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INTERN REPORT: The importance of connecting people with environmental data: visualisation, access and understanding

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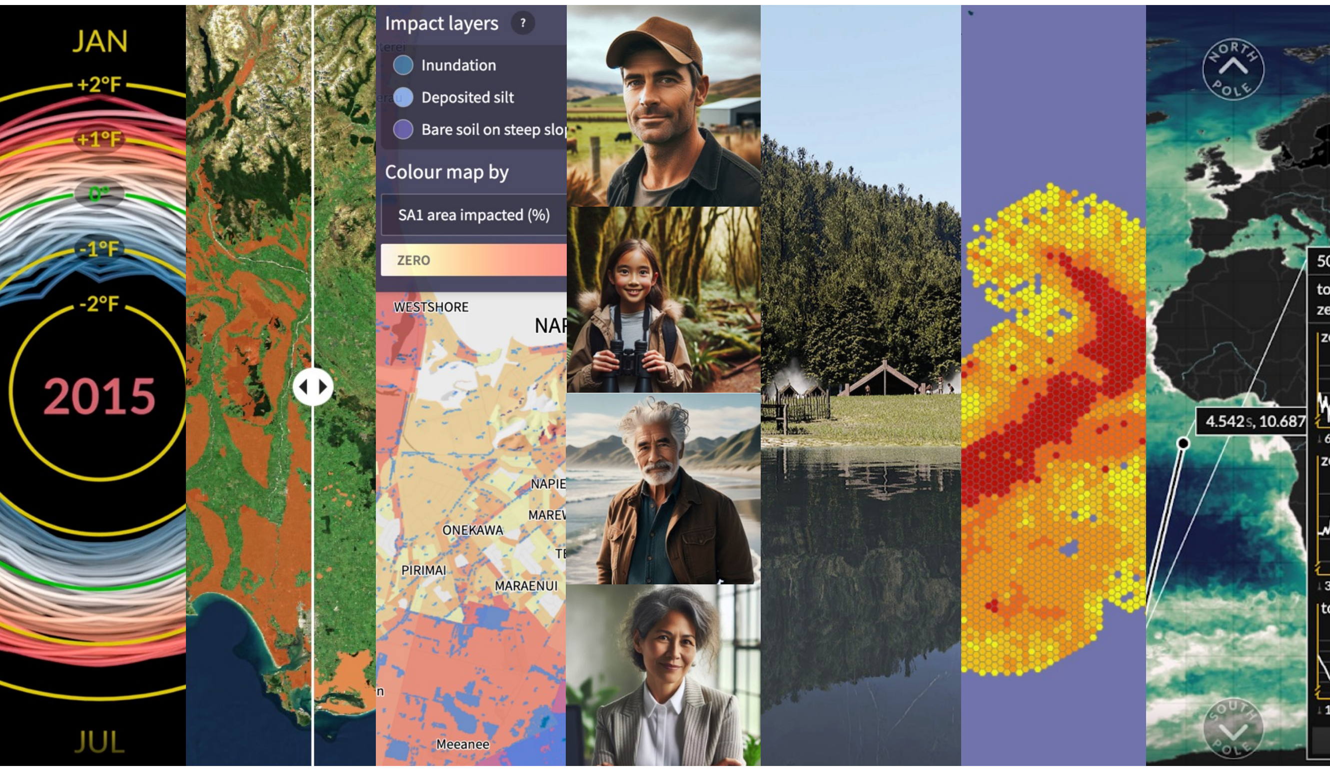
INTERN REPORT

The importance of connecting people with environmental data: visualisation, access and understanding



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1. The importance of connecting people with environmental data: visualisation, access and understanding – Intern Project – Non-peer-reviewed – June 2024

Note on report authorship

This is an intern project report from the Office of the Prime Minister's Chief Science Advisor (OPMCSA) published in June 2024. The lead authors on the report are Nathan Hill and Dr Marissa Le Lec, who contributed equally to this work. The supervisory panel of Prof Bunce, Dr Collins and Prof Tylianakis contributed to both conceptualisation of the work and writing the report. Note that this intern project was commissioned from the Office of the PMCSA and has not been peer reviewed - the views expressed herein remain the sole view of the named authors.

Note on use of images and websites

This report cites and captures images from numerous websites and reports all of which are in the public domain or shared via a creative common licence. The image caption and footnotes seek to provide accurate attribution. The report also contains AI-generated images of personas created using Microsoft Designer. References and links are provided as footnotes when they are used to enable the reader to more quickly access sites they may want to visit.

Report design by Matt Walters, University of Canterbury

Contents

Preface

"Visualisations act as a campfire around which we gather to tell stories." — Al Shalloway, CEO of Net Objectives, 2011.

Natural and productive environments underpin our survival, economy and national identity.

Yet, the cumulative impact of human activities on land, water and atmosphere is difficult to miss. If you look out of your nearest window you will see examples of these impacts—they are all around us.

From climate change through to the biodiversity crisis, our understanding of how to live within sustainable (planetary) limits requires us to measure nature and listen to what it is telling us. We also need to communicate our environmental credentials to achieve market access and to meet global agreements. Whether it be CO2 concentrations, sea surface temperatures or the amount of plastic waste, there is a fundamental need to collect, collate and understand environmental data.

Ideally, this data should underpin our decision-making and policies, but equally it should inform communities of the consequences and cost of both action and inaction. If we need action to tackle these far-reaching environmental issues - it seems obvious that data to support these actions should be both accessible and understood by people from a wide diversity of backgrounds.

With a focus on Aotearoa New Zealand, but looking at overseas examples, this report seeks to explore environmental data visualisation, access and understanding. The report teases out themes and trends in this space, including the value of animations, personalisation, forward projections, artwork and storytelling.

The report concludes with a set of key findings that highlight where gains could be made in understanding and communicating environmental data. We will not be able to tackle the environmental challenges that we face without the support of engaged people and empowered communities. While the use of science to measure the environment is a vital first step, an equally important part of the playing field is to make the data accessible and useful.

Our Starting Point

"The purpose of visualisation is insight, not pictures" — Ben Shneiderman, information visualisation pioneer, 2019

Against a back-drop of crises such as climate change and biodiversity loss, it could be argued that now more than ever, there is an imperative for environmental data to sit at the core of decision-making.

The ecosystems and climate patterns that exist within our environment are inherently complex things. This complexity makes it challenging to study and predict these systems, but it also presents challenges in how environmental data and trends are communicated and visualised.

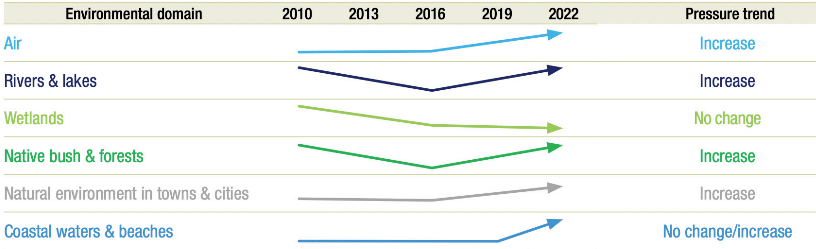
This poses the question that; if we don't understand the data, how is it possible to use data as a decision-making tool? Likewise, how will we understand the consequences of the decisions we make today that future generations will inherit?

"It has to be underlined immediately - no amount of information is valuable if it isn't going to be used" — Simon Upton, PCE, 2022

The Parliamentary Commissioner for the Environment's (PCE) comment above, coupled with his reports on environmental reporting (and funding)[2] were, in part, the stimulus for this report. In Aotearoa New Zealand, we have serious deficiencies with regard to environmental data accessibility, use and reuse. Put simply, and with few exceptions, it is difficult to find, use, and engage with environmental data within Aotearoa. What environmental data does exist online is often fragmented across multiple sites, or worse still, some is held by organisations (some partially publicly funded) that require payment for access.

Due to a gap in commentary on the topic from within Aotearoa, the aim of this project was to take a high level view of how environmental data is visualised and communicated, then reflect on how we, as a country, are going. What can we learn about environmental visualisation and engagement tools being employed overseas, and what are the trends that we should be paying attention to? Is environmental data in Aotearoa New Zealand FAIR (findable, accessible, interoperable and reusable)?

2 Parliamentary Commissioner for the Environment reports



Direction of trends in average perceived state of environmental domains between 2010 and 2022. In general, people perceived the state of the environment to be better in 2022 than they did in 2016. Source: New Zealand Environmental Perceptions Survey 2022 Published by Manaaki Whenua – Landcare Research.

Accessibility can mean different things to different people. Consider water quality of a river; a scientist may focus on the availability of datasets for levels of nutrients or fish quantities. A decision maker might want to know the investment required to achieve a desired outcome, and a member of the public may be seeking to know if it is safe to swim in the river, or to understand if river health is improving. Below, via a set of personas, we explore who might absorb environmental data and their motivations.

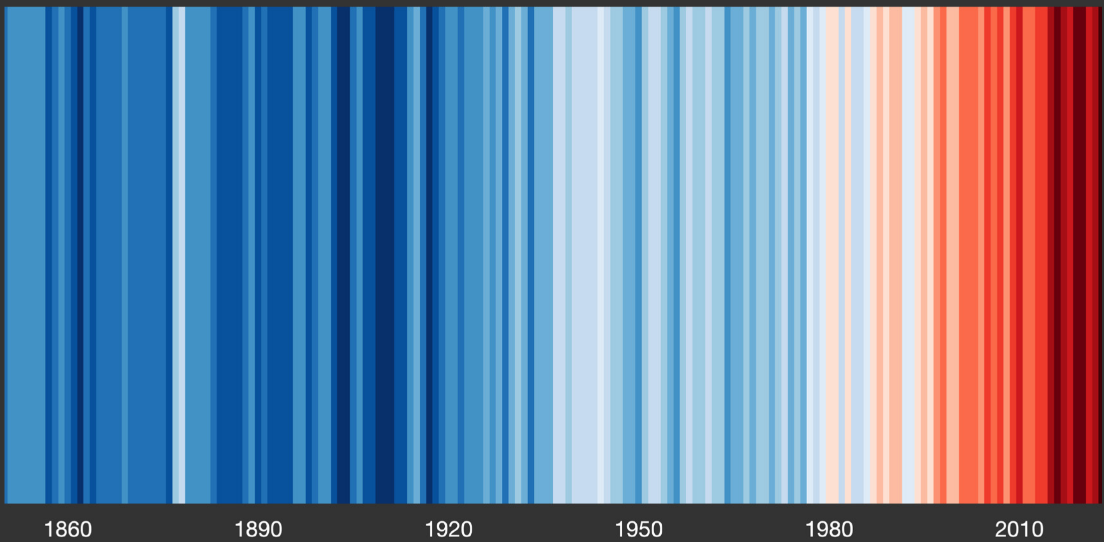
Since 2000, Aotearoa New Zealand has run an Environmental Perceptions Survey[3]. One troubling trend in the most recent report is that the NZ public think that the condition of our rivers, lakes and oceans has been improving. This is at odds with the scientific data where, for example, the 'Our Freshwater 2023' report[4] finds that the health of our rivers is in decline. The reasons for this apparent disconnect might be interesting to explore further, but regardless of the contributing factors, there is a pressing need to visualise environmental data effectively, understand what it is telling us and raise the awareness of environmental issues across the motu.

