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URCHIN BARRENS: THE SPINY THREAT TO OUR NATIVE SHORES

Editors' Note

Nau Mai, Hoki Mai! Welcome back to yet another edition of *Scientific*.

As we settle back into semester two after a well-deserved inter-semester break, it's the perfect time to learn something new! The second edition of the year promises to indulge your brains in science at varying scales.

The cover article takes place in Aotearoa New Zealand, where rocky reef forests are threatened by the formation of urchin barrens. Jarod McTaggart discusses the implications of this ecosystem shift on the ecology of the marine environment and how these barrens can be prevented in the first place. Prepare to be transported to space, where Ayush Varma discusses how quantum mechanics has the potential to be a game-changer in the industry of space research. Indigenous population equity is highlighted by Caleb Smith, providing insight into his summer research which showed the use of Kaupapa Māori principles to understand how to create equitable research frameworks.

This edition also shows a strong contribution of diverse articles from the executive team. Milly Darragh explains her own research, which focussed on the neuroanatomical changes in MCI patients using diffusion tensor imaging. The science of ageing is explored by Lucas Tan, understanding the developments made in the prolonging of health span as opposed to lifespan. Nargiss Taleb provides a brief overview of what really happens to chemicals in the environment and why this is important for both human and ecological health. Primates, primates, primates - where did they come from and how did we evolve from them? Jasmine Gunton discusses the more strange and unusual evolutionary theories.

As always, we are incredibly thankful for the invaluable contributions of the writers and their commitment to communicating scientific knowledge. To the readers, we are grateful for your support and hope our articles continue to spark your curiosity for science!

Mā te wā
Nargiss Taleb, Head Editor for UoA Scientific 2023

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Research

White Matter Differences Between Mild Cognitive Impairment Patients and Control Patients

Milly Darragh

Clinical Neuroscience

Alzheimer's Disease is an increasingly common condition, and is often identified too late for patients. How can micro-structural changes influence our understanding in the early stages of cognitive decline, and what role will biomarkers play in this?

Introduction

Mild cognitive impairment (MCI) is a condition in which an individual experiences cognitive decline at a more rapid rate than ageing, but has not yet progressed to the severity of Alzheimer's disease (AD) [1]. It is characterised by a mild decline in memory and cognitive ability, and affects approximately 6%–8% of the population at any given time [2]. MCI patients have a significantly higher rate of conversion into clinical dementia when compared to control conversion rates, observed at 10%–15% and 1%–2% respectively [3]. Some patients with MCI will progress to dementia, but there are currently no accurate ways to predict whether or not a patient will convert to more severe symptoms and diseases [4]. Current research aims to address this issue by investigating possible biomarkers via neuroimaging methods [5] and has yielded promising results. Amid this uncertainty is a consensus that white matter reduction occurs with MCI. White matter abnormalities have been noted in previous studies exploring MCI, but definitive correlations are still being explored within the literature [8]. White matter itself is subcortical, consists of axons and myelin, and is heavily involved with cognition, processing, memory, and intelligence [9]. When white matter reduction occurs, the death of neurons results in decreased cognition, memory, and neural health [10].

Previous research has suggested that the fornix is involved in memory functions, thus playing a part in MCI [11]. The fornix itself is a c-shaped white-matter tract working as part of the basal ganglia system and is closely associated with the hippocampus and cingulum [12]. The fornix is heavily involved in memory and cognition, with studies showing that fornix transections and damage are linked to amnesia and episodic memory impairment [12]. Furthermore, autobiographical memory has been enhanced when bilateral deep brain stimulation occurred to the limbic system, again suggesting the fornix's role in memory and processing [13]. Previous studies have analysed how the fornix may be used to identify and monitor MCI and AD progression in patients, with significant fornix abnormalities found in MCI patients compared to controls [14].

Another region of interest for MCI white matter integrity is the cingulum, a white matter fibre tract involved in connecting the lobes of the brain [14]. Atrophy of the cingulum has been shown in MCI and AD patients when compared to control participants, as have links to the hippocampus atrophy experienced by many MCI and AD patients [15]. Higher degrees of posterior cingulum atrophy have also been observed in memory impaired patients when compared to functioning memory patients, further suggesting the cingulum's role in memory and its possible interactions with MCI pathology [16].

Voxel-based analysis (VBA) is currently the predominant method for neuroimaging research and diagnoses [17]. However, there are limitations to understanding white matter organisation with VBA; the immediate concern is the inability to correctly reproduce crossing fibres in white matter, leading to spurious results and understanding—especially in more complex structures [18]. This issue occurs when fibres cross within a single voxel, meaning the orientation of said fibres is no longer individual but can easily be misinterpreted as such [19]. Behrens et al. [20] found that approximately one-third of all white matter voxels comprised at least one fibre population, suggesting that the VBA dilemma may have had significant effects in both previous and present studies that use this method.

Secondly, the partial volume effect can cause notable issues when using VBA. This effect occurs when more than one tissue type appears in a voxel. Intensity then becomes dependent on the proportions of each tissue type in a voxel, causing issues with volumetric output [17]. This creates an average output of the many cells within the voxel and is unrepresentative of the numerous components comprising a true voxel. Ignoring this effect may produce significant measurement estimation errors of white matter.

These disadvantages were addressed by the production of a new method that would allow for correct representation with crossing fibres and multiple tissue types: fixel-based analysis (FBA) [21]. 'Fixel' refers to fibres within a population of a voxel, and an FBA uses spherical deconvolution to allow for accurate and consistent analysis measures of white matter crossing fibres [21]. However, this method presents its own set of problems. FBA results fail to accommodate their bias towards positive results, hence increasing the rate of type I

errors [22]. This claim is based upon FBA's increased specificity showing a clear preference for larger fibre bundles, therefore often overestimating the significance detected in data. Furthermore, recent research suggests that the complexity of white matter fibres is not necessarily an issue with VBA that can be fixed with FBA, but rather an issue of diffusion MRI (dMRI) itself [18]. Another considerable challenge with FBA is its increased complexity and the extra steps required to use it [21, 24]. Both VBA and FBA have their own advantages and disadvantages, yet voxel-based approaches still remain the most widely used and accepted technique within neuroimaging literature [23].

Two of the leading measures in neuroimaging research are Fractional Anisotropy (FA) and Mean Diffusivity (MD). FA refers to a value between 0 and 1 produced by measuring the diffusion directionality of water molecules in white matter, in which a value of 0 refers to isotropic diffusion and a value of 1 refers to anisotropic diffusion [24]. FA values closer to 0 represent a general loss of white matter via decreased axonal myelination, while FA values closer to 1 represent healthier axons and, therefore, more white matter present [24]. Mean Diffusivity (MD) refers to the overall diffusion observed in neurons. A high MD value would therefore suggest more space for diffusion to occur—indicating loss of matter. In turn, a low MD value would imply little room for diffusion and a high number of functional axons [24]. Sexton et al. [25] investigated the white matter abnormalities in patients with MCI and noted decreased white matter consistent with previous studies [31, 32] via increased MD and decreased FA values compared to control patients. Furthermore, recent findings support these results by confirming decreased FA and increased MD values in the fornix and cingulum of aMCI patients [27]. Specifically, the relationship between the fornix and hippocampus has been reviewed in literature, as AD patients with hippocampal atrophy have been reported to present decreased FA values of the fornix [28]. MCI patients experienced significant FA decreases of the cingulum when compared to control patients, and AD patients experienced significant FA decreases when compared to MCI patients and control patients—which conforms with the progressive nature of these diseases [29]. Interestingly, FA has been found to be highly sensitive to any structural changes, but has little ability to determine the type of change occurring [30].

MCI is clearly prevalent in wider populations, and expanding our knowledge of the underlying mechanisms occurring can provide significant insights into our understanding of the disease. By exploring the components of MCI successfully observed using FSL (a software library for MRI data), we may be able to strengthen predictive prognoses for patients who experience rapid cognitive decline. We can expect to see decreased FA and increased MD in patients diagnosed with MCI based on previous studies and our current understanding of the relationship between MCI and neuronal atrophy.

Methods

Participants:

There were 30 participants in this project, all recruited via the Dementia Research Prevention Clinic (DPRC), of which 15 were control patients and 15 were MCI patients. The aMCI subgroup consisted of 10 female subjects and 5 male subjects, with a mean age of 72.8 years (SD = 6.3). The control subgroup consisted of 3 female subjects and 12 male subjects, with a mean age of 67.0 years (SD = 7.6). Addenbrooke Cognitive Examination III (ACE-III) (Beishon et al., 2019) scores were obtained from participants in both groups. The aMCI group had a mean ACE-III score of 85.5 (SD = 7.0), and the control group had a mean score of 94.7 (SD = 3.6). The difference in these values was significant ($p < .001$). Estimated Total Cranial Volume (eTIV) was also calculated for both groups, with a control group mean eTIV of 1470348.2 (SD = 92448.8) and an aMCI group mean eTIV of 1575569.1 (SD = 158009.0). Statistical significance was also found with differences in eTIV scores ($p = .034$). Intracranial volume measurements were also taken between groups, but no significant difference was found ($p > .05$).

