indicator to be useful it must provide a true measure of a component of an ecosystem. For this reason, water used in this experiment was collected directly from four sources across New South Wales (NSW), Australia:

1. **Sea water** – Sydney Harbour, NSW.
2. **Lagoon water** – *Untreated* – Glenbrook Lagoon, Glenbrook, NSW.
3. **River water** – *Untreated* – Nepean River, Penrith, NSW
4. **Municipal drinking water** – *Treated* – Warragamba Dam, NSW.

In this series of microcosm experiments, the influence of sustainable-origin fibres on the following water quality indicators was investigated:

▶ pH

pH is an expression of hydrogen ion concentration in water (US EPA 2023). Specifically, pH is the negative logarithm of hydrogen ion (H+) concentration (mol / L) in an aqueous solution:

$$pH = -\log_{10}(H^{+})$$

The term is used to indicate basicity or acidity of a solution on a scale of 0 to 14, with pH 7 being neutral. As the concentration of H+ ions in solution increases, acidity increases and pH gets lower, below 7. When pH is above 7, the solution is basic.

As pH is a logarithmic function, one unit change in pH (e.g., 7 to 6) indicates a 10x change in H+ concentration in that solution. However, what is actually measured is hydrogen ion activity, not concentration.

pH affects most chemical and biological processes in water. It is one of the most important environmental factors limiting species distributions in aquatic habitats. Different species flourish within different ranges of pH, with the optimal for most aquatic organisms falling between pH 6.5 - 8. U.S. EPA water quality criteria for pH in fresh water suggests a range between 6.5 to 9.

Fluctuating pH or sustained pH outside this range physiologically stresses many species and can result in decreased reproduction, decreased growth, disease or death. This can ultimately lead to reduced biological diversity in streams.

Even small changes in pH can shift community composition in streams. This is because pH alters the chemical state of many pollutants (e.g., Copper, Ammonia), changing their solubility, transport and bioavailability. This can increase exposure to and toxicity of metals and nutrients to aquatic plants and animals.

Figure 1. Aquatic species are highly sensitive to chemical changes, including pH.

Heavy Metal Concentrations

Metals and metalloids are electropositive elements that occur in all ecosystems, although natural concentrations vary according to local geology. Land disturbance in metals-enriched areas can increase erosion and mobilize metals into streams. Human activities redistribute and concentrate metals in areas that are not naturally metals-enriched (US EPA 2023).

While some metals are essential as nutrients, all metals can be toxic at some level. Some metals are toxic in minute amounts. Impairments result when metals are biologically available at toxic concentrations affecting the survival, reproduction and behaviour of aquatic organisms.

The following heavy metals and metalloids were investigated in these experiments: Cadmium, Chromium, Copper, Iron, Lead, Manganese, Nickel and Zinc.

Figure 2. Dissolved water is important for aquatic ecosystem health.

Dissolved Oxygen

Dissolved oxygen (DO) refers to the concentration of oxygen gas incorporated in water. Oxygen enters water by direct absorption from the atmosphere, which is enhanced by turbulence (US EPA 2023). Sufficient DO is essential to growth and reproduction of aerobic aquatic life (Murphy 2006, Giller and Malmqvist 1998, Allan 1995).

The presence of certain toxicants can reduce DO to below tolerance thresholds, causing illness and injury for many species in the short-term, and increased mortality, decreased function, and ecosystem impairment in the longer-term.

▶ Water Colour

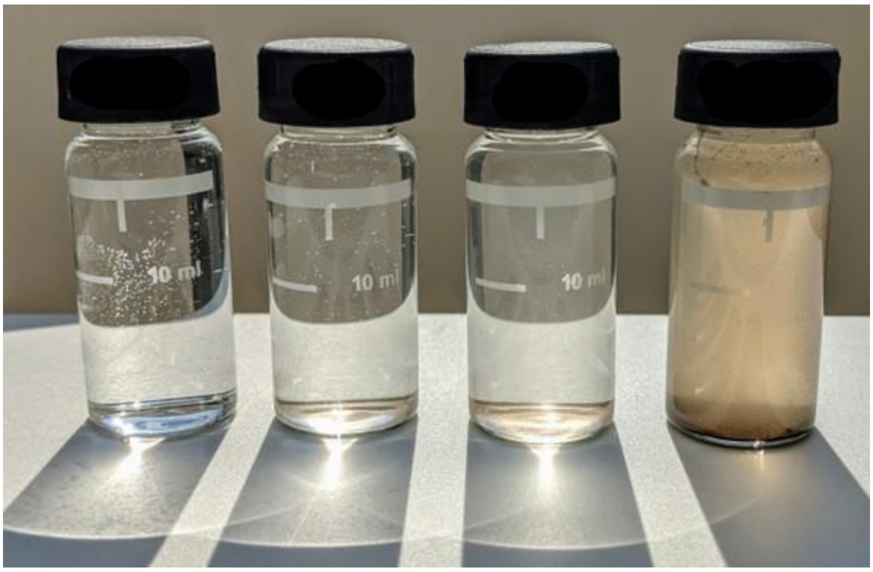
Suspended and dissolved particles in water influence colour. Suspended material in water bodies may be a result of natural causes and / or human activity. Colourless water is considered pure though it may still be unsafe for human health (i.e., heavy metals, other toxicants without visible pigments, etc).