Our initial starting point for environmental data visualisation was climate stripes (pictured). This is a simple, yet effective means to visualise how global temperature has changed since 1850. Developed by climate scientist Ed Hawkins for an IPCC report in 2018 the #showyourstripes movement has grown and has been used to illustrate numerous other global trends including sea level rise and glacier retreat.

As we all look at the environment around us through different lenses, there is likely no perfect tool (or formula) for how to visualise or engage with environmental datasets. So with this in mind we set out to get an overview on what resonates with us, and how visualisations and communication of environmental data are evolving to better empower students, the public, decision-makers and scientists.

3 New Zealand Environmental Perceptions Survey 2022
4 Minister for the Environment 'Our Freshwater 2023' report

Global temperature change (1850-2023)



Climate stripes show change in global temperature between 1850 and 2023 - a simple, yet striking, way to visualise climate change Source: #showyourstripes, University of Reading.

Who needs to understand environmental data and why?

"If we care about our common future and the common future of our descendants, we should all in part be naturalists" — Sir Partha Dasgupta, 2021

This report is a high-level exploration of why it is important to connect people with environmental data, and how to do it effectively. One of the key concepts in science communication is identifying the target audience. In the case of information regarding the environment, and our impacts on it, we feel that the audience encompasses everyone. Therefore it is crucial that we tackle the challenge of making environmental data and science accessible and engaging to a wide diversity of people.

In an attempt to break down our audience into more manageable parts, the NZ-based personas below are fictional (yet hopefully relatable) examples of people who may benefit from improvements to the visualisation, access and understanding of environmental data. As we explore how environmental data is packaged and visualised throughout this report, we will revisit these personas to highlight areas that could help Daryl, Hemi, Naomi, and Sam address the challenges they face within their workplaces and communities.

Persona

Daryl

40 year old Dairy farmer from near Geraldine, Canterbury

AI-generated image

Bio

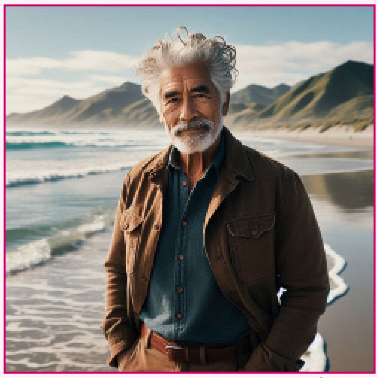
Daryl's whānau has farmed in the Canterbury region for five generations. He, his wife and their three children live on a dairy farm with ~400 cows. He believes it is important to help mitigate climate change for market access and sustainability, but also needs to ensure that his farm remains profitable into the future for the security of his whānau. In addition to meeting environmental regulatory requirements, Daryl is mindful that the market continues to shift towards requiring proof of environmental credentials. He also wants to be able to understand what the effects of climate change will mean for his farm so that he can plan for the future. To realise this aspiration Daryl collects a large amount of environmental data on his farm, such as soil moisture, water quality and feral animal numbers. He wants to maintain control of his data, but also be able to easily combine this with other trusted data sources, such as weather and temperature projections, to get the best picture possible.

Questions that Daryl asks:

- How can he communicate the sustainability efforts he makes on his farm to consumers?
- Are environmental interventions on his farm (e.g. riparian planting) working?
- How are conditions on his farm likely to change in the future? For example, what will the consequences for irrigation and grass growth be?

Challenges that Daryl faces

- No common location to aggregate data from multiple sources including data he and his farmer colleagues have collected themselves.
- Control and privacy concerns; he needs certainty that his own data won't be used against him in any way.
- He is busy and not an expert in data or analysis. He needs a straightforward and easy to interpret data platform to help guide his decision making.
- Environmental decisions at regional and national level which impact on his farm practice and profitability should be made on timelines that he can adapt to.



AI-generated image

Hemi

70 years old. Retired school principal
Te Tai Tokerau (Northland)

Bio

Hemi is a keen fisherman; he enjoys heading out in his dinghy and collecting kai moana with his mokopuna. He is also a kaumātua of his Iwi, and is often looked to for advice.
As a kaitiaki of his whenua, he wants to be well informed about the health of the species and environment in their rohe. Looking to the future, he and other leaders are concerned about the potential risk that sea level rise, ocean acidification and warming oceans poses to te taiao

Questions that Hemi asks

- What are the population trends of local species to inform sustainable harvesting and to support kaitiakitanga?
- Is it safe (e.g., contaminant levels low enough) to collect kai moana from a human health perspective?
- Are species (and data on them) being given appropriate respect as taonga?
- How much risk do climate change and increases in extreme weather events pose to his Marae and rohe? What is the time frame over which they need to adapt?
- What is the best way to share his mātauranga and information about the species and the land?

Challenges that Hemi faces

- Data is not aggregated into a common source and is difficult to access. When data can be found, it is often still difficult to interpret (e.g. are levels of contaminants or nutrients bad enough to be concerned?).
- Long term data is limited, which reduces the ability to see trends in the past or make future predictions (e.g. to inform different harvesting options or whether interventions have worked).
- Hemi would like to see mātauranga interwoven with data collected by scientists as he feels his iwi's deep knowledge of place is being overlooked.

Naomi

50 years old. Policymaker,
Te Whanganui-a-Tara (Wellington)

AI-generated image

Bio

In her job, Naomi has to make environmental decisions in freshwater management that shape the health of waterways across Aotearoa. She values having a thorough understanding of complex issues, so that she can have an informed opinion to present to ministers and her executive team. But she is often overloaded with information, which means that data and concepts that are presented clearly enable her to do her job more effectively. When Naomi gets time out from her busy job, she likes to take her tamariki and her golden retriever to one of the local swimming spots. She is very aware of the joy these natural places bring to her and her whānau and wants to make sure that, through her work, she contributes to helping leave Aotearoa's environment in a better place for future generations.

What Naomi wants to know

- What are the key trends/pieces of information for her to consider when making decisions and prioritising action?
- What are the predicted outcomes for the different environmental management options she is considering? What is the uncertainty associated with these outcomes?
- What technologies should be employed to collect freshwater data - are they appropriate?
- Are the streams and bays safe for her tamariki and dog to swim in?

Challenges Naomi faces

- Data is often complex and difficult to interpret without having substantial experience in the specific subject area. Does she have staff with the necessary skills?
- There is a lack of data showing before and after interventions so it is difficult to track outcomes for investments that she is approving.
- There are few projections of cost of action relative to the costs of doing nothing.
- Water quality information is available for some areas, but limited in many others, particularly in less popular sites.

Persona

Sam

11 years old. Primary school student, Ōtepoti (Dunedin)

AI-generated image

Bio

Like many kids her age, Sam is passionate about nature, and Aotearoa's native species in particular. She enjoys looking for all sorts of creatures in her backyard after school. On the weekends, her parents sometimes take her out to Orokonui ecosanctuary, where she keeps her eyes peeled for sunbathing tuatara. Otherwise they go to one of the many beaches on the Otago peninsula, where she loves to watch pakake or sea lions ride in the surf. Sam wants to see these species thrive, so she is heavily involved with local restoration projects and trapping programmes, and hopes that these will make a difference.

Questions that Sam asks:

- What is the name of a species she has just seen for the first time?
- What species should she be looking out for in her local area or a new place she is about to visit and explore?
- Are the species that Sam finds threatened, common or invasive? Are they improving or declining?
- What did her local region look like before human arrival?
- Are all her restoration efforts such as trapping and weeding making a difference?

Challenges that Sam faces

- Platforms like iNaturalist exist that show species that exist in a particular location but the data is sparse in many locations.
- Like many restoration projects, the project Sam is working on lacks long-term monitoring data or baselines, so any changes to biodiversity are unclear.
- Sam did a school project on the Atlas of Living Australia and wonders why Aotearoa does not have something similar?

Our approach and purpose

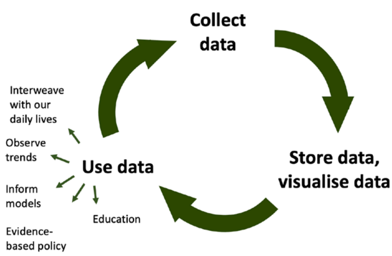
"The greatest threat to our planet is the belief that someone else will save it." — Robert Swan OBE.

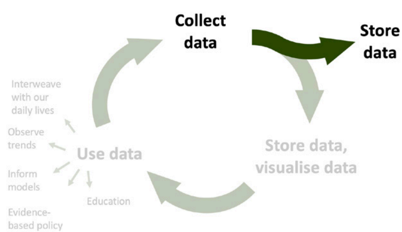
Armed with a sense of why engagement with environmental data is important, and the kind of questions that people ask (or expect) of the data, we next explore how we can elevate this topic within Aotearoa New Zealand.

A detailed dissection of how environmental data is collated, stored, used, understood and visualised is a large undertaking that is beyond the scope of this 3-month project. As many environmental data tools sit on websites, and not in the literature, we rejected the idea of a systematic review of published papers.

In the end, we went exploring for data portals and visualisations that we thought made the data (or concepts) both accessible and engaging. After exploring over 150 websites and documents that host or publish environmental data, the section below showcases examples that resonated with us, or at least provided a glimpse of what good looks like and what trends and techniques work for different audiences. We then interviewed a range of scientists, science communicators and data visualisation experts in Aotearoa to better understand the trends, challenges and opportunities within the New Zealand context.

Rather than focus on one single domain area, we cast the net wide to gain an appreciation for how different disciplines choose to visualise their environmental data. From the simple (e.g. climate stripes pictured above) through to the complex (e.g. water quality metrics), in the scoping phase of this project we categorised the websites we visited as belonging to one of four domains; climate, freshwater, land, and ocean. The aim of these case studies was to provide representative examples where each site/approach demonstrates elements of good data visualisation and points to future possibilities.





Left: Ideal scenario of environmental data 'life cycle' which enables it to be used to its fullest extent. Using the data will highlight gaps in our understanding and incentivise further data collection to fill gaps. **Right:** If environmental data is simply collected and not made accessible, then many opportunities to benefit from it will be lost. In turn this makes it harder to justify ongoing collection of environmental data.

The focus of this report is not on environmental uses of AI, but as we explore this topic, the field of artificial intelligence (AI) is booming and has an increasing footprint within data visualisation. Rarely a day goes by without new innovations in AI including how analytical tools are used to tackle environmental issues. While AI tools may assist in visualisation and explanations of data, any machine learning algorithm is only as good as the data that it can access.

To distil the issue back to its core, we advocate that if people (or AI) don't see the data, trends and consequences of our collective impact on the environment will be missed, the end result being that the status quo will persist. While it could reasonably be argued that we are not measuring enough 'things' in the environment, we would counter that it is also important that what we do measure is findable, accessible, interoperable and reusable (FAIR). In a feed-back loop (see graphic on page 15), we envisage a state where the accessibility of environmental data is the catalyst for collecting more of it as opposed to collection of data to simply store away.

Exploring environmental data and visualisation across four domains: climate, freshwater, land & ocean

"I wish the world was twice as big - and half of it was still unexplored." — Sir David Attenborough

This section of the report explores examples of data visualisation which have been used to shed light on some of the environmental challenges within four different domains—climate, freshwater, land and ocean. These examples illustrate how visualisations have been used to inform decision making, empower action or encourage engagement. Then, in the following section of this report, and following interviews with experts, we explore themes and trends we have seen across these environmental domains as a whole.