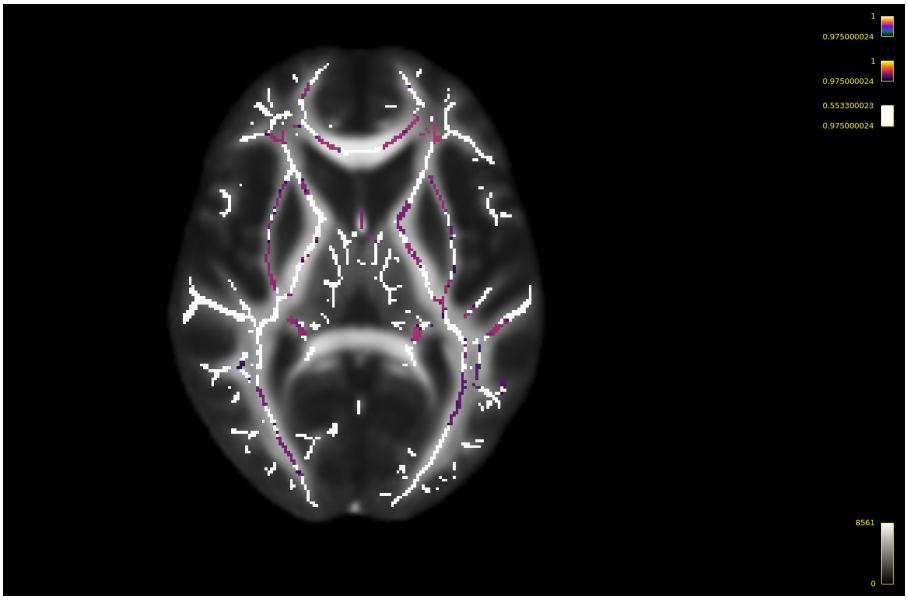
Apparatus/measures:

Diffusion Tensor Imaging (DTI) refers to the type of method used to measure diffusivity and composition within neural structures [30]. The data from these patients were accessed from the DPRC as part of Brain Research New Zealand. Diffusion-weighted images were provided as data after Magnetic Resonance Imaging (MRI) had occurred on all participants. The data was acquired using 3 shells b0 s/mm_2, b1000 s/mm_2 and b2000 s/mm_2, in 105 diffusion volumes with a b0 s/mm_2 volume as volume 1, 22, 43, 64 and 85. Preprocessing of the images used the FSL tool 'fsleyes' to inspect our data, then continued to remove sources of noise within our data. This process included distortion or warping effects that may occur within our diffusion data.

Tract-Based Spatial Statistics (TBSS) is a methodology that was designed to improve the specificity and interpretability of dMRI studies [31]. TBSS follows non-linear registration, in which all FA data images are aligned to an anatomical reference which consists of a previously decided target [31]. Then, an average of FA images in the data set is produced and thinning occurs. The second step is the projection onto a pre-existing anatomical reference, which is formed by the mean FA values in the data [31]. This allows for differences to be seen within subgroups of datasets.

TBSS provides a more sensitive visualisation and analysis of white matter structure changes, which previous studies have displayed when comparing with other analysis tools such as Statistical Parametric Mapping [32].

Results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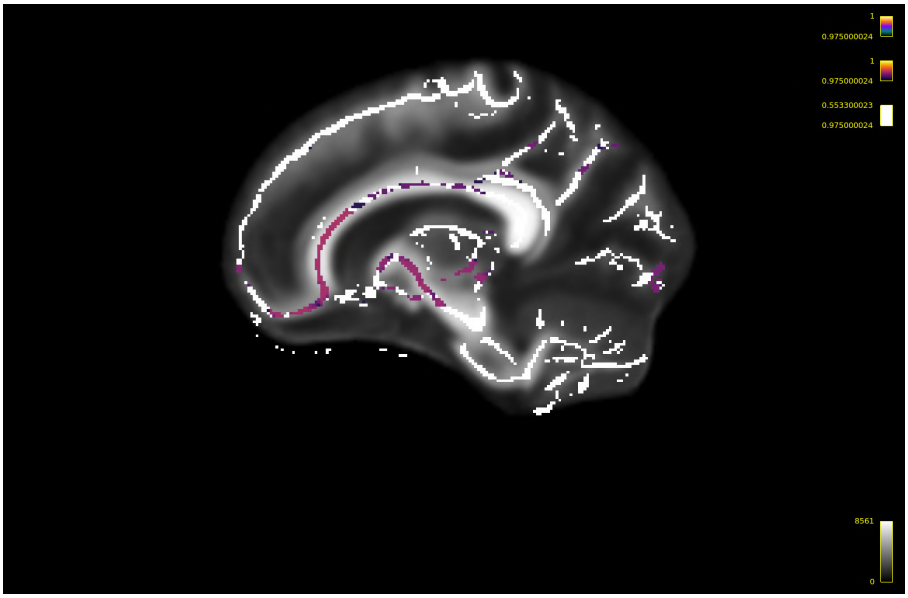
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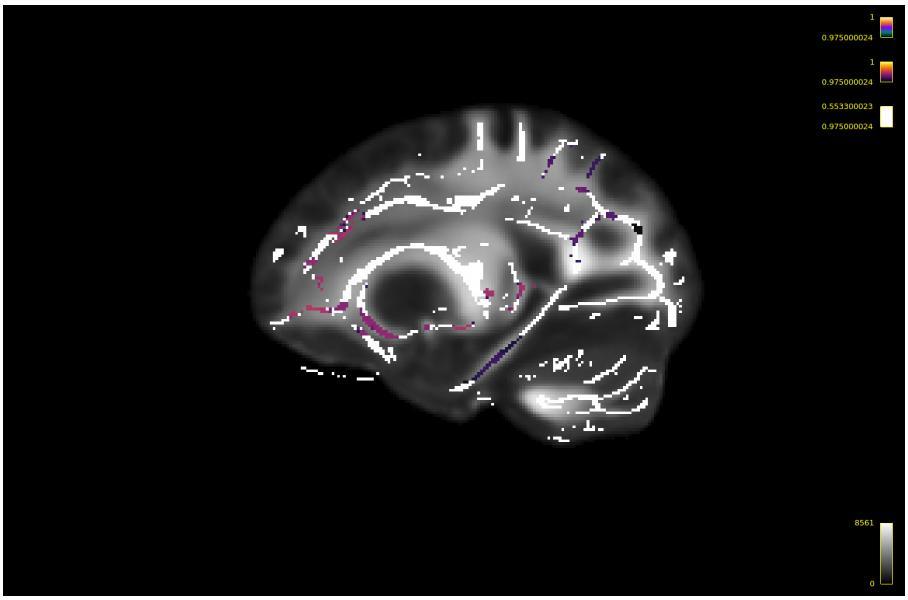
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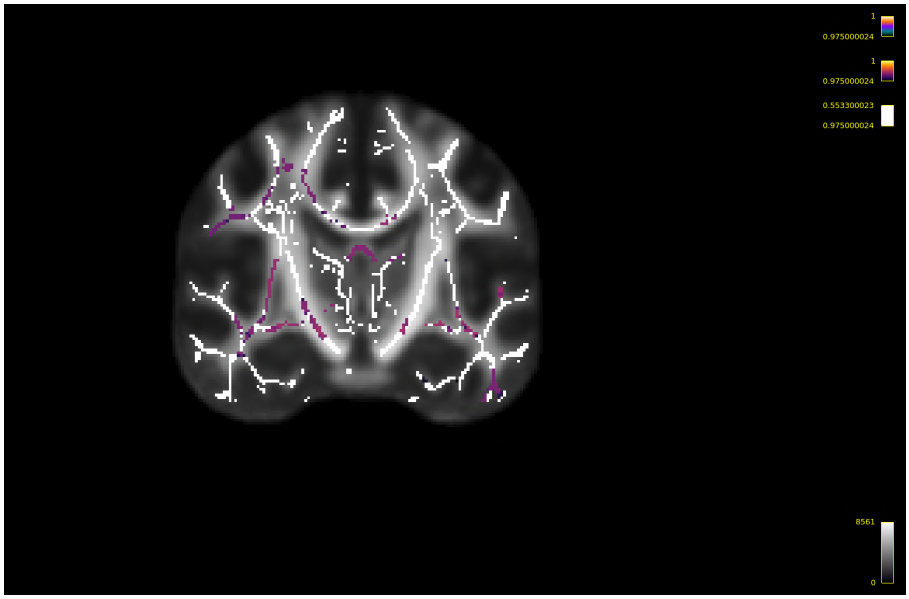

Discussion

This research project aimed to assess the use of FSL as a reliable and concise method of observing MCI white matter abnormalities and has successfully suggested the use of FSL as a comprehensive image analysis method. This research has also examined the involvement of the fornix fimbriae with white matter abnormalities in MCI patients and found consistent decreases of white matter in MCI patients compared to control patients.