As pure water doesn't possess any kind of colour, the colour of water may provide visible evidence that there is contamination occurring. All kind of particles - organic matter, algae, sediments, dissolved minerals or other artificial chemicals may contribute colours into water and provide different levels of concern for human and aquatic ecosystem health. Coloured water may also stain clothing textiles and other absorbent materials. Accurate documentation of water colour is important as it indicates source of water and pollutants.

▶ Turbidity

Turbidity is the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity.

Figure 3. Aquatic turbidity increasing across glass containers.



High concentrations of particulate matter affect light penetration and ecological productivity, recreational values, and habitat quality, and cause lakes to fill in faster. In streams, increased sedimentation and siltation can occur, which can result in harm to habitat areas for fish and other aquatic life. Particles also provide attachment places for other pollutants, notably metals and bacteria. For this reason, turbidity readings are an important indicator of pollution in aquatic environments.

Ammonia and Nitrogen Changes

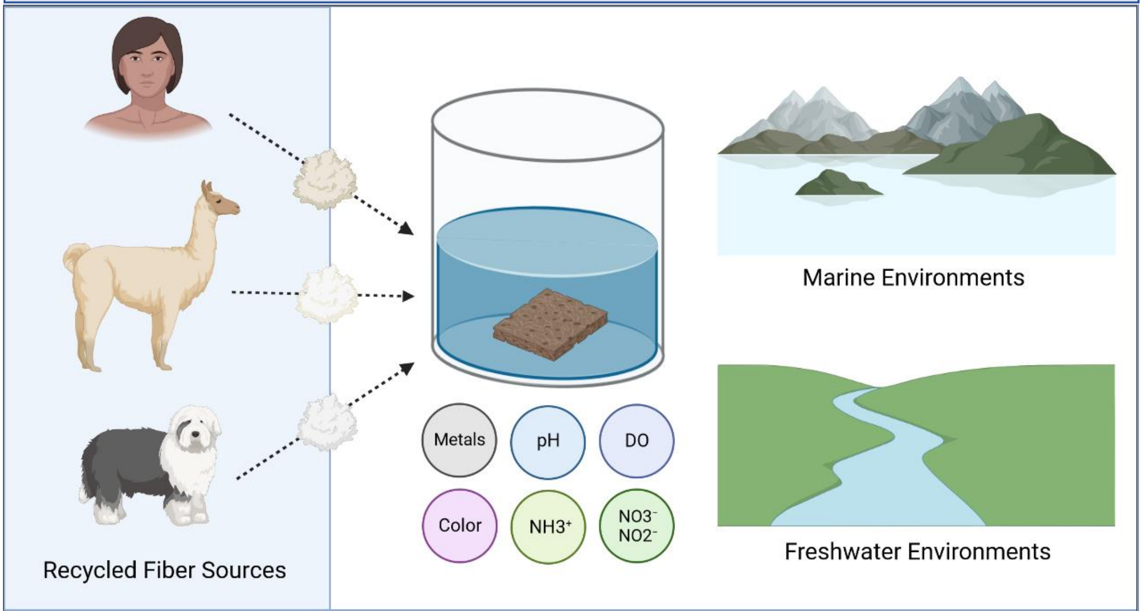
Nutrients are elements that are essential for plant growth. They include Nitrogen, Phosphorus, Potassium, Calcium and other elements. Nitrogen is considered a primary nutrient and can be a limiting factor for growth in many terrestrial and aquatic environments. In most cases, nutrients are not proximate stressors for aquatic communities. However, certain forms of Nitrogen (e.g. Ammonia, NH_3) may be toxic in high concentrations.