Climate

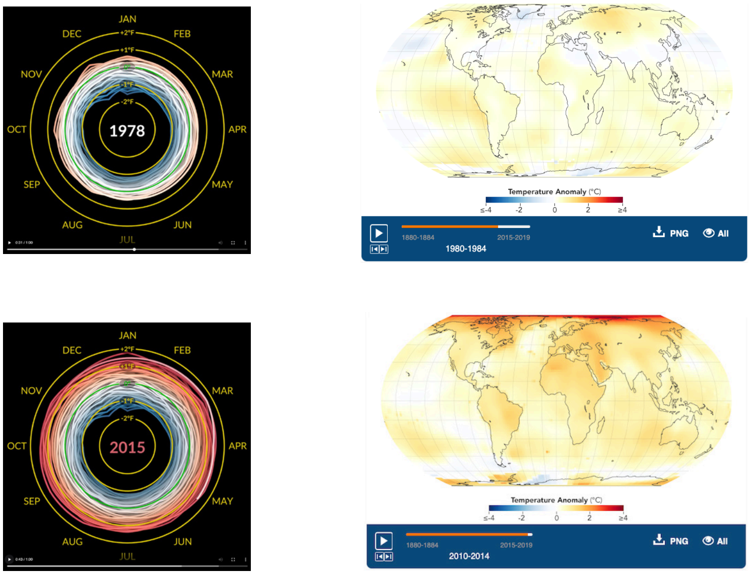
The Earth's climate is in a state of rapid change as a result of greenhouse gas emissions from human activities. Currently, the mean global temperature is 1.1 degrees Celsius higher than in pre-industrial times, and continuing to increase, driving a cascade of other changes. Impacts of climate change are being experienced globally, and are also evident within New Zealand. For example, extreme weather events such as those that hit the North Island in early 2023 (Auckland floods and Cyclone Gabrielle), which caused between 9 and 14.5 billion in damages[5], are around four times more likely to occur in the current climate than pre-industrial times[6].

Extreme weather events such as floods, storms, droughts and wildfires are expected to continue at increased frequency . Rainfall patterns are changing—the south of New Zealand is predicted to become wetter, while the north and east become drier. Sea level rise due to melting of the polar ice caps, in combination with increasing frequency of storms, is putting many coastal areas at risk of inundation. Effective use of climate and environmental data will be essential to understand and respond to climate change impacts.

5 Impacts from the North Island weather events, *Treasury report*
6 Harrington *et al.* (2023). The role of climate change in extreme rainfall associated with Cyclone Gabrielle over Aotearoa New Zealand's East Coast. *World Weather Attribution Initiative Scientific Report*

Current state and events

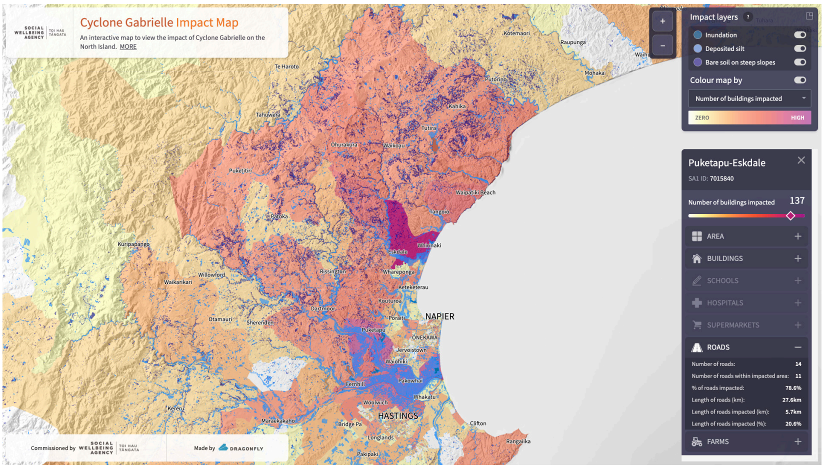
The climate stripes plot shown earlier in this report is a simple and effective way to track the state of the climate and keep the issue in the public consciousness. Animations have also been used extensively in this space. They are an engaging and dynamic way to show change over time, whether that be the average global temperature presented in an animated climate spiral , or temperature anomaly maps relative to a historical reference period[9].



Left: Screen captures of animated climate spirals which show a clear change in average global temperature over time. **Right:** Temperature anomalies over time, relative to a historical reference period, also lend themselves to showing change over time using animated maps. Sources: NASA Climate Spiral (1880-2022) and NASA Earth Observatory.

Visualisation of environmental data can also be used as part of the response effort to extreme weather events. For example, within New Zealand, the Social Wellbeing Agency and Dragonfly Data Science produced an interactive map showing areas impacted by Cyclone Gabrielle[10]. They used changes in satellite images before and immediately after the event to identify areas where inundation had occurred, where silt had been deposited, and where landslides had occurred. Overlaid with social data, for example the locations of buildings, roads and farms, the map was a valuable tool in understanding the scale of the damage and in directing response efforts.

7 Our atmosphere and climate 2023, Ministry for the Environment report
8 NASA Climate Spiral 1880-2022
9 NASA Earth Observatory
10 Cyclone Gabrielle Impact Map



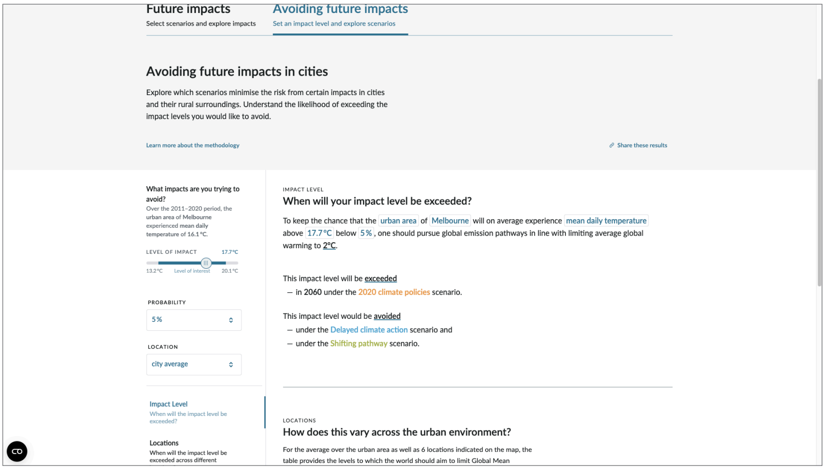
The Cyclone Gabrielle Impact Map produced by Dragonfly Data Science and the Social Wellbeing Agency shows the extent of environmental impacts such as inundation as a result of the extreme weather event, and overlays them with social and infrastructure data. Source: Cyclone Gabrielle Impact Map.

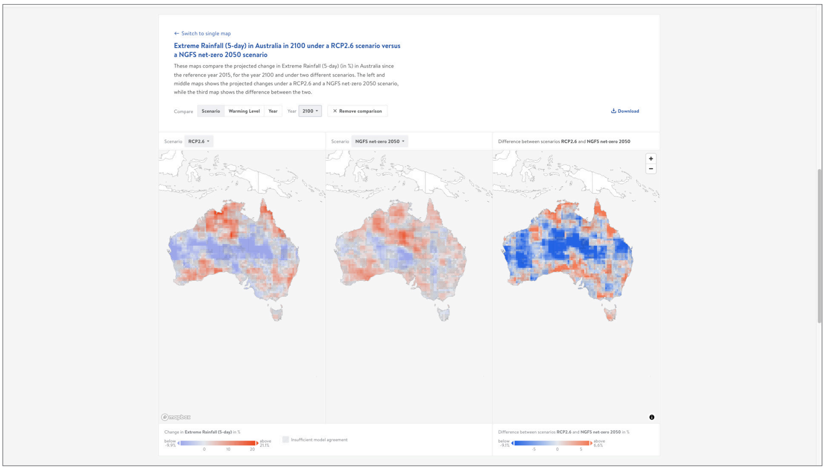
Future predictions

Understanding probable future scenarios for our climate and weather will be critical in many areas of our lives. For example, farmers need to know how weather changes will impact their area in order to make informed decisions about which agricultural practices to pursue, and understand the risks. Likewise city planners and home buyers alike will need to know which areas might be impacted by extreme weather events and flooding. Finally, conservationists might wish to model how species distributions will change as localised climates change, to ensure that ecosystems and species can persist even if their ranges shift (see pages 43–46 for more on modeling).

Presentation of forward projections under different climate scenarios often comes in the format of interactive dashboard-style pages where the user can explore the projected changes to their specific region. This allows a complex dataset to be presented in an intuitive way, and allows the user to quickly find the information relevant to them. For example, the Climate Risk Dashboard[11] and Climate Impact Explorer[12] produced by ClimateAnalytics use dropdowns and sliders to quickly narrow down the desired location, model scenario, and probability thresholds that the user wishes to view.

11 ClimateAnalytics Climate Risk Dashboard
12 ClimateAnalytics Climate Impact Explorer





Climate Risk Dashboard (top) and Climate Impact Explorer (bottom) from ClimateAnalytics make predicted climate scenarios easy to explore by using a dashboard-style visualisation, so that users can quickly find the information they are interested in. Sources: ClimateAnalytics Climate Risk Dashboard and ClimateAnalytics Climate Impact Explorer

Daryl's use case

Daryl needs easy access to high quality climate prediction information to understand how climate change will impact the profitability of his family farm. Does he need to plan for changes to his irrigation strategy? Should he consider sowing a more drought tolerant grass and crops? A dashboard showing predictions of variables such as future rainfall and temperatures, with easy to use filters, and a map where he can zoom in on his family farm, would make it possible for him to access this information.

While these visualisations of climate predictions are on quite a broad global scale, the same principles can be applied to more local-scale data. For example, maps of flood risk areas already exist for some regions, such as the Auckland Council flood viewer[13]. NIWA also presents this sort of information in their 'Our Future Climate New Zealand' page[14], with options to change the climate scenario, climate variable and time period. However, the results are presented on a static image of a national scale map, which makes it tricky for the user to see impacts in their own backyard.

Tracking climate warming-mitigation goals

Stopping further climate warming requires concerted effort at all scales—from the decisions of individuals in their daily lives through to international organisations and policy. Visualisation can help in understanding how we are tracking with our climate change mitigation efforts.

The Systems Change Lab[15] presents social, infrastructure and environmental indicators of progress, which they have identified as being needed in order to achieve the Paris agreement target of limiting global warming to 1.5 degrees Celsius.

Top and bottom-left The Systems Change Lab presents a dashboard of indicators of progress towards climate warming mitigation goals and categories them based on the trend direction and whether they are on track. **Bottom right** Additional detail about each indicator which is available by clicking the 'explore data' button. Source: Systems Change Lab

13 Auckland Council flood viewer
14 Our Climate Future New Zealand
15 Systems Change Lab dashboard

Each indicator or goal is categorised and colour coded into categories of: 'on track', 'off track', 'well off track', 'no target', 'wrong direction' or 'insufficient data'. Each also has an associated plot showing the current trend and the required trajectory to reach the target. There is also the option to see a more detailed graph and text explainers of the data for that target.

This breakdown of a complex system into a set of understandable, actionable points with clear visual indicators is an effective way to understand the progress towards climate change mitigation goals, or lack thereof. The Climate Change Commission He Pou a Rangi is tasked with reporting New Zealand's progress towards our climate change targets, and a dashboard similar to this Systems Change Lab example could be an accessible and intuitive way for the public to engage with New Zealand's progress to mitigating and managing climate change and risk.