As shown in our results, significant white matter changes between the aMCI group and the control group were observed. These differences are reflected in the purple-coloured tracts of our results, which are present in a range of areas. Noticeably, the fornix fimbriae experience a significant difference in white matter tracts. This aligns with previous knowledge suggesting their role in memory and cognition, as decreased fornix fimbria integrity has been observed with patients experiencing aMCI.

Specifically, the fornix fimbriae have recorded involvement with spatial learning and memory, with evidence that damage/removal of the fornix fimbriae causes an inability to complete spatial memory tasks in rats [33]. These findings were expanded when Gaffan and Parker [34] showed episodic memory was severely impaired in monkeys after a unilateral fornix-fimbriae transection. This experiment also observed the role the fornix fimbriae may play in processing visual information in episodic memory and learnt skills. Furthermore, forn- fimbriae transection surgeries interrupted spatial and episodic memory in rats [35]. These studies reflect the link in literature between damaged fornix fimbriae and decreased or absent memory and cognition. From this literature, studies turned to how this knowledge could translate to clinical MCI or AD, and whether decreased fornix fimbriae white matter in MCI patients can be approached with the same understanding. Recent research has shown that decreased fornix fimbria integrity (specifically FA) was present in aMCI patients, but not naMCI patients [14]. Again, this would imply that part of aMCI patients' symptoms could be due to decreased fornix fimbriae integrity. MCI patients have also been recorded to have significant atrophy within limbic pathways compared to healthy ageing counterparts, and white matter degeneration has been suggested to occur in MCI patients prior to grey matter degradation [11, 42].

Another region of interest in this project was the cingulum, which experienced significant white matter changes as well. This area of the brain has been associated with memory processing before, specifically episodic memory [37]. The cingulum bundle has shown clear cognitive detriment in traumatic brain injury patients, who experience memory and episodic verbal learning difficulties [38]. Furthermore, decreased FA was observed in the cingulum bundle in these patients using the DTI methodology. Further work implicating the cingulum in memory and cognition describes decreased object recognition and object location skills in rats with cingulum lesions, as well as decreased cingulum integrity in older healthy adults associated with decreased FA [45, 46].

However, the role of cingulum integrity in aMCI patients has only recently been explored. [40] explored the relationship between cognitive decline in aMCI patients and the severity of cingulum tract atrophy. Interestingly, cingulum bundle integrity was able to predict cognitive impairment and memory skills in aMCI patients. Furthermore, Chang et al. [41] found cingulum disruption correlated with cognitive impairments across types of MCI, stating that multiple-domain aMCI and single-domain aMCI were both significantly impaired on all memory tasks.

Additionally, significant white matter differences were observed in areas such as the superior fronto-occipital fasciculus and the uncinate fasciculus. The superior fronto-occipital fasciculus has been noted in spatial

awareness and processing cognition in prior studies [42]. This tract runs from the frontal lobe to the occipital lobe, and a significant decrease in this tract was observed in our data. The uncinate fasciculus is also a white matter tract, running from the frontal lobe to the temporal lobe. This tract has assumed declarative memory involvement in human cognition [42]. Declarative memory refers to the conscious retrieval of experiences and information, which aligns with symptoms of aMCI [50, 51]. While these findings are consistent with the expected pathology of aMCI patients, it is surprising to observe these effects using a rather conservative method. It is important then, to consider factors that may have contributed to these findings, which may suggest slight biases or amplification of results.

Our subject group was predominantly female (n = 17) for both control and MCI patients, which may have influenced our results. Gender and sex differences have been observed and reported widely in literature—with varying explanations. MCI has been suggested to affect male populations more than female populations in prevalence. However, it is well established that females experience AD at a significantly disproportionate rate when compared to males [52, 53]. Furthermore, there have been multiple reports of female patients with MCI experiencing faster cognitive decline and neural atrophy related to MCI and AD [45]. This has been attributed to the disproportionate healthcare females often experience when compared to their male counterparts and suggests that the reason more rapid rates of conversion to AD occur in women is potentially due to the cultural and social factors regarding women's healthcare [46]. Since the subjects were primarily female for the MCI patient group, this may have skewed the symptoms and anatomical abnormalities towards higher severities. This could imply that the degree of significance observed in the results is due to the above-average severity present in our sample when compared to the general population. Furthermore, the gender imbalance in the participant populations was reflected through other measures. Demographic measures showed a significant difference of eTIV between male and female participants ($p < .001$). Gender differences in eTIV have been well established in neuroscientific research, with males displaying significantly higher eTIV values than females [47]. The effects this may have in our project are likely reflected in our results, with disproportionate gender ratios in both sub-groups.

This project used TBSS as part of FSL software during our analysis, which is traditionally considered a conservative method to analyse any data. However, using TBSS as part of FSL did not seem to face the issues that an overly cautious analysis may face, as we still gained significant expected results.

Being able to correctly identify patients with MCI via biomarkers (such as the neuroimaging data presented in the project) could provide opportunities to diagnose and treat MCI in the where treatment is far more effective. Furthermore, using biomarkers to identify MCI could allow for diagnosis before severe symptoms set in, as well as increase our understanding of how MCI mechanisms occur in different sections of the brain. There are many calls for more biomarker-based studies of MCI and progressive neurodegenerative diseases, with hopes this could become a screening tool or objective diagnosis technique [5]. Mito et al. [5] also considered Diffusion tensor imaging (DTI) and FT as reliable approaches in neurodegenerative biomarker studies. DTI uses anisotropic diffusion to analyse and observe white matter tissue and tracts, providing insight into cerebral organisation [6]. Once this data has been collected, FT can be used to reproduce and analyse DTI data using 3D modelling. This method has been used to identify diseases affecting the nervous system and in exploratory research of conditions like MCI, AD, and dementia [7]. By using a fibre-tract-specific model instead of a diffusion tensor model, we are able to analyse white matter tracts that contain multiple fibre populations and crossing fibres. This also allows us to use more measurements that are fibre specific, such as fibre density (FD) and fibre cross-section (FC) measurements. While this method can successfully explore the mechanisms of neuronal atrophy relative to neurological diseases, there are still limitations that come with using DTI and FT, related to the assumptions this method holds.

Despite conflicting literature regarding the ability of voxel-based imaging techniques to accurately analyse complex fibres, this project has shown that this method can be effective and did not express any issues with complex fibres.

Acknowledgements

This research project was supported by Brain Research New Zealand and the Dementia Prevention Research Clinic, which provided all data, participants, and patients. This research project was supervised by Professor Ian Kirk in the School of Psychology and was submitted to the Faculty of Science in partial fulfilment of the Bachelor of Advanced Science (Honours) program.

Milly Darragh - BAdvSci (Hons), Cognitive Neuroscience

Milly is entering her 4th year of the Bachelor of Advanced Sciences (Honours) programme in cognitive neuroscience. As an honours student she is fascinated by translational neurology and neuroscience, specifically neurodegenerative diseases. She is the current vice-president of *Scientific*, and the president of UoA Campus Neuroscience Society.

Explained

Environmental Fate: Tracing the Journey of Chemicals in our Ecosystems

Nargiss Taleb

Environmental Chemistry

Environmental fate pertains to the behaviour and ultimate destiny of chemicals in the environment, encompassing their interactions, transformations and potential toxicity. Comprehending the intricacies of chemicals within an environment is crucial to provide insights into the risk they may pose, enabling policymakers to create well-informed decisions regarding their regulation and utilisation of them. This article aims to provide a broad overview of the factors influencing environmental fate.

Introduction

Chemistry plays an elemental role in our incredibly complex world, shaping the interactions and processes that occur within ecosystems and within ourselves. It is thus important to understand how factors like composition, structure, and properties play into the intricate workings of our environment. Environmental fate describes the behaviour of a chemical in the environment and thus what the ultimate destiny of it will be. Recognising the significance of comprehending environmental fate lies in its ability to provide insight into the potential hazards it may present to both humans and the environment. It allows policymakers and those in charge of regulating these chemicals to understand what is safe and what is not.

As synthetic chemistry advances, we discover more and more chemicals that have the potential to contribute to our way of life. More than 100 million in fact, are currently registered in the Chemical Abstracts Service (CAS), with about 4000 new ones registered every day [1]. In Aotearoa, there are more than 30,000 chemicals approved for nationwide use [2]. So how do regulators decide which of these millions of chemicals are allowed on the market? Well, it's all about environmental fate.