Ammonia is a common cause of fish kills. The most common problems associated with ammonia relate to elevated concentrations affecting fish growth, health and survival (Milne et al. 2000). Exposure duration and frequency strongly influence the severity of effects (Milne *et al.* 2000).

Ammonia is especially prevalent in anoxic sediments because nitrification (the oxidation of Ammonia to Nitrite) is inhibited. Ammonia generated in sediment may be toxic to benthic or surface water biota (Lapota et al. 2000).

For this reason, Ammonia and total Nitrogen concentrations were measured.

Chemical tests on the sustainable fibre materials and their leachates were conducted at two dilution factors: 50 gram per litre and 10 grams per litre. All fibre types and aquatic environments were replicated (N = 5) and compared to control microcosms.



Changes in physico-chemical parameters were *ecologically significant* if they exceeded ANZECC & ARMCANZ (2000) water quality guidelines.

5. RESEARCH FINDINGS

▶ Natural Variations in Aquatic pH

Average water pH was found to be naturally **varied** across aquatic sources:

- Drinking water: 7.85
- River water: 7.63
- Lagoon water: 7.95
- Sea water: 8.02

Human hair as a fibre material was found to be mildly acidic, even after chemical dying and processing. Immersion of all human hair samples (i.e., dyed, undyed, felted mats) **did not significantly change water pH** within any of the microcosm groups. All other sustainable fibres were close to pH neutral and did not influence pH.

All water remained within safe ANZECC & ARMCANZ pH guidelines for aquaculture and recreational water bodies.

▶ Water Turbidity Unchanged

According to ANZECC & ARMCANZ guidelines for turbidity: '*The natural visual clarity (of water) should not be reduced by more than 20%*'

Although the fibres themselves added physical shading (i.e., opaque fibre strands, solid mat pieces) to the aquatic microcosms, when physically extracted, the leachate remaining had highly similar visual clarity to the control microcosms with no sorbent materials present.

▶ Water Colour Changes – At Low Dilution Only

According to ANZECC & ARMCANZ guidelines for water colour: '*The natural hue of the water should not be changed by more than 10 points on the Munsell Scale*'.

Only dyed hair samples changed the colour of water, including copper (red) and purple dyes of traditional and natural pigments. These colour changes were consistent across microcosms, but apparent only at relatively low dilution (e.g., 50 grams of hair per 1 litre of water). There was no visual difference in colour found at increased dilution of 10 grams per litre.

▶ Dissolved Oxygen Unchanged

No sustainable sorbent tested was found to significantly influence dissolved oxygen saturation when compared to control microcosms.

▶ Ammonia and Nitrogen Changes – At Low Dilution Only

There were consistent increases in water ammonia from selected dyed fibres, particularly copper dyed hair, but only evident at low dilution. The natural hair dyes still had low readings of ammonia, but these was markedly lower readings than traditional copper dyed hair samples. These changes became non-significant at higher dilution. All animal fibres and undyed hair did not influence ammonia at either low or high dilutions. Total nitrogen, as well as nitrate and nitrite, were not significantly increased by any sustainable sorbent.

▶ Heavy Metal Concentrations – Not Evident in Leachate

Certain sustainable fibres had chemical characteristics associated with their origins. Animal fur and hair samples in agricultural and outdoor contexts tended to have slightly increased Iron concentrations. Copper concentrations varied across samples, with certain dog breeds, dyed samples and felted mats having slight increases in concentration. Zinc was consistently increased in dyed hair samples (e.g., purple dye), felted mat samples, as well as most animal hair and fur samples. Nickel and Lead were detected in very low concentrations approaching the limit of detection for analysis, and no sample had detectable concentrations of Cadmium.

Importantly, when all samples were immersed within all four types of aquatic microcosm environments, leachates were significantly lower than heavy metal thresholds for aquaculture and recreational water bodies, indicating that although trace concentrations of metal could be detected within certain materials, these either remained within the sorbents, or was diluted to well within safe water guidelines.

6. FUTURE RESEARCH

While physico-chemical indicators are highly important for identifying causes of environmental problems, they may provide limited insights on the extent that treatments or pollutants actually impact fauna and flora. To understand this, further research specifically investigating biological indicators and interactions is required.

Research building on this series of microcosm experiments is in preparation for Q1 2024, including aquarium microcosms with a range of ecologically important vascular and non-vascular plant species.