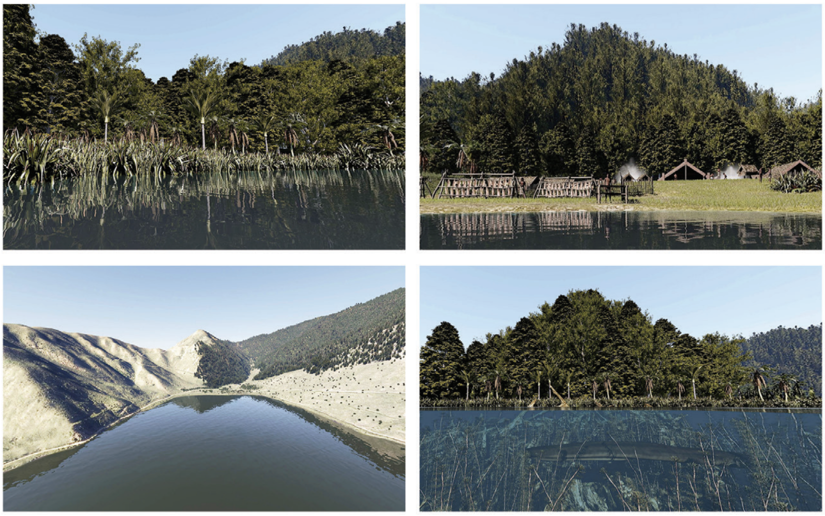
Freshwater

New Zealand's freshwater environment has, and continues to, experience significant change and environmental stress as a result of human actions[16]. Excess amounts of algae can grow as a result of high nutrient levels and invasive species can exacerbate the issue. Collectively, these stresses negatively impact water clarity, recreation activities, and drinking water. Many sites are also no longer safe for swimming or harvesting kai, due to contamination with harmful microorganisms. Finally, changes to the natural courses of waterways, as a result of dams and irrigation, have threatened or destroyed habitat or prevented migration of native species such as tuna (eels) and īnanga (galaxid fish/whitebait).

The changes to our freshwater environments have often occurred gradually over a long period of time, so it becomes tricky to know what the baseline or 'normal' state is. Many people have anecdotes of being able to swim in their now-polluted local rivers when young, but data on the decline of these rivers is not easily accessible. This lack of long-term data is a problem for planning and assessing the effectiveness of interventions and freshwater restoration efforts. What is the state we are trying to restore our lakes and rivers to? What would they have looked like if we had done nothing? A combination of time series data and forward-projection models is needed to address these questions.

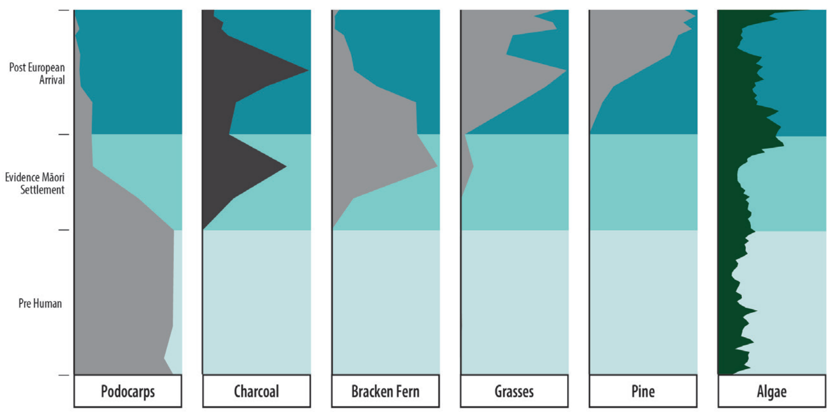
"It's incredibly powerful because we can go back in time now and understand what that lake was like fifty years ago, hundred years ago, or even a thousand years. When community groups and iwi are thinking about what they want the lake to look like, we've got this timeline of where it was. We can have a look at those different points in time and balance that with their current values." — Susie Wood, Lakes 380 project co-lead, 2024.

16 Our freshwater 2023, *Ministry for the Environment report*



The Lake Moawhitu virtual experience, He Reo Nō Te Puehu, produced by Lakes380: Users can choose to view the likely state of the lake during pre-human times **(top left)**, Māori Settlement **(top right)**, present day **(bottom left)**, and in the year 2122 (bottom right). Users can explore a 360 degree view underwater **(bottom left)**, at lake level (top left and right) and from above the lake (bottom left). The virtual experience is accompanied by audio, and pop up icons that provide context and information bites about various aspects of the lake in the different time periods. Source: He Reo Nō Te Puehu.

LAKE MOAWHITU | POLLEN, CHARCOAL AND ALGAE LEVELS FOR THE PAST ~1200 YEARS



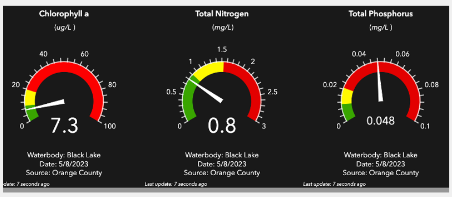
The shaded area indicates the concentration of plants, charcoal or algae through time.

LAKE MOAWHITU SEDIMENT CORE IMAGE

Paleolimnology plots **(top)** and sediment core **(bottom)** for Lake Moawhitu by Lakes380. Source: Lakes380. The virtual experience for Lake Moawhitu shown in the previous images is an alternative way to visualise similar information.

The Lakes 380 project used pollen records from sediment cores, and environmental DNA (eDNA), from lakes across New Zealand to reconstruct the historic state of lakes at various points in history. This has proved not only invaluable in understanding how environmental stressors have impacted the lakes over time, but also inspirational in setting restoration goals for these lakes. They presented their reconstruction of the historic states of the lake as an interactive virtual experience for Lake Moawhitu[17] (pictured on page 23) which transports the viewer into the past and potential future of the lake. When we spoke to Mikayla Holloway and Dr Susie Wood (from the Lakes 380 team), they also highlighted that this approach had much greater appeal to the general public than scientific visualisations like paleolimnology plots (see example below for comparison).

Our freshwater data needs to be easily interpretable. This is not always the case, because of the large number of variables (e.g. nitrate levels, turbidity or secchi depth, *E. coli* levels), which can be unintuitive to someone outside the field. The Florida Orange County freshwater dashboard made this information more accessible by indicating what a 'normal' or 'good' value is, by presenting some tested water quality variables as intuitive dials. At a glance, it is easy to tell whether the values are within 'normal', 'caution' or 'impaired' ranges, and what a 'good' value for that variable would look like. Reducing the effort required by the viewer to understand the data makes for more effective communication of freshwater quality data.



Vs

Chlorophyll a (ug/L)	7.3
Total Nitrogen (mg/L)	0.8
Total Phosphorus (mg/L)	0.048

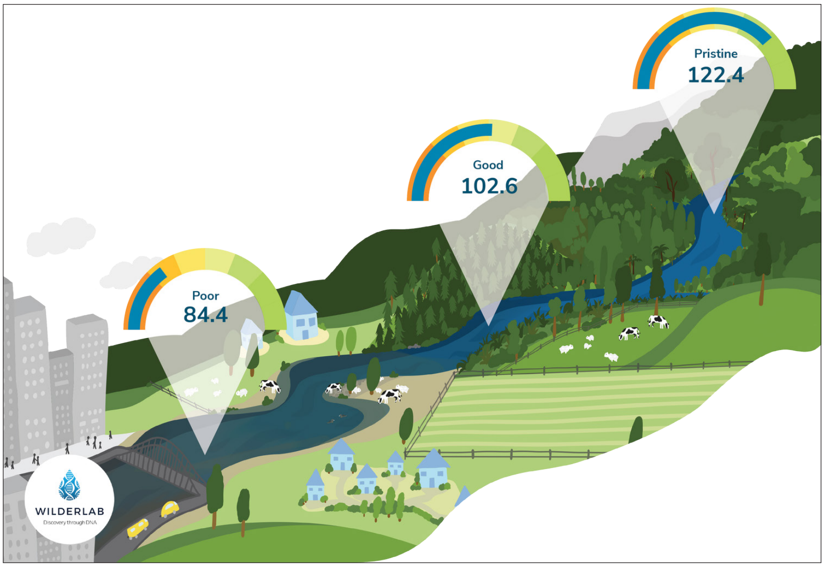
The Florida Orange County freshwater dashboard uses dials to display freshwater variables. These dials put the values into context by showing the ranges of values that would be considered healthy or impaired. **Right:** By comparison, a presentation of these values without context is hard to interpret (fictitious example modelled after many similar real-world examples we found). Source (left): Florida Orange County freshwater dashboard.

Naomi's use case

Naomi is assessing the merit of a budget proposal for the next step of a freshwater restoration project. She needs clear and understandable information on the outcomes of the previous phase of the project, so she can communicate this to her leadership team. Simplifying the many variables from the river sampling into a single index of freshwater health, or displaying them on dials would help her to communicate more effectively.

17 He Reo Nō Te Puehu, virtual experience
18 Florida Orange County freshwater dashboard

Another approach to making freshwater data more understandable is to develop indices, which summarise complex datasets into an understandable single value. For example, a recent study has developed an eDNA index for freshwater health in Aotearoa. The TICI (taxonomy independent community index) is a new DNA-derived index[19] that builds on a similar, but more expensive morphology based index based on freshwater invertebrates. Over 20,000 TICI values have been calculated across Aotearoa in the past two years and it is emerging as a promising way to monitor river health, which distils complex DNA data down to understandable metrics. The TICI index can also be displayed on a dial to put it into context of the expected ranges of values for healthy or unhealthy freshwater environments (see example below)[20].



Graphic illustrating how an eDNA-derived river health metric (called a TICI score) is presented as an accessible way to track the health of a river from its source to a city. Source: Wilderlab.

Land

The 'Our Land 2024' report by the Ministry of the Environment[21] outlines that the largest pressures on land environments in Aotearoa New Zealand are climate change, land use change, invasive species, and pollution. One particularly relevant consequence of all of these pressures is their impact on our species and their contribution to widespread biodiversity loss. For instance, climate induced temperature changes and habitat destruction can make areas unsuitable for some species. Invasive species are also responsible for historic declines in Aotearoa's biodiversity and remain a key threat to many native and taonga species. Two important strategies for engaging people with biodiversity and the pressures they face are biodiversity portals and visual forecasts of species distributions.

19 Wilkinson et al. (2024). TICI: a taxon-independent community index for eDNA-based ecological health assessment. *PeerJ*
20 Wilderlab TICI index
21 Our land 2024, *Ministry for the Environment report*

Biodiversity portals

Biodiversity portals host records of species' occurrences at national and global levels. Increasingly these portals provide in depth insights into where species are located—a crucial step to help protect them. A leader in this area is the Atlas of Living Australia (ALA)[22] which combines Australia's biodiversity data, primarily recordings of species occurrences, with environmental (e.g., temperature, precipitation, vegetation type) and geographical information (e.g., indigenous areas, state, elevation).

Sam's use case

Sam wants to find information about the flora and fauna she might see on her upcoming school trip to the Catlins. There are a few different web pages out there which have some information, but they are complicated, hard to use and require internet access. What she really wants is a platform where all the data is aggregated and she can find a (downloadable) list of species which are found in the Catlins.