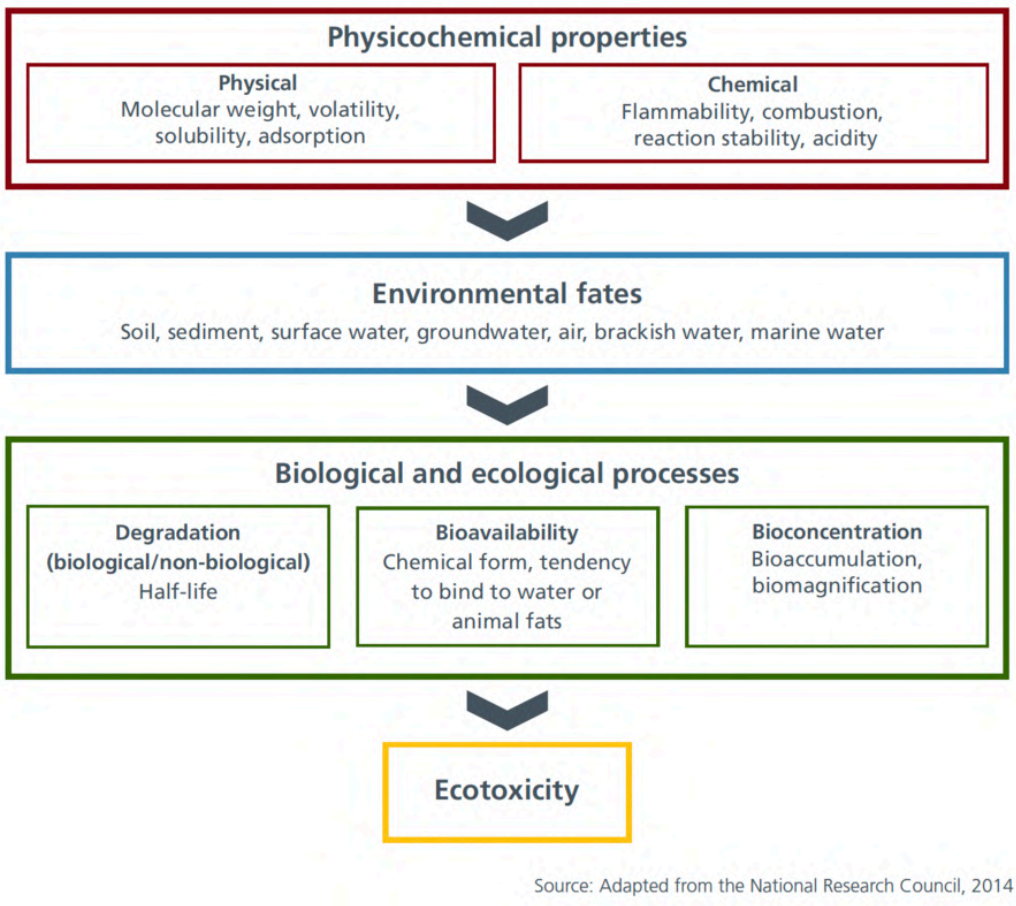

Figure 1. Relationships between physicochemical properties and their relationship to environmental fate, biological and ecological processes, and toxicity [3].

Physicochemical Properties

The structure and thus the inherent physical and chemical properties heavily influence the fate of chemicals (Figure 1.). Characteristics including but not limited to molecular weight, polarity, solubility, and volatility, all help create a chemical identity allowing for scientific understanding of its behaviour in different environments [3]. Solubility for example, determines the ability of a chemical to dissolve, whether this be in water or other liquid mediums. Scientists use the solubility product constant (Ksp) in which a higher value means more solid has dissolved into an aqueous phase [4]. The amount in which a chemical is soluble is not only important but to what phase would it partition to in the environment. Here scientists will use a term called Kow, the octanol-water partition coefficient, which acts as a gauge to assess the relative lipophilicity (fat solubility) and hydrophilicity (water solubility) of a substance [5]. In the environmental fate context, this is important as it dictates whether a chemical will accumulate in fat tissues of organisms, partition into sediments or has the ability to be transported through water bodies. Volatility refers to the tendency for a chemical to evaporate. This is often simply determined by the chemical's vapour pressure or boiling points. Here, molecular weight and the strength of the intermolecular forces between molecules heavily influence whether a chemical will turn into its gaseous phase. The relevance of this is that volatile chemicals can undergo long-range transport through the atmosphere, having the potential to disperse and deposit in very diverse environments.

It is important to note that it is not solely the physicochemical characteristics of the chemical itself that determine where a chemical may end up but also its interactions with the environmental conditions it is exposed to. Temperature, humidity or pH are a few of the relevant factors that play a role.

Environmental Fate

Earth, air and water – three of the four elements of nature, but also the potential locations for these chemicals to end up in. Chemicals in the environment can undergo various transportation mechanisms, ultimately determining their distribution in the environment. These mechanisms include air, water, soil, biological and human-mediated transport. Air transport shows air currents carrying volatile compounds, allowing for their distribution through global wind networks. This poses the potential risk of contamination far from a chemical source. Water transport moves chemicals through water bodies such as rivers and lakes, which feed into oceans and seas. This mode of transport is significant for water-soluble compounds, which can be carried far distances simply by water currents. Soil transport involves processes such as leaching, where water infiltrates the earth, allowing for the chemical to become mobile and percolate through layers in the soil profile [6]. This is where surface interactions of chemicals, such as their ability to adsorb onto a surface, are significant, determining their ability to hold onto the solid soil particles rather than penetrating the soil further. Biological transport refers to living organisms, both flora and fauna. Flora (plants) can uptake chemicals from the soil through their roots or from the air through their leaves before translocating these to various other parts of the plants. Particular animal (fauna) species that show migratory practices also have the potential to change the geographic scale of chemical distribution. The last mode of transport is through anthropogenic means. Humans can physically move chemicals through goods transportation or events like unintentional spills.

The above transportation mechanisms all have the ability to interact with each other to determine the distribution scale and final location of chemicals. It is crucial to understand these processes as they directly influence biological and ecological processes.

Biological and Ecological Processes

Once in these environments, chemicals are able to undergo various biological and ecological processes. This includes but is not limited to degradation, bioaccumulation, and biomagnification. Physical, chemical and biological processes can help to degrade a chemical in the environment. Physical processes, like weathering, change the physical appearance of the chemical, like a reduction in particle size. Chemical degradation involves breaking down a chemical into smaller molecular constituents, most commonly hydrolysis or oxidation [7]. Chemicals can also be broken down by biological organisms such as fungi, bacteria and other microorganisms. These organisms have enzymes capable of metabolising chemicals, which change the toxicity compared to the original substance (detoxification lowers toxicity whilst bioactivation increases it) [8]. Chemicals that persist in fauna (animals) also can bioaccumulate and thus biomagnify chemical concentrations. Bioaccumulation here refers to the process in which chemicals build up in the fat/tissues of organisms. As chemicals bioaccumulate, the result of predator/prey relationships shows chemical concentrations increasing further up the food chain - this is called biomagnification [9]. It is acknowledged that this is a limited list of all the processes and that many other processes and influencing factors can change chemicals in the environment.

Ecotoxicity

The environmental fate of chemicals is closely tied to their toxicity and their potential to have ecological consequences. After undergoing various processes to degrade or biotransform these chemicals, it has the potential to pose toxicity. Different organisms exhibit varying degrees of sensitivity to particular chemicals, the most sensitive species being used by regulators as indicators [10]. These indicators are exposed to varying concentrations of a chemical to evaluate its potential hazard in the environment using toxicity metrics like $LC_{50,}$ EC_{50} or NOEC.

LC_{50} refers to the concentration of a chemical that causes mortality in 50% of the test organisms within a specified period [11]. This is typically used for acute toxicity. EC_{50} is the concentration of a chemical that produces a biological response in 50% of the test organisms [11]. NOEC (no observed effect concentration) is the highest concentration of a chemical where no statistically significant adverse effects are observed, this being a good determinant for the threshold at which toxic effects start to occur [11]. One challenge with using exclusively indicator species data for these metrics is that not all species and other organisms in the ecosystem will display the same sensitivity as the 'test' species. So how can we extrapolate the data produced for a small subset of species to help predict the potential impact on the larger ecosystem?

According to the Hazardous Substances and New Organisms (HSNO) Act 1996, a document that Aotearoa uses to determine chemical risk, we can assign these toxicity metrics under physical, health and environmental hazards [12]. Some subcategories include acute/chronic toxicity, mutagenicity, carcinogenicity, reproductive toxicity, and hazardous nature to soil, aquatic or terrestrial organisms. To address the issue of being reliant on indicator species data, an arbitrary 'safety factor' can be applied to the toxicity metric (dividing the metric by 10, 100, 1,000 or 10,000) to determine whether the chemical can be considered 'safe' [10].

Conclusion

By understanding the factors that govern chemical behaviour, transport, transformations and ecotoxicity, well-informed policies and risk management strategies can be put in place to mitigate their effects. Insight into the environmental fate of chemicals and thus the effective regulation of the chemical market is thus highly important to protect both human and ecosystem health.

Nargiss Taleb - BSc(Hons), Green Chemical Science

Nargiss is a dedicated early career researcher with a passion for utilizing chemistry to address environmental challenges. Having recently completed her BSc (Hons), she aspires to make scientific contributions through innovative research. Currently employed as a research assistant, she is investigating compostable packaging and the potential for implementing Aotearoa-specific policies.

Academic

Three Case Studies on Unusual Primate Evolutionary Ideas

Jasmine Gunton

Evolutionary Biology

What do hippos, bats, and snakes have in common? Yes, they are all animals, yet they are also all involved in some strange ideas concerning primate and human evolution

Introduction

By now, we have all (hopefully) accepted that humans are very closely related to other primates. To be specific, humans likely evolved from the ancestors of chimpanzees (*Pan troglodytes*) [1]. With the advent of this popular scientific theory filtering into society, many wondered: But where did the primates come from? Most evolutionary anthropologists will claim that primates evolved from creatures similar in appearance to the modern-day colugo (Order: Dermoptera), a small gliding mammal [2-3]. Nevertheless, there currently exists some strange fringe theories that are as amusing as they are complex. In this article, we will analyse three case studies of unusual primate evolutionary ideas that have been thrust into the scientific community (with little acknowledgement/ welcome). This article is not trying to spread pseudoscience; it is simply an entertaining look into alternate evolutionary ideas. When viewing a new scientific idea, I encourage the audience to think critically about its validity in relation to the current scientific consensus. Additionally, I wanted to clarify that when I use the word 'theory' in this article, I am not referring to its traditional scientific definition. Instead, in this article, a 'theory' is analogous to an idea or hypothesis.

Aquatic Apes

To summarise, the aquatic ape theory (AAT) claims that modern humans evolved from the great apes by adapting to an aquatic environment [4]. The primary 'evidence' given to this theory is the evolution of hairlessness and bipedalism in humans. These two traits would have been advantageous for swimming and collecting shellfish on the seabed [5]. It has been argued that human hairlessness is analogous to the traits seen in hippos (*Hippopotamus amphibius*) and whales (Infraorder: Cetacea), mammals that made the evolutionary transition from the land to the water. In 1942, anthropologist Max Westenhöfer suggested that human-held traits, including webbed fingers and the regression of smell, also supported the AAT [6]. One cannot deny that seafood is an important food source for many communities, and fishing is still implemented on large scales. Recently, some anthropologists have hypothesised a shore-based diet scenario emphasising the human requirement for iodine. Iodine-deficiency illnesses are often seen in inland habitats that do not have regular access to seafood. Hence this scenario implies that humans evolved from aquatic ape-like ancestors [7]. Today the vast majority of anthropologists and adjacent academics reject the AAT, claiming that it constitutes an 'umbrella hypothesis'[8]. In this case, an umbrella hypothesis can be defined as an idea that explains certain features of a species as a result of a single adaptive breakthrough. There are many issues with the AAT, including that its ideas are inconsistent with the fossil record and that inferring aquatic behaviour from traits such as subcutaneous fat and hairlessness is an excessive reach. Anthropologist Henry Gee points out that humans likely only began to eat seafood in large quantities around 200 kya, far after the human species had emerged [9]. The critique of AAT by academics can be nicely summarised by a quote from biologists Caroline Pond and Dick Colby, describing AAT as *"speculative, theoretical and in many places so imprecise as to be misleading"*.

Bat Primates

The flying primate theory (FPT) takes a drastic turn from the previously mentioned theory. It postulates that the megabat order Megachiroptera is a sister group to primates [11]. In other words, this theory suggests that bats are the closest relative to primates, not colugos. The FPT supports a phylogenetic scenario of diphyletic origins, in which megabats can be considered 'flying primates' and are less closely related to microbats (Microchiroptera). Recent genetic studies support a monophyletic scenario in which megabats and microbats should be considered as one order: Chiroptera, and that they are not closely related to primates [12]. First, we will consider the 'evidence' in support of the FPT. A 2000 study in support of FPT argues that the complex visual system of the bat genus *Pteropus* is similar to that of early primates [13]. Additionally, perceived differences in the neurology of microbats and megabats imply that megabats are more closely related to primates [14]. The main evidence against FPT comes from modern molecular studies focusing on the genetic differences between bats and primates. A 1992 study found that parsimony analysis of gene sequences supported the monophyletic hypothesis [12]. Additionally, a presentation from 2001 found that most morphological evidence supported bat monophyly and that bat DNA was distinct from species known to be closely related to primates, such as tree shrews (Order: Scandentia) and colugos [15]. Most zoologists agree that bats are monophyletic and that megabats are not 'flying primates'.

Snakes Snakes Snakes

The third evolutionary theory we will discuss here has arguably more legitimacy than the AAT or FPT. This hypothesis, which we will refer to as the snake detection theory (SDT), suggests that

the threat of snakes (Order: Squamata) to early primates shaped our brain structure and vision. In a 2006 study, anthropologist Lynne Isbell proposed that the presence of snakes helped result in the evolution of several neurological features in humans, namely orbital convergence, visual specialisation, and brain expansion [16]. In early primates, the threat of predation would have selected for the appearance of orbital convergence. In later primates, the threat of being poisoned by venom would have acted as further selection for this trait [17]. In other words, snakes may be the reason why our eyes are angled closer together rather than on the side of our heads. The other traits, visual specialisation and brain expansion, would have helped early primates and humans to detect and avoid snakes. A 2011 study tested the SDT by analysing whether orbital convergence was more likely to be found in species that regularly dealt with snakes. However, the results of this study were inconsistent with SDT [17]. It seems likely that the evolution of human stereoscopic vision would have helped with detecting snakes but was not caused by snakes. This is a slightly depressing conclusion, so I will now attempt to amuse you with the results of a similar study on snakes and humans. In 2008, it was found that when shown four visual stimuli (snakes, flowers, frogs, and caterpillars), both children and adults detected snakes more rapidly than the other three stimuli [18]. Other studies have found that snakes are deeply embedded into human behaviour systems designed to evade predators [19]. From these studies, it appears that it can not yet be disproven that snakes had some role in human evolution.

Conclusion

There will always be mysteries associated with evolutionary biology, as we cannot physically go back and have a look. Whilst we gather evidence that allows us to garner a greater understanding of primate evolution, it is delightfully fun to explore all the unusual hypotheses we come up with. I want to emphasise again that the 'theories' presented in this article should be taken with a grain of salt. I have discussed them to entertain and encourage readers to think about some cool aspects of anthropology. The emergence of humans is like nothing the Earth has ever seen; it is only normal to be interested in how we came to be.

Jasmine Gunton - BAdvSci(Hons), Ecology

Jasmine is a third-year Bachelor of Advanced Science (Honours) student specialising in Ecology. She is interested in researching areas in insect ecology and ecological restoration. This year she is also a part of the Science Scholars programme.

Explained

Urchin Barrens: The Spiny Threat to our Native Shores

Jarod McTaggart

Marine Biology

Kelp forests are one of New Zealand's most valuable and biodiverse marine ecosystems. Unfortunately, they are under threat of becoming urchin barrens. These barrens form due to the overgrazing of sea urchins, transforming this biodiverse ecosystem into a barren undiverse stable state. Anthropocentric fishing of urchin predators causes a trophic cascade that initiates a regime shift of the alternative stable state from kelp forest to urchin barren. Conservation of existing kelp forests and restoration of degraded ecosystems is necessary and should be complemented by fisheries management and marine protected areas, driven by legislation and cultural awareness of the issue.

Introduction

New Zealand is home to many unique, beautiful, and valuable marine ecosystems. The rocky reef kelp forest is one of the most economically, ecologically, and culturally valuable on our shores. However, due to sea urchin overgrazing, these ecosystems are being transformed into barren wastes that are far less valuable. This alternative stable state is known as an urchin barren. These barrens are beginning to dominate New Zealand shores, where once green forests of kelp stood, is now bare rock dominated by urchins (Evechinus chloroticus).

Kelp Forest Benefits

Ecosystem benefits are defined as ecological characteristics, functions, or processes that directly or indirectly contribute to human well-being. These services are further divided into categories that relate to how they benefit humans. Provisioning services are services that are utilised or exploited by humans to produce resources humans use directly. Regulating services are passive benefits that ecosystems have, whereby existing in a healthy state they protect human populations from environmental and biological threats. Cultural services are related to the recreational, aesthetic, and spiritual benefits that an ecosystem provides. Supporting services are the basic ecological services that an ecosystem provides, where through functioning it provides a passive benefit [1].

The major provisioning service these kelp forests provide is to fisheries, where the ecosystem acts as a source of food and habitat for economically important species and the food webs that support these stocks. In many cases, they are a nursery habitat for juveniles of important fish species [2]. Filbee-Dexter and Wernberg estimated the value kelp forests provide directly from provisioning services globally is ~$1.6 million NZD per km per year [3]. This is not even counting the other services kelp forest provides, just the economic value from direct use. There is also potential for direct harvest and use of kelp in developing new markets from agriculture to the food and supplement industry [4].