The ALA caters to a wide audience. It has features which are suited for education and community groups through to more advanced features that provide value to scientists (e.g., the aggregation of multiple sources of data in a format that can be used for analyses). The portal is used extensively by environmental consultants across Australia in environmental impact assessment (EIA) and restoration projects. ALA supports >500 citizen science programmes and thus, at the community level, helps people to engage with their local biota.

There are many ways for people to engage with Australia's biodiversity within the ALA. For example, users can explore the species in their own neighbourhoods through features such as the interactive maps and downloadable field guides (customised to a specific area) as well as identify unknown species or investigate species that interest them. Importantly users can also participate in building insights by contributing their own observation data (ALA recommended individuals submit observations via iNaturalist Australia[23], Note: iNaturalist is discussed in more detail in Data sources and systems, page 47).

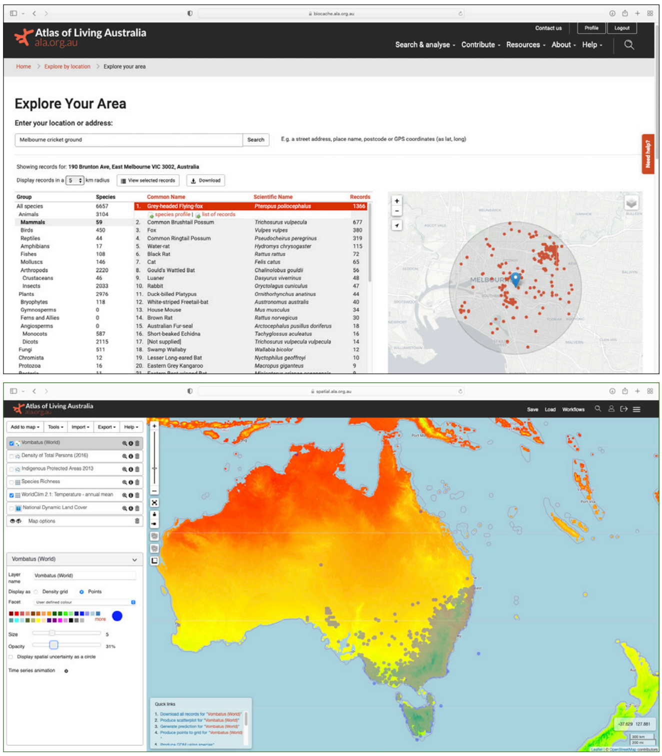
A 2016 cost–benefit analysis was performed on ALA found that for every $1 invested there is at least $3.5 economic value created—the annual value delivered by ALA is at >$26.9 million (AUD)[24]. The report concluded that, based on how it is used by different people across Australia from schools to consultants, ALA provides very good value for money.

Thanks in large part to assistance from ALA, around 25 countries throughout the world such as Austria, Estonia, and the United Kingdom have developed their own living atlas with progress on others underway[25]. Importantly, each living

22 Atlas of living Australia
23 iNaturalist Australia
24 Assessment of the Atlas of Living Australia's Impact and Value, *report*
25 Living Atlases - participants

atlas acts as a node of the Global Biodiversity Information Facility (GBIF)[26] which aggregates biodiversity data on a global scale, making it easily accessible to researchers throughout the world. Any organisation can contribute biodiversity data but GBIF nodes, which are not necessarily part of the living atlas community, manage biodiversity data at national levels and facilitate transfer of local data to GBIF. Since its establishment in 2001, GBIF has become an invaluable scientific resource that currently hosts almost 3 billion occurrence records which have contributed to over 10,000 peer-reviewed papers.

Aotearoa New Zealand does not currently have a living atlas despite strategic calls for one to be established[27]. However, NZ does have a GBIF node to manage biodiversity data in this country—there are ~14 million occurrences, with over half the records originating from eBird[28] and iNaturalist[29]. A living atlas could present this biodiversity-specific information from GBIF within many other features such as the 'spatial portal' (pictured below) and non-biodiversity data (e.g., climate and human population data) included in ALA.

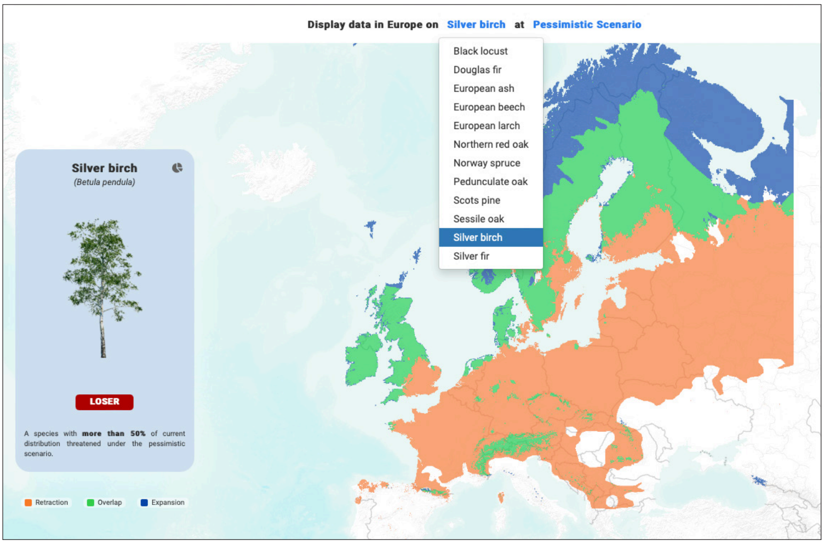


Examples of two features available on the Atlas of Living Australia (ALA). **Top:** The ALA '[Explore Your](#)' feature returns all species occurrences within a 1, 5, or 10km radius of a given location, such as the Melbourne Cricket ground (pictured), or a home address. **Bottom:** The ALA '[Spatial portal](#)' feature displays different types of data simultaneously. Users can add layers to the map and select which to display using the tick boxes (see top left of the image). In this example, occurrences of Vombatus (Wombats) and annual mean temperature are shown. Density of total persons (2016), Indigenous protected areas (2013), Species Richness and National dynamic Land Cover layers have been added but are not displayed in the current view. Aspects such as colour opacity (see bottom right of the image) can be adjusted to make it easier to view different layers together. Source: Atlas of Living Australia.

26 Global Biodiversity Information Facility
27 *Discovering Biodiversity, Royal Society Te Apārangi decadal plan*
28 eBird
29 iNaturalist

Visual forecasts of species distributions

Biodiversity data can also be used to visualise how different species will be impacted by future environmental changes caused by humans. The 'Future Forest Ranges' website[30] is a good example of this. It provides an interactive map showing the predicted range of a selection of European tree species under different climate scenarios. Users can select species of interest and see (through different coloured regions on a map) which areas a species could expand into and which areas might no longer provide suitable habitat in 2070. These sorts of visualisations that project to the future help people to better connect with the consequences of climate change and other environmental changes. Instead of species range shifts being an abstract concept, people can see whether species that they care about might be found in their local area in the future.



The Future Forest Ranges website, produced by Appsilon, shows a map of the predicted range of a selection of European tree species under different climate scenarios. The user can select the climate scenario and species they are interested in and see where its range might retract, expand or stay consistent under that climate scenario. Source: Future Forest Ranges.

Oceans

Oceans within Aotearoa New Zealand's exclusive economic zone cover an area approximately 15 times greater than our land. Although they are less visible to the majority of us, environmental pressures and changes are also affecting our oceans. Increasing temperature due to the changing climate, ocean acidification, plastic pollution, natural resource extraction and fishing are all putting pressure on marine ecosystems[31]. In coastal areas, the environmental impacts of sediment and nutrient runoff, invasive species, aquaculture and coastal development are also evident.

30 Future Forest Ranges
31 Our marine environment 2022, *Ministry for the Environment report*

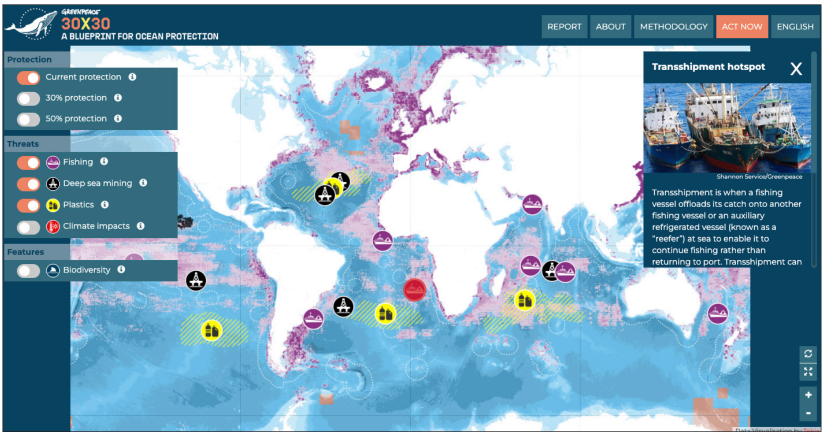
Given that the vast majority of the ocean is not visible to people in their daily lives, it is easy for issues in the marine environment to slip out of people's awareness. Visualising information in a way that creates a link between people and the marine environment can bring these topics into the spotlight by providing pathways to engagement. The plastic tracker visualisation from The Ocean Cleanup[32] personalises the issue of plastic pollution by allowing the user to track where a piece of plastic from their location might end up in the world's oceans (see Wellington example below).

The Ocean Cleanup's interactive plastic tracker allows the user to input a location and watch the trajectory of a piece of plastic from that location and to where it might end up. In this example a piece of plastic is tracked from Wellington, NZ deep into the South Pacific garbage patch. Source: The Ocean Cleanup Plastic Tracker.

Despite only 62.3% of the world's fish stocks being fished within biologically sustainable levels[33], there appear to be relatively few visualisations of fishing impacts outside of technical reports or scientific literature.

The Greenpeace 30x30 Ocean Blueprint visualisation[34] is one of the few exceptions. It gives a broad overview, showing fishing effort (purple) as well as protected areas within international waters (orange). Filling this visualisation gap would allow non-experts to be more informed of the state of fisheries, both within Aotearoa and on a global scale. However, we acknowledge that this is a challenging area, especially because of the commercial sensitivity of knowledge of the location of fish stocks. Therefore, expanding this area of environmental visualisation requires careful and nuanced treatment.