Kelp forests provide a number of regulating services that include lowering wave action by forming physical barriers, which reduces erosion of coastlines as well as protecting coastal settlements from storms [5]. Kelp forests have also been researched as a carbon sink that captures atmospheric CO2 supporting blue carbon schemes [6].

Healthy rocky reef kelp forests also provide a number of cultural services. These include recreational fishing and diving, as well as providing biodiversity people can observe and appreciate. Additionally, many of the species that occupy the rocky reef, including urchins/kina and their predators are taonga species. Taonga is the Te Reo Māori term for something that is treasured and/or culturally significant to Māori - many native species are classified as taonga due to their importance to Māori culture and tradition. These taonga are protected under Te Tiriti o Waitangi (The Treaty of Waitangi), with taonga species being specifically addressed in Wai 262, a claim lodged with the Waitangi Tribunal in 1991. In 2011, the Tribunal released their report detailing reform and recommendations that protect Māori rights over taonga, thus there is a legal obligation to protect and preserve these species. Furthermore, having native ecosystems that are biodiverse makes them more resilient to exotic invasion, further protecting native species [5].

The supporting services are perhaps the most significant services this ecosystem provides. Kelp is important in a number of cycles, from nutrient cycling, to carbon cycles, and larval distribution [7-8]. Primary productivity is critical to the function of any ecosystem where organisms, including kelp, use light to produce energy. These photosynthetic organisms are at the base of every food chain and thus support all higher trophic levels in the ecosystem. The kelp in these forests provides food for every species that inhabit the ecosystem, thus this primary productivity is integral to life. Kelp provides complex habitat and refuge for organisms within the ecosystem, many of which are native and protected species. Paired with the fact that it is a rich source of food, there is a high level of

biodiversity in kelp forests. Biodiversity is incredibly important as it provides communities with resilience as well as a greater number of services the assemblage may offer.

Urchin Barren Causes

Rocky reef kelp forest ecosystem is under threat, with increasing numbers of urchin barrens forming. These barrens form where urchins overgraze kelp and prevent the kelp population from recovering. This is an ecosystem regime shift, where the ecosystem shifts to a different stable state, often due to disturbance in ecosystem function.

Urchin barrens are a discontinuous phase shift, where the threshold to reverse the regime shift is higher than what was required to initiate the shift. The principle of hysteresis describes this lag, where to return to the alternative stable state of a kelp forest, the urchin barren needs to fall well below the urchin density required to initiate the shift [9]. This creates an issue as the more valuable ecosystem state (kelp forest) is more sensitive than the alternative state, which is compounded by hysteresis, making it more difficult to maintain and conserve. In a study looking at urchin barrens globally, Ling et al. found that the hysteresis of this particular regime shift is approximately one order of magnitude between stable states [9]. Thus to revert back to a kelp forest, urchin numbers must be significantly lower than is required to initiate the original change in stable state.

The commonly understood reason for the regime shift of rocky reefs is the overfishing of urchin predators. These predators are higher in the trophic level and thus control urchin numbers in normal circumstances, however, due to anthropogenic fishing of these species, urchin numbers become uncontrolled [10]. The removal of these predators triggers a trophic cascade, where due to lower pressure on the urchin population from predators, urchin numbers increase drastically. This as aforementioned applies pressure to kelp, as with larger urchin populations kelp is overgrazed, resulting in the regime shift. This negatively affects all species that rely on kelp in this ecosystem, including urchins and their predators, as well as various other organisms.

The most common predator species that are fished are snapper (Pagrus auratus) and lobster (Jasus edwardsii & Sagmariasus verreauxi), both of which are recreationally and economically valuable species. When populations of these and other urchin predators drop due to either anthropogenic or environmental disturbance, urchin populations explode. This leads to the overgrazing and destruction of kelp forests. Not only does this impact every other organism in the environment, but the urchins themselves are negatively affected when kelp populations cease to recover. Studies show that urchins occupying barrens tend to have lower fitness than those in a healthy kelp forest ecosystem. In a number of different aspects, urchins are less healthy after a barren is established, from having lower growth rates to poorer body conditions and smaller gonad sizes [11]. It is clear that urchin barrens have a negative impact on every species that would normally occupy a healthy kelp forest, not to mention the anthropocentric benefits of having healthy kelp forests.

Urchin Barren Prevention

While it is clear that having healthy kelp forests is universally more valuable, urchin barrens are persistent, especially due to them having a high level of hysteresis. So what can be done in order to combat the formation of these barrens as well as facilitate the restoration of existing barrens to kelp forests? There are two facets to the problem of urchin barrens; conservation of healthy kelp forests and restoration of degraded barren ecosystems. Both approaches must be considered and utilised in tandem in order to reverse urchin barrens and maintain kelp forests.

Like any multifaceted problem, there is a litany of solutions and actions that must be considered. Further research is important. The more data there is to understand how kelp forests and barrens function, the more tools can be developed and introduced. For instance, little is known about the exact density of urchins per square metre required to trigger a regime shift from kelp forest to urchin barren. Monitoring techniques and technology are a necessary piece of the puzzle that is restoration and conservation. For instance, in an interview with Arie Spyksma, he explained that he is involved in developing artificial intelligence to classify urchin barrens from still and video imagery. Numerous other researchers are working to find solutions to aid in the understanding and restoration of kelp forests.

Another dimension that we must consider is the political discourse around Aotearoa's oceans. Fishing, both commercially and recreationally, is the human pressure that has the largest impact on urchin predators. If any long-term success is to be had then there must be management and legislation put in place to protect predator species from overexploitation. The key is effective fisheries management that considers ecosystem health and long-term species population success over purely economic gains. Establishing more marine protected areas (MPA) in order to provide refuge for predator species, also results in spill-over, so surrounding areas will be more resilient to the formation of barrens. This spill-over effect has been shown as beneficial to fisheries [12], with this economic advantage of MPA's potentially offering additional support for their creation.

Contemporary science is coming to accept that multifaceted approaches and transdisciplinary action is required for large-scale environmental issues. Urchin barrens are no exception, where researchers may be able to understand and provide tools to help with the restoration and conservation of kelp forests. Policymakers and community action must also work to contribute,

be it by regulating commercial and recreational fisheries or by creating more marine protected zones. Science and technology are not the only tools that must be used to combat the urchin barren problem - science communication, education, policy, and community action are required to make a positive long-term change. Without a cultural understanding of the value these ecosystems have, legislation will not have the support it requires to pass. Without legislation, cultural support science and technology can only do so much, fighting an uphill battle. Like trophic levels we observe in nature, all of these dimensions are linked, they rely on each other to function. Thus, a multifaceted effort must be undertaken to make a long-term and sustainable impact in protecting one of New Zealand's most valuable and diverse marine ecosystems.

Conclusion

Rocky reef kelp forests are an incredibly valuable native ecosystem. Anthropocentric fishing has reduced the number of urchin predators to the point that urchin populations have exploded. Due to this, urchin overgrazing leads to a regime shift turning the once productive and biodiverse ecosystem into a barren that is comparatively undiverse and unproductive. To combat these changes, a mixed approach is required, where passive restoration of degraded ecosystems must be paired with active management (eg. removal or harvesting of urchins). This is further complemented by the formation of more marine protected areas and more effective fisheries management. For the long-term health of New Zealand shores, fisheries, biodiversity, taonga, and people, kelp forests must be restored.

Jarod McTaggart - BA/BSc, Communication, Ecology
Jarod is studying a BA (Communications / Media, Film and Television) / BSc (Biological Science - Ecology) conjoint degree at the University of Auckland. He has a passion for filmmaking as well as the environment. His goal is to make a substantial contribution to conservation in New Zealand, be it through education, research, policy, or environmental management.

Research

Critical Kaupapa Māori Analysis of Theoretical Frameworks that Underpin Longitudinal Studies and Analysis

Caleb Smith

Disparities in Indigenous research exist due to various reasons. The dominance of colonial research structures excludes Indigenous ideologies and knowledge within utilised frameworks. Achieving an equitable research future thus requires addressing Indigenous-specific determinants, involves a Kaupapa approach, engaging Indigenous populations, and decolonising Western research frameworks.

Although in recent years there has been a continuation of progress made concerning the identification of socio-political and economic inequities, the implementation of sustainable changes within the structures that cause these inequities have been far less productive. In New Zealand, colonisation is the root cause of historical and contemporary inequities experienced by Māori that have led to worse quality of life and health outcome statistics compared to their European counterparts. Therefore, the conversation about how we can create and maintain equitable change for Māori populations is not only essential for the health outcomes of Māori now, but also for generations to come. What could be a better goal to strive for than the deconstruction and decolonisation of Eurocentric structures that continue to oppress Māori communities? As this sets an example for other countries around the world to take responsibility for their crimes against Indigenous communities and provide a form of redemption through implementing productive changes that redistribute power, wealth, and freedom back from where it was taken.

The decolonisation of oppressive Eurocentric structures in New Zealand will take time. This is the unfortunate reality of understanding the complexities of deep-rooted systems of oppression where every identified area of productive and equitable change will be met with maximum resistance by the establishment in order to maintain the status quo. Therefore, my research aims to contribute toward the movement forward for the future of equitable health outcomes for Māori. Research, as an example of a discipline that is dominated by colonial and Eurocentric ideologies and worldviews, is oppressive and exclusive of Indigenous populations to ensure the favouring of European populations. This has meant that within longitudinal research, Māori have been excluded as populations that would benefit from the insights that long-term and consistent research has provided European populations. The research I conducted as part of my summer research scholarship identifies areas within longitudinal research methods that could be more equitable both nationally and internationally and provides solutions from a Kaupapa Māori perspective. Kaupapa Māori theory refers to the 'Māori way' of conceptualising the world where Indigenous ideologies and knowledge are prioritised and utilised with the purpose of promoting equitable outcomes for Māori and other Indigenous populations. Longitudinal research methods and outcomes prioritise European populations through implementing Eurocentric dominant ideologies that are disproportionately reflective and inclusive of Māori populations.

The research I conducted specifically looked into the major trends of current longitudinal research practices both nationally and internationally and how these influence the health outcomes of Indigenous compared to European populations. After undergoing an extensive data extraction process, 31 articles were selected and the themes of (1) Indigenous knowledge systems; (2) Indigenous conceptualizations of life course; (3) dominant Western approaches and discourses within longitudinal research; and (4) the progression of equity within the collaboration of Western and Indigenous research. These outcomes were then compared with the Kaupapa Māori theory principles of (1) the right to monitor the crown; (2) the right to have a powerful voice; (3) the right to be counted; and (4) the right to name colonisation and racism.

The main outcome of this research was to present evidence that long-term and sustainable change at both a systematic and structural level is what's required for equitable transformation to occur within not only research but broader contexts. Further, Māori and other Indigenous populations should be prioritised within contexts where the effects of colonisation are prominent. This redistribution of resources, services, and outcomes within longitudinal research outcomes will move the needle in an important and sustainable manner for the advocation of equitable Indigenous outcomes in New Zealand and Internationally.

Glossary

Kaupapa Māori: the principles associated with the 'Māori way of living' which encompasses the philosophy of being "by Māori, for Māori"

Eurocentric: refers to the integrated European structures and systems that prioritise European populations which actively discriminate and dispossess Māori communities.

Caleb Smith - MBChB
Caleb Smith completed a BHSc, graduating in 2021 while developing a passion and focus for Māori and Indigenous health outcomes. He completed an internship at Te Rūnanga o Ngāti Whātua conducting undergraduate research concerning the implementation of equitable changes within sugar-sweetened beverage policy.

Opinion

A Brief Exploration of Developments in the Science of Anti-Ageing

Lucas Tan

Biotechnology

Ageing is an inevitable consequence of life, or is it? This article briefly explores several developments made in the science of longevity, which aims to prolong healthspan rather than lifespan.

The Australian ageing researcher David Sinclair is a professor of genetics and co-director of the Paul F. Glenn Centre for Biology of Aging Research at Harvard Medical School. He mentioned in his 2019 book, Lifespan, that there is no biological law that we must age and that there isn't an upward limit to our age [1]. While medical technology and treatments are advancing at an unprecedented rate, death is still an inevitable predicament we must face. Ageing is a "disease" that all individuals "suffer" from. The average worldwide life expectancy as of 2019 sits at 72.7 years. Developed countries such as New Zealand (81.7 years), Singapore (83.5 years), and Japan (84.4 years) already possess average life expectancies of approximately 150% of the worldwide average in 1960 (52.6 years) [2]. This article aims to briefly explore developments made in prolonging healthspan—a part of a person's life in which they are generally healthy—rather than lifespan, as there would be little benefit of living for an extended period while being bound by machinery or drugs [3].

Exercise

It is no secret that exercise brings about significant health benefits regardless of age group. Regular physical exercise partially mitigates the impact of ageing on physiological functions and helps to sustain the functional capacity of older individuals. Multiple studies have indicated that maintaining a minimum level of exercise, in terms of both quantity and quality, reduces the risk of cardiovascular mortality, protects against certain types of cancer, decreases the likelihood of developing osteoporosis, and promotes longevity. Training programs should incorporate both aerobic and resistance exercises. Additionally, exercises that improve flexibility and balance should be included. While the benefits of exercise appear to be closely linked to the duration and intensity of training, further research is necessary to establish clearer guidelines, allowing the scientific community to provide more precise recommendations [4-5].

Despite the above and there being a sea of scientific literature that demonstrates the potential benefits of exercise in counteracting ageing, it has been found that undertaking excessive chronic endurance exercises may negatively impact cardiovascular health. If one's objective is to reduce the chances of cardiovascular events and enhance life expectancy, a consistent routine of moderate physical activity may be sufficient [6].

Yamanaka Factors

The belief that cells follow a one-way path of differentiation during development was debunked by Takahashi and Yamanaka in 2006 [7]. Yamanaka factors or OSKM factors, including Oct3/4, Sox2, Klf4, and c-Myc, have the ability to transform ordinary somatic cells into pluripotent induced pluripotent stem cells, resembling embryonic cells. However, this transformation was too drastic to be used for in vivo rejuvenation. Nevertheless, scientists have successfully achieved rejuvenation in mice by partially reprogramming cells through the temporary activation of Yamanaka factors [8-10].

Cellular reprogramming using Yamanaka factors has been garnering significant interest, likely due to its feasibility for intervention purposes. Remarkably, this process can lead to the reversal of several key molecular indicators of ageing, offering a promising approach to achieving rejuvenation [11]. Despite their potential, such a rejuvenation method may require extensive testing, and there are multiple regulatory barriers to overcome.

Calorie Restriction (CR)

Restricting calorie intake can extend the lifespan of various species and safeguard non-human primates from age-related ailments, as demonstrated in various studies [12]. The use of CR as an anti-ageing strategy holds promise, but it is essential to have a clear understanding of its definition and limitations before considering its application in humans [13]. CR continues to be an active and dynamic field of research, offering a promising avenue for promoting healthy ageing. However, there is still a wealth of knowledge yet to be acquired in this area, e.g. the long-term effects of calorie restriction in humans. In addition, it is essential to acknowledge that caution should be exercised when considering self-implementing CR without the guidance of healthcare professionals such as physicians, dieticians, or psychologists. This is especially important for older individuals, those with a low body mass index (BMI), individuals experiencing negative emotions, or those taking multiple prescriptions [14].

Resveratrol

Multiple studies have documented a diverse range of bioactivities associated with resveratrol, including antioxidant, anti-inflammatory, cardiovascular protective, anti-cancer, anti-diabetic, anti-obesity, neuroprotective, and anti-ageing effects. The anti-ageing mechanisms attributed to resveratrol primarily involve mitigating oxidative stress, reducing inflammatory responses, enhancing mitochondrial function, and regulating apoptosis [15-19]. Resveratrol holds promise as an effective and safe compound for preventing and treating ageing and age-related diseases.

Concluding Words

The science of longevity has made significant strides in recent years, promising a future where human life expectancy can be extended and the ageing process can be mitigated. Through ground-breaking research and technological advancements, scientists have gained deeper insights into the biological mechanisms underlying ageing and have identified potential interventions to slow down or reverse its effects. Collaborative efforts across different disciplines and the involvement of various stakeholders, including researchers, policymakers, and healthcare professionals, will be crucial in translating these scientific discoveries into practical applications and ensuring their widespread accessibility. Ethical considerations surrounding longevity interventions and their societal implications also need to be carefully addressed.

Access to these interventions should be equitable, ensuring that the benefits of longevity science are accessible to people from all walks of life. Developments in our knowledge of the science of longevity offer a tantalising glimpse into a future where living longer, healthier lives become a reality. By continuing to push the boundaries of scientific knowledge, investing in research, and fostering collaboration, we can pave the way for a world where ageing is no longer seen as an inevitable decline but as a manageable process, unlocking the full potential of human life.

Lucas Tan - MBChB

Lucas is particularly interested in the intersection of medicine, techbio, and venture building. He is also intrigued by the applications of AI and LLMs in driving better health outcomes and longevity.

Opinion

Unravelling the Quantum Cosmos: From Uncertainty to Revolutionising Space Exploration

Ayush Varma

Quantum

This opinion piece particularly focuses on the tweaks that quantum mechanics (QM) and associated technology can bring to important space research. The purpose of this piece is to portray strong alternative theories that can be a game-changer in the industry if it is applied in the near future and in this technologically devoted era. This piece uses some qualitative examples to prove points and includes personal foresight that convinces the reader about the impacts QM can make if applied on large-scale space system ventures.