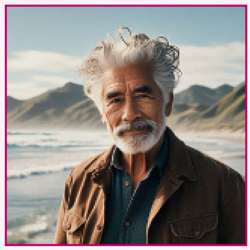
32 The Ocean Cleanup Plastic Tracker
33 The State of World Fisheries and Aquaculture 2024, FAO *report*
34 30x30: The Ocean Blueprint



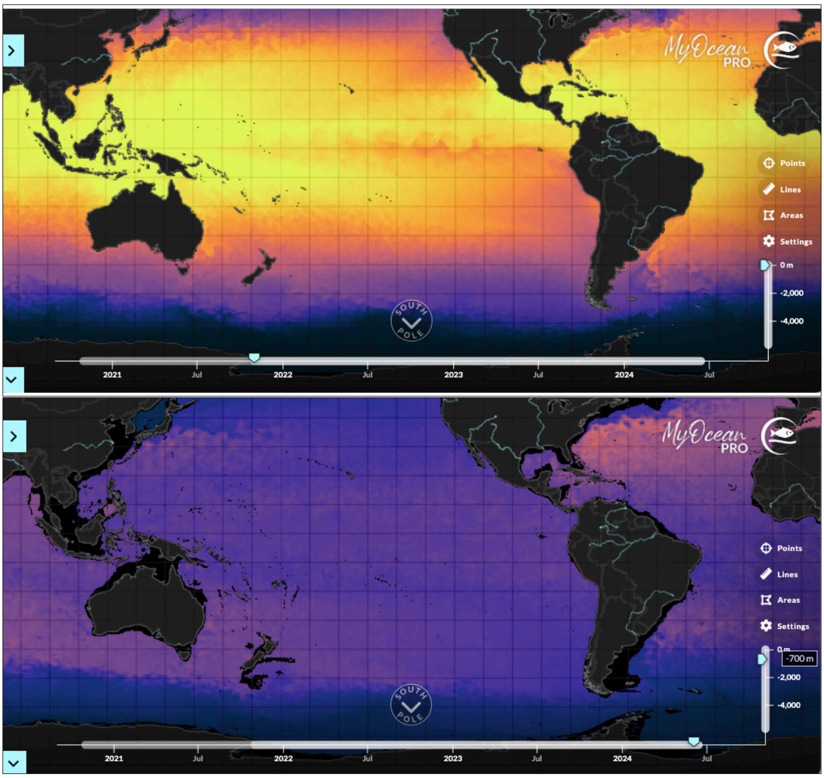
The Ocean Blueprint visualisation, produced by Greenpeace, shows fishing effort and protected areas in international waters. This information is overlaid with other threats to the marine environment such as deep sea mining and plastic pollution. Source: 30x30: The Ocean Blueprint, Greenpeace

Hemi's use case

Hemi is concerned about how marine biodiversity is changing. Lower fish numbers in recent years and the arrival of an invasive algae into the area are making him and his iwi concerned. He would like to see trend data for key fish species, and understand if more should be done to control the spread of this unwanted invasive visitor to his rohe.



A particular challenge for presenting ocean data effectively is the three dimensional nature of the ocean, especially when also trying to understand change over time. The Copernicus MyOcean visualisations tackle this challenge in an innovative way by using two sliders (horizontal for time, vertical for ocean depth) to allow the user to easily scroll through and see all the dimensions of the data.



Horizontal and vertical sliders in the MyOcean Pro visualisation allow the user to scroll through all dimensions of the data. For example, the sea surface temperature **(top)** or temperature at 700m depth **(bottom)**. Source: Copernicus MyOcean Pro.

Emerging themes in how to engage with and visualise environmental data

"Never has there been a greater need for writers who can communicate about the environment in such clear, immediate and powerful ways, who can envisage the past as well as the future". — Isabella Tree, Granta, 2020

As we explored over 150 visualisations, and then talked to experts within Aotearoa, we identified a broad set of themes and important considerations when presenting environmental data. While this is by no means a comprehensive treatment, we hope that the commentary below forms a useful starting point for future exploration of this topic.

Understanding and catering to the audience

What is your target audience? This is one of the first things a science communicator will ask. Indeed, the personas above are our attempt to explore who might be (or should be) engaging with environmental data.

Understanding who your message is aimed at will shape decisions around the level of complexity (or the amount of simplification needed) in how the information is presented. It also opens up the possibility of personalising the content, which can often lead to a more engaging visualisation. One trend that we observed is that, while difficult, it is possible for a single interface to have multiple 'modes' which ratchet up the complexity and thereby serve multiple target audiences. Finally, it is important to ensure that the visualisation will be findable by your target audience.

Understanding the audience, and these considerations of personalisation, simplification and findability, will in turn inform the most effective style of visualisation to use.

Personalisation

People are inherently most interested in the information that is directly relevant to them. Whether it be Daryl's farm or Sam's field trip to the Catlins to explore nature, personalising environmental data is a key form of engagement. The practicalities of such personalisations can be a challenge, as it is hard to tailor visualisations to an audience with a diverse range of perspectives and expertise. However, when done well it can lead to greater interest and engagement than more generalised information.

"We are engaging with a lot of our target audience because we are telling them something that is relevant to them" — Javell Pereka, MfE, 2024

Links to place are a particularly powerful way to engage people with environmental data, because so much environmental data is spatial. If a person collected that environmental data themselves, the connection is stronger still. While place is likely to be important to all audiences, this is particularly true for tangata whenua, because of their strong connection to the land, forged over generations. Therefore maps where users can zoom in and discover information about their local area are a really engaging tool.

"The power of place, in terms of how we tell stories about [environmental] science, is really really important" — Aaron Napier, MfE, 2024

During the Covid-19 pandemic, wastewater dashboards were heavily used to explore and track levels of virus across communities and regions[35]. Most users chose to share their location so that viral trends in their catchment were displayed. This illustrates the strong interest in seeing information relevant to them, their friends and whānau.

Likewise, the Lakes 380[36] team saw evidence of the value of personalisation to place in the hits on their website, which were far higher for resources that were of personal interest to people (the pages about individual lakes—presumably for their local lakes), than the general information pages.

The notion of forging connections between communities and their local data, and then scaling to broader more general datasets, provides a realistic pathway to engage more people in environmental stewardship. Some people may stop at

Daryl

"I've seen the climate predictions saying that NZ is going to be on average 0.8 degrees Celsius warmer by 2040. That's interesting, but it doesn't really tell me much about what it's going to be like on my farm near Geraldine. It'd be great to see that local detail so I can plan for the changes, ahead of time."

35 ESR SARS-CoV-2 wastewater surveillance dashboard
36 The Lakes380 research project

local activities and outcomes, but others may continue their journey and engage at regional, national and international levels too.

Simplification

Simplifying environmental data and concepts is essential to make them accessible. The climate stripes example at the front of this report is a case in point. However, it does come with the potential to oversimplify or even mis-represent the data if not done with care. Therefore, it carries the risk of alienating some audiences. While there is no clear silver-bullet solution to this problem, it may be partially resolved by presenting the information at multiple different levels.

For example, a general understanding of 'freshwater quality' is often all a member of the public would be looking for, not details of nitrates, phosphates, turbidity, *E. coli* levels etc. This user from the general public is likely to be more interested in whether a section of the river close to their house is safe to swim in, rather than the point values of water quality at more distant sampling locations. Presenting too much detail risks alienating them.

Environmental data that resonates across audiences

Environmental data is relevant to a wide range of audiences across Aotearoa, but their needs are different. Sam, as an 11-year old primary school student embarking on a school science project, will be looking for something different in environmental data compared to a policy maker such as Naomi, who might be aiming to use information to make a funding decision or in environmental reporting. A university researcher will be looking for something different again, and may see a portal as deficient if they cannot access the raw data.

"That's putting the public into this amorphous sort of group as though they all have the same needs and wants - and of course - they don't." — Siouxsie Wiles, University of Auckland, 2024

In accordance with FAIR principles the data we collect should be made accessible to all of these groups, but it is unreasonable to expect that the same way of presenting it would work well for all target audiences. A trend emerging is that environmental data should, where possible, be presented at multiple different levels in order to capture diverse audiences and the ways in which they want to engage with environmental data. Some sites show the same data in different ways within the same interface by having toggleable 'simple' and 'complex' modes.

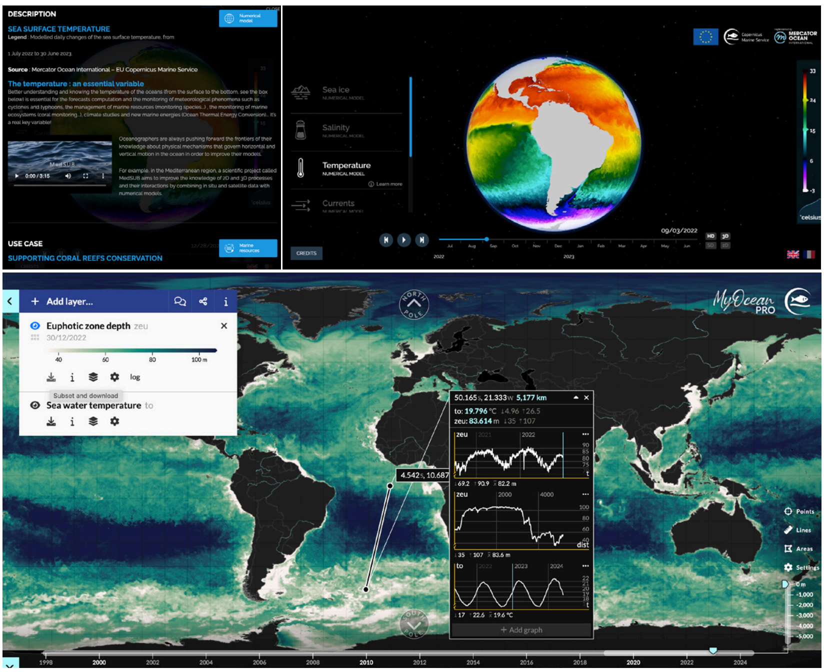
The MyOcean[37] series of visualisations by Copernicus demonstrates an engaging way to cater to multiple different audiences, through the use of its 'Learn', 'Light' and 'Pro' versions (basic, intermediate and advanced). While the same dataset underlies all three, in the 'Learn' basic version, a selection of the simplest variables are presented. They are accompanied by text explainers and links to videos that go into more detail or show examples. The 'Light' version contains a greater range of variables and some basic functions to allow exploration of the dataset. The full

37 Copernicus MyOcean

breadth of the dataset is only captured in the 'Pro' version, which also acts as a portal so that the data can be downloaded for further analyses.

A trend we observed in data visualisations is that starting simple and adding complexity is a preferred approach. Given the complexity of many environmental datasets it is easy to see how intimidating this information can be if overwhelming complexity is presented as the first point of contact.

Another example where presenting data in different forms enabled a broader range of audiences to be reached are the story maps that were produced to go alongside the Ministry for the Environment (MfE) NZ 'State of the Environment' reports. We spoke to Aaron Napier, Javell Pereka and Rowan Howard-Williams, who are some of the team behind publishing the story maps. They made it clear that story maps are better at capturing people's attention and communicating information in a more engaging and understandable way, to a wider audience, than standard reports. Aaron explained that there is an audience (usually specialists) who will always read MfE's 'State of the Environment' reports. However, there are other groups which are less likely to engage with reports, such as school students, for which story maps provide a more effective way to communicate the issues covered in the reports.



MyOcean Learn **(top)** and MyOcean Pro **(bottom)** present ocean data at different levels of complexity to enable different audiences to engage with the data. MyOcean Learn features four simple variables, with text explainers and links to videos associated with each. In contrast, MyOcean Pro gives access to a much larger and more complex dataset, some basic analysis tools, and the ability to download the data. Source: Copernicus MyOcean.

"Are you going to sit down and read a hundred page report? For a huge chunk of the populace—probably not. But if we can hook them with something really interesting for two minutes, maybe we can just land one thing that really resonates" — Aaron Napier, MfE, 2024

Regardless of the quality of data visualisations and dashboards, if their audience doesn't know they exist, then they will not be used. This is the benefit of one-stop-shop resources such as the Atlas of Living Australia, where users only need to locate one platform in order to find a wealth of information. This information can still be presented in different ways suitable for a range of audiences within the single platform.

Styles of visualisation

There are a myriad of ways that environmental data can be visualised. The best options to pick will vary depending on the audience and the type of data. Some of the most common examples we have seen are interactive dashboards, story maps, animations, cartoons and dynamic graphics. Beyond visualisation, a recent trend is to explore data sonification for environmental data where trends are converted into sounds[38].

Interactive data and dashboards

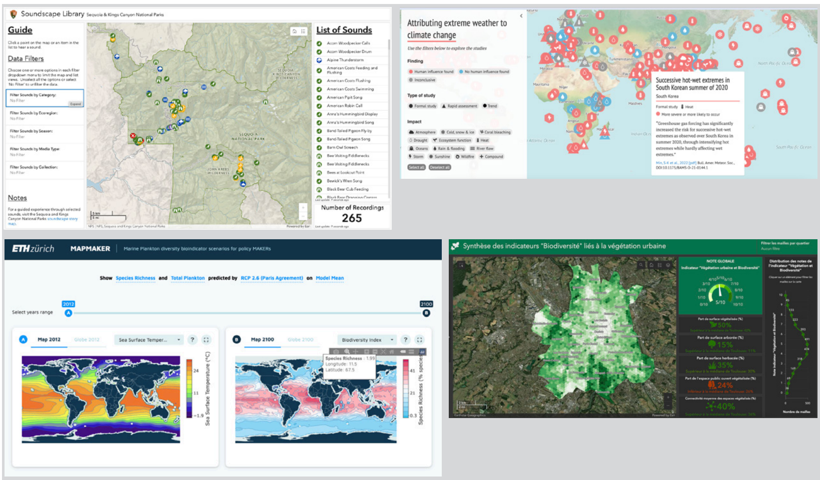
At the scale and complexity that environmental data now exists, presenting all information in a dataset at-a-glance is not really feasible. Using interactive data visualisations or dashboards allows the user to quickly find the data that interests them.

"With complex issues, people have a range of questions that you can't readily answer in one report or analysis. An online presentation of those data allows people to find the information they need to answer their own questions." — Edward Abraham, Dragonfly Data Science

These visualisations usually feature maps that allow the user to zoom in on an area that is of particular interest to them. Sliders are also often used to scroll through the data and see changes over time. Filters allow quick sub-setting of the data. Often plots or dials are used to show summaries of the subset of data currently on display. Finally, clicking or hovering over a point on the map often

38 Russo *et al.* (2024). Improving Earth science communication and accessibility with data sonification. *Nature Reviews Earth & Environment* gives additional information, such as changes over time at that point. This allows a general overview to be displayed, but more detailed information to still be easily accessible.

Dashboards and interactive presentations of data have been used in a wide range of contexts. While discussing the environmental data domains, we gave examples such as the MyOcean visualisations, the Atlas of Living Australia, or the ClimateAnalytics Climate Risk Dashboard. However, there are many other interactive presentations of environmental data, ranging from collections of sound clips in the Sequoia and Kings Canyon National Parks Soundscape Library[39], to maps of extreme weather events attributable to climate change[40], forward projections of marine plankton under different climate scenarios[41], or urban biodiversity indicators[42].



Examples of interactive data and dashboards: **Top Left:** Sequoia & Kings Canyon National Parks Soundscape Library, **Top Right:** Attributing extreme weather to climate change, **Bottom Left:** MAPMAKER marine plankton scenarios, **Bottom right:** Toulouse urban vegetation biodiversity indicators.

Communicating environmental issues through art, stories and more

"Data is powerful but we don't always know how to tell a story with it" — United Nations Sustainable Development Group, 2018.

As we lead increasingly busy lives, environmental issues are often not at the forefront of our minds. Furthermore, many of the general public will not have an in-depth understanding of environmental challenges. If they do not understand the concepts surrounding these issues, they may be less willing to engage with the data or prioritise environmentally conscious actions. Communicating environmental concepts in engaging and emotionally connective ways through art and stories can help bridge this gap. This area encompasses a wide variety

39 Sequoia and Kings Canyon National Parks Soundscape Library
40 Attributing Extreme Weather Events to Climate Change
41 MAPMAKER: Marine Plankton diversity bioindicator scenarios for policy MAKERs
42 Toulouse urban vegetation biodiversity indicators

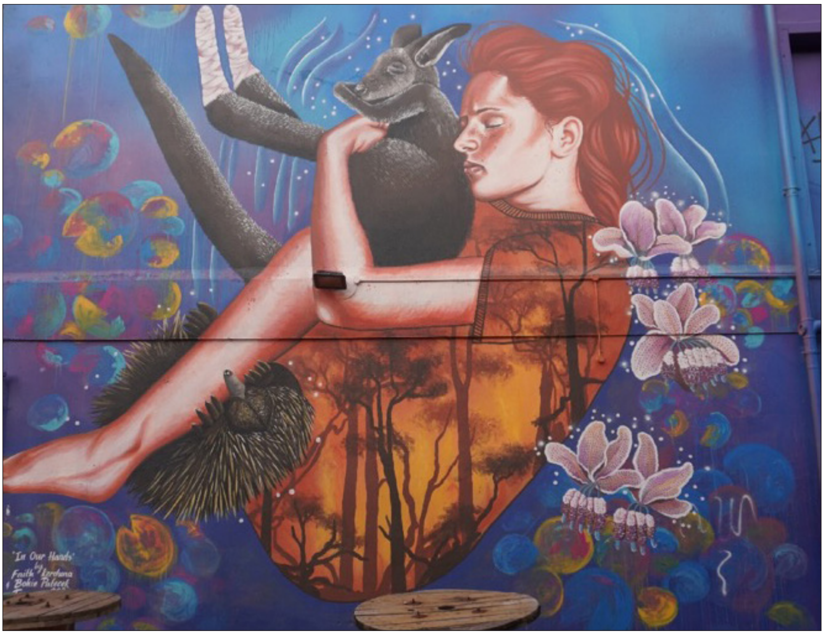
of media, including films, novels, cartoons, paintings, and virtual reality, as the possibilities only expand with the advancement of technologies and the development of AI. Here, we explore just a small selection of examples which we came across during our research and interviews.

A picture is worth a thousand words

Examples such as the virtual experience (see Freshwater, page 22) and future representations produced by the Lakes380 team illustrate that being able to see something in picture form, can help people to better engage with the current, past and potential future states of the environment.

"Photorealistic illustrations are valuable tools for uniting communities striving towards long-term goals. For example, illustrations like the 100-year vision for Lake Oporoa can inspire community members and garner increased support for revitalization efforts." — Mckayla Holloway, Lakes380 Science Communicator, 2024

The Lake Oporoa 100-year vision shows a photograph-like image of what Lake Oporoa could look like in future, based on the actions and goals outlined in Whakahokia te mauri o Oporoa, the restoration plan for Lake Oporoa. It serves as an inspiration for those involved in the restoration work by showing the possibility for the future. Source: Whakahokia te mauri o Oporoa, Lakes380.



Top: A photograph of flooding in Bangladesh by Muhammad Amdad Hossain/Climate Visuals. This image was sourced from the Climate Visuals[43] who specialise in evidence-based photography of climate change. Impactful photographs allow people to see the real-life consequences of environmental change in a way that is often difficult to convey in words. **Bottom:** Street art titled "IN OUR HANDS" (Canberra, Australia) by Faith Kerehona and BOHIE (Photograph by Blake Thompson) which captures the concern of the community about the impact of bushfires on wildlife and their habitat[44]. Paintings like this example can combine multiple ideas and communicate powerful messages, and when presented in public places can take environmental issues to a large audience.

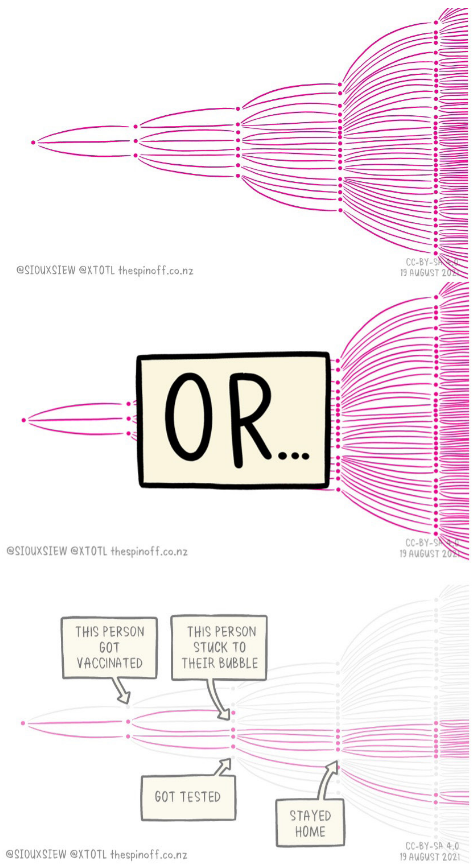
43 Climate Visuals
44 Thompson *et al.* (2023). Street art as a vehicle for environmental science communication. *Journal of Science Communication*

Graphics

In a world dominated by social media and a 24-hour news cycle we are often bombarded with information competing for our often limited attention spans, short-form graphics have emerged as a powerful way to help people to absorb the science and, when needed, to explain difficult concepts.

We spoke to microbiologist and science communicator Associate Professor Siouxsie Wiles about her collaboration with cartoonist Toby Morris, of the Spinoff , during COVID-19 pandemic. The successes and challenges in communicating science during a pandemic are often applicable to environmental domains. The Wiles/Morris team generated ~70 short GIFs to communicate important public health concepts in a simple and engaging way with much of their work going viral online[46].

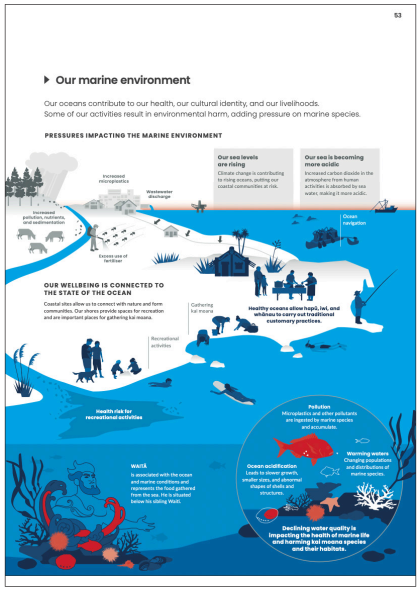
In the interview, Siouxsie Wiles explained that their graphics tried to highlight the importance of individual actions. Reflecting on one of their most successful graphics, titled 'Break the chain' (pictured), a simple illustration about the role of individual actions in reducing exponential spread, she said "It shows how one case becomes many, and then it had this word OR and then we showed if, for example, you stayed home you can basically stop a transmission chain." Siouxsie later commented that "what was really important to us was to show that our actions matter and that each one of us could stop a transmission chain." This GIF went on to receive over 2.5 million impressions on Twitter and was adapted by governments across the world.



Still images of the animated GIF, 'Break the chain' by Siouxsie Wiles and Toby Morris CC BY-SA 4.0. The work shows how our actions can break transmission chains of COVID-19 and was used globally to stress the importance of social distancing.

45 The Spinoff
46 Wiles *et al.* (2023). Going viral: A science communication collaboration in the era of COVID-19 and social media. *Frontiers in Communication*

There are also many longer formats for combining visually engaging images with text which offer a step up in complexity from short-form graphics such as those of Wiles & Morris. These are not as easy to quickly digest but have other advantages such as being able to tell more of a story, provide greater context and illustrate more complex concepts. For instance, comics have been produced to cover environmental topics in Aotearoa[47] and overseas[48,49], and tend to make it easier for people to understand and remember knowledge than equivalent texts[50]. Storyboards or infographics are another example, which have been used by the Ministry for the Environment in Aotearoa (see example below) to represent the content in different sections of their state of the environment reports. These infographics provide a view of the whole environment to show how different parts, including people and their activities, are connected.

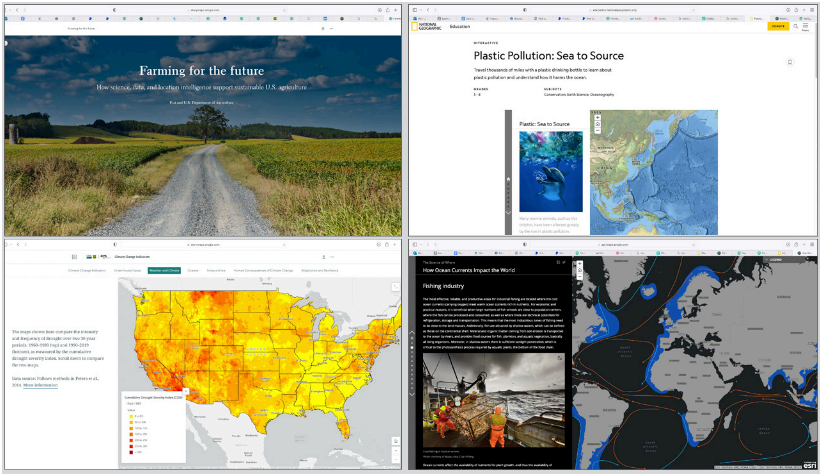


Left: A section of a colouring-in comic strip to help educate 7–11 year olds about climate change by Allan J Hesse (Creative Commons "Sharealike"). Source: Tes website. **Right:** An example of a storyboard from the 'Environment Aotearoa 2022' report.

Integrating interactive visualisations into narratives

As we have seen throughout this report, there are a plethora of interactive visualisation options out there, particularly maps. Just like static images, these can be integrated into a narrative form though Story Map platforms, such as ArcGIS Story Maps[51]. New visualisations and multimedia (e.g., maps, audio, photos, videos) appear to compliment the current piece of text as the user scrolls through. Story maps have been used widely to communicate information on a variety of environmental topics throughout the world for many different organisations (e.g., United Nations[52], USDA Forest Service[53], National geographic[54]).

47 A predator-free New Zealand by 2050 is a goal within our grasp, *The Spinoff article*
48 Are we irreversibly screwed on climate change? This comic gives perspective, *Popular Science article*
49 A kid's guide to climate change, *NPR article*
50 Aleixo and Sumner. (2017). Memory for biopsychology material presented in comic book format. *Journal of Graphic Novels and Comics*
51 ArcGIS StoryMaps
52 WESR Story Maps, UN Environment Programme
53 Minnesota Forests 2018: Interactive Report
54 Plastic Pollution: Sea to Source, National Geographic

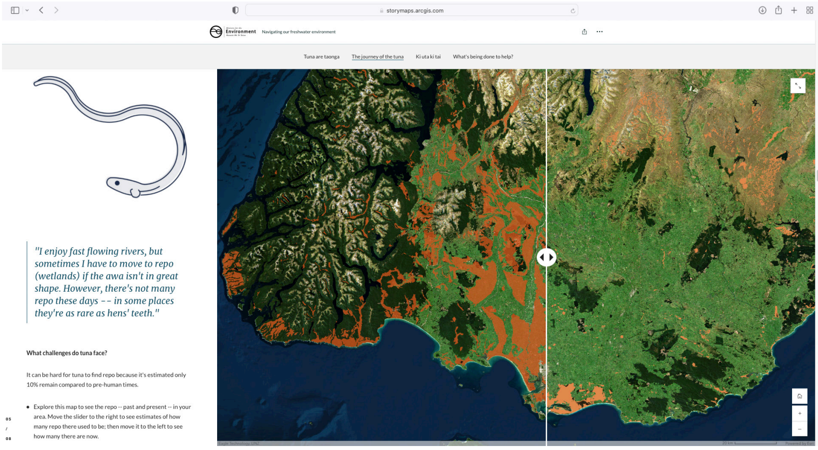


Examples of story maps. **Top left:** Farming for the future (Esri and the US Department for Agriculture), **Top right:** Plastic Pollution: Sea to Source (National Geographic), **Bottom left:** Climate Change Indicators (USDA Forest Service and US Environmental Protection Agency), **Bottom right:** How Ocean Currents Impact the World (Esri).

Story Maps have also been produced by a variety of organisations in Aotearoa. Javell Pereka, from the team that produces story maps for the Ministry of Environment (see: Understanding and catering to the audience, page 32), highlighted that a major strength of story maps is their ability to connect with people with data and concepts through storytelling. For example, their story map, 'Navigating our freshwater environment'[55] (page 43) interweaves a story about the journey of tuna (one of our endemic taonga species – the longfin eel) with information and visualisations that guide the reader through different issues relevant to the freshwater environment from the perspective of tuna (Note: Javell also commented that when working with mātauranga Māori and pūrākau we must acknowledge this indigenous knowledge often belongs at place with iwi, hapū and whānau. This may require permissions or engagement). The MfE storymap team mentioned that another key advantage of story maps compared to normal reports is their ability to explore interactive maps and personalise the data to your own place (i.e., they can explore the areas that they care about)—a powerful way to help people understand the issues they are communicating. They also explained that by allowing their audience to interact with the western science data, story maps facilitate a better understanding of what data is available.

"That's what we want, for people to be interacting and understanding the data so then it makes it meaningful for them and their place" — Javell Pereka, MfE, 2024

55 Navigating our freshwater environment, Ministry for the Environment



Example from the 'Navigating our freshwater environment' story map. A section of the story describing the journey of the tuna (eel). The interactive map allows users to scroll throughout the country and visualise the pre-human and current extent of repo (wetlands) using the slider. Source: MfE

Sam

"My class just looked at a story map which took us on a time traveling journey through Aotearoa's forests from before humans arrived to the present day. I learnt how trees used cover almost the whole country and were teeming with all sorts of bird species that we don't see today. There were fun interactive maps to explore as well, I could even zoom in on where we live in Ōtepoti and see how different it used to look!"

Modelling and predictions using environmental data

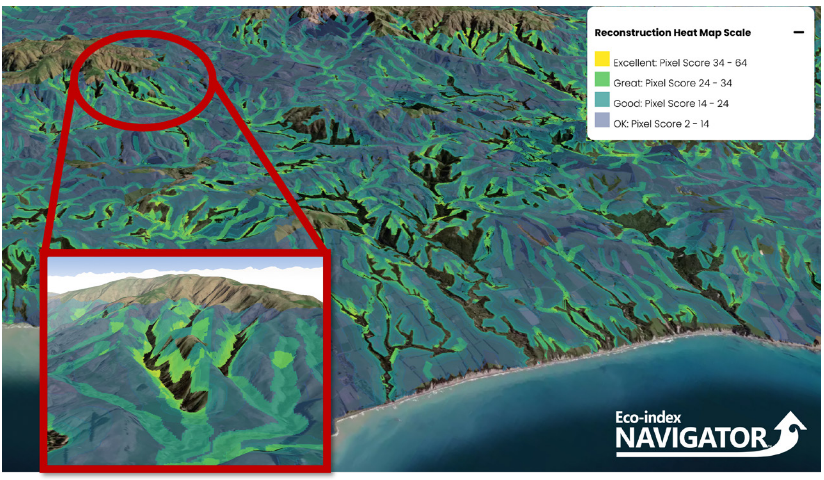
Scientists are typically conservative in predictions of future state, and this is especially true when modelling biodiversity trends. In climate science it has taken decades for the IPCC to land and communicate a set of robust climate models that predict CO_2 levels, temperature changes, sea level and even the financial and health costs of climate change[56]. Difficult as they may be, models, such as those advocated by the IPCC, are vital to understanding national and global environmental trajectories.

Until recently it has been commonplace for decision makers to focus on biodiversity models that predict outcome of a single species (e.g. a commercial fish species or an endangered species). However, increasingly complexity is being

56 Synthesis Report of the Sixth Assessment Report 2023, IPCC report interwoven into species distribution models and also those that can factor in underpinning ecosystem data (e.g. foodwebs) and climate.

Robust modelling of ecosystems (i.e. beyond species models), is difficult due to the complexities of measurement, but as technologies such as remote sensing, acoustics, genetics and cameras improve, so does our ability to improve 'data to decision' pathways. This topic was the focus of a recent Long-term Insights Briefing[57] by the Department of Conservation and Land Information NZ (LINZ).

An example of a promising innovation in 'data to decision' pathways within Aotearoa New Zealand comes from Eco-Index[58]. Eco-Index brings together a range of environmental data and ecological principles into GIS tools to fill information gaps for land managers interested in ecoystem reconstruction. These tools aim toprovide insights into the best bang-for-buck locations to undertake ecosystem reconstruction, as well as estimated costs to establish and maintain native ecosystems, the value of the ecosystem services provided in return, and how the work relates to ecological priorities on a wider catchment, region or national scale. These tools will soon be complimented with AI-driven remote sensing of native ecosystems from satellite imagery that promises to significantly improve options for planning, monitoring and reporting ecosystem changes.



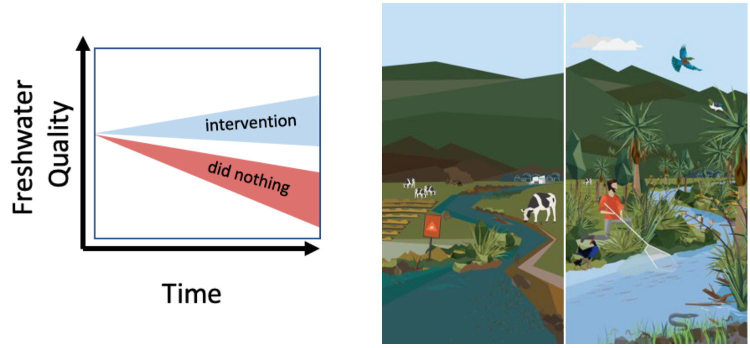
Eco-index Navigator, is one of a suite of digital decision-support tools for ecosystem management produced by Eco-index. It provides guidance on the best bang-for-buck locations to undertake ecosystem reconstruction. Source: Eco-Index

Counterfactuals

In a simple form of model communication it is interesting to consider the outcomes from an environmental intervention with those of the counter-factual which encompasses doing nothing (or the status quo). In the conservation domain, it is crucial to understand the outcomes of conservation actions and investment. In some respects it addresses a key underlying question within Naomi's work where she commonly asks the question "what do I get from investing in this intervention and how can I track outcomes?"

57 The Long term insights briefing from DOC and LINZ 2023
58 Eco-index®: guiding biodiversity investment

In a recent publication Langhammer et al. (2024)[59] explored how we might measure the positive impact of conservation action. The authors conclude that; "More and better counterfactual studies are needed for a wider range of conservation interventions". A NZ-based representation of a counterfactual study that tracks freshwater quality in response to river restoration work is pictured below.



The importance of restoration interventions is more evident when compared to a counter-factual of 'doing nothing'. **Left**: In this theoretical example, models predict that freshwater quality is expected to improve slightly with riparian planting, but by comparing to the 'did nothing' scenario, it is evident that the intervention will have a large positive impact. **