Astronomical observations aided by fundamental physics to assist in exploring space and beyond can be further enhanced by utilising quantum methods. The industry is moving in to equip upgrades in technology; one such prospect is quantum computing. It has proven its capability in past space lab trials to benefit remote satellites and any Earth-to-Space communications [1-2]. Furthermore, it enables more precise measurements that will yield accurate explanations of the phenomena and properties of celestial objects. Alongside equipment improvements, such as sensors, lasers, and reflectors, quantum technologies shall serve to develop better physical mechanisms [1]. Experiments deemed impossible or prohibited earlier due to logistical drawbacks could proceed. It even opens up the possibility for a quantum internet from point A to B, which shall be incomparably faster than current fibre-operated network capacities. These sensing and measuring perks in turn, enable several posed questions to be addressed while setting up a basis for new discoveries. In other words, the application and advancement of QM in space indeed permits the excavation of fresh insights around the expandable and visible universe [1-2].

The theory of the position of matter being uncertain, appearing in two distinct forms, originating from the pioneering wave particle-duality by Broglie, helped define the behaviour of quantum-scale objects. This opened up the scientific world for nondeterministic approaches filled with probabilities. Against Newton's 'Principia' of classical mechanics, Bohr and Heisenberg's findings tried to reconcile subatomic activity with the precise mathematical accuracy of energy states. The experimental results to test the dualism of a quantum object were conducted in the Copenhagen Interpretation, where Einstein famously quoted, "God does not play Dice.'

We know that due to the homogeneous and isotropic nature of our universe, Einstein's relativity is obeyed and matter is governed by the equations of classical mechanics. But to understand the creation of matter, the early stages of the universe need to be considered. The universe underwent an inflationary epoch that fuelled its expansion. As theorised, quantum fluctuations in the cold dark state of the cosmos seeded the first 'budding' atoms and gave rise to the structures we observe today in the post-stages of cosmic evolution.

Advances in high-energy physics and quantum information can point out deeper connections of inflation than just structure-forming perturbations. To identify the earliest light in the universe, we have to travel back in time when the universe was hot and dense. This was a 'mixer' state of antimatter, matter and radiation energy. Radiation in the optical waveband of light, in the form of photons, is extremely energetic. Mapping out its interactions with low-mass charged particles by gauging how the photons react (its density and pressure, as seen by fluctuations in the cosmic wave background) is handy in conceptualising matter's patterns of motion in the early plasma state of the universe.

Every quantum particle with electromagnetic radiation, when measuring its wavelength, corresponding to its energy condition can be directly linked with the associated cooling effect and consequently, the expansion of the universe. At high-energy states, every collision between two quanta could create particle-antiparticle pairs in the presence of the right temperatures. The age of the universe can be estimated in such phenomena, as when the universe expands and cools, these pairs of quanta annihilate away from each other upon collision, resulting in a third particle creation. An example of this is the simple beta decay seen in atomic nuclei, where a neutrino and electron pair are given off as a result of excess energy dissipation. When photons cool off sufficiently, nuclear fusion occurs that oozes out life-giving elements, just like our sun does in its present main sequence phase. Stabilising of the universe theoretically occurs as it is kept ionised by these super-energised photons, at about 3000 K, to form neutral atoms (ground-state electrons), helping us see 388,000 years back in time after the Big Bang. Thus, quantum mechanical transitions and the power of atomic orbitals, thanks to the works of Schrodinger and Lyman, assist in reaching the farthest possible reaches in deep space and view into the distant universe.

More recently, the avenue for space exploration had a brand new addition with the embracing of Einstein's mass-energy equivalence at the speed of light with quantum theories. Research on quantum gravity enables space-time to be considered on a Planck scale with all elemental constants integrated, up to a certain extent. In other words, the fundamentality of gravitational behaviour at astronomic scales (as described

by general relativity with spacetime curvature) cannot be bridged with the probabilistic world. Classically, mass and energy are represented relativistically as vector fields and tensor networks, considering electromagnetic forces. However, the theories of every particle interaction are all quantum mechanical, with contrasting roles of time. Particle physics is solidified by quantum electrodynamics (QED) and the strong and weak nuclear forces shaping our world. This incompatibility of including relativity causes technical difficulties for physicists, causing the need for new concepts. This gives rise to effective quantum field theories involving fluctuations that help 'quantise' gravity [3].

A concrete understanding of quantum gravity can lead to answers to why we live in the particular vacuum we do and the features of the typical ground-state matter in our universe. It does not yet exist as a working physical theory, with implications and existence being debated for over a century - it is still under construction. Forthcoming applications based on the work by Dirac and Femi (on the quantisation and formulation of QED) could include understanding how gravity impacts cosmic scale phenomena at minute levels. Quantum gravity fills a huge missing piece on black hole behaviour and can bring further insight into the origin of our universe [3].

Moreover, the infamous EPR paradox theorises the spin of two quantum particles. Satisfying Bell's inequality, where our universe is 'non-local' and interactions between events, regardless of distance and time, can be connected if at the speed of light. Bell also provided concrete underlying theories of hidden variables to prove that two polarised particles across space cannot be reproduced and shall stay in entanglement under all circumstances. Entanglement is a prospect to behold and can be regarded as a resource to dwell on impossible imaginations. If and once it is commercially applicable, quantum teleportation via sending information to distant receivers at light speed is probable. This means that a packet of data can do a mile across space…literally and can hence drastically upgrade current space communication systems [4]. Quantum security is also a significant innovation. User privacy should be ensured as only a single quantum state of 1/2 spin particle is essentially allowed. At this stage, however, entanglement is nothing more than an abstract mathematical notion that needs severe quantifying research [2].

Proposed by Benioff and coined by Sir Feynman, quantum computers and their operations have been in the spotlight to be a brilliant alternative for their sheer speed and processing perks. (Hughes, 2021) IBM, proactively being the current ambassador for quantum prototyping, introduced the system of qubits in practice. Qubits, replacing classical bits (consisting of 0's and 1's), comply with quantum mechanics' most fundamental idea of a quantum particle existing in superposition, i.e., both places simultaneously [5]. This was famously theorized by the 'cat in the box' experiment by Schrodinger. Tweaking these qubits to an extra mode allows the probability of 0 or 1 to occur as per need and via channelling. Superconducting materials and electrical circuitry birth an extremely powerful algorithmic machine that has even been trialled to find through a phonebook of 100 million names with 10,000 operations. This is 5000x fewer operations than those of a conventional computer. Machine learning and AI are likely to be enhanced by the use of quantum computers, improving image and pattern recognition, which in turn can be valuable for the analysis of astronomical data and decision-making technology for spacecraft [5].

A present disabling force stopping worldwide commercial applications of a god-like technology such as this is the control of quantum effects that are extremely finicky and delicate. Quantum computers need to be stored at sub-zero temperatures and within insulated shielding, which allows error correction algorithms to operate by cancelling environmental noise. Groundbreaking space communication feats are in the making with quantum cryptography, which encrypts information between spacecraft and ground stations for missions. [6] Due to the finicky tendency and quantum nature of qubit systems, cosmic phenomena under high pressure, temperature, and strong gravitational fields in space can be simulated. Obstacle detection by remote quantum sensing is tested to be extra sensitive, providing higher precision for spacecraft and satellite navigation, and accurately studying and gauging celestial objects [4, 6].

However, it is important to acknowledge that these devised technologies adopted from century-old concepts, which are ever-so-prone to be violated and revalidated thousands of times mathematically, will face hurdles that will take decades to bring them to full fruition.

In conclusion, the commercial scalability of QM-integrated space research to further craft our scientific understanding of the cosmos is a sight to behold. We can strongly look forward to revolutionising the engineering of practical solutions for safer and transformative space explorations, reaching new heights.

Ayush Varma - BAdvSci(Hons), Applied Physics

Ayush is an astrophysics student who has particular interests in cosmic inflation and the higgs field, with a dream of visiting CERN to witness the LHC in action. He plays competitive badminton and cricket, and enjoys watching astronomy documentaries. You can mostly always find his talkative-self outdoors. He claims to be a buff for Indian movies, and reads fictional thrillers.

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Fun Fact

Polar bears have visible tails, but grizzly bears do not.
They can mate to form 'grolars,' which appear to always have visible tails.

Closing Comments

And with the last turn of the page, that's the end of our second edition of 2023!

A big whakawhetai koe (thank you) to our passionate writers, your extensive knowledge and curiosity for science is what makes our magazine so interesting! We are so proud of the sheer quality of work produced by our own students and look forward to their future involvement with the publication.

Thank you once again to our readers for supporting the magazine and the executive team for all your hard mahi to make this magazine great!!

Keep an eye out for an incredibly exciting edition three, where we explore the intersection between language and science, facilitated by a major collaboration with an international group.

Until then, Ka kite anō!

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Website - uoascientific.com
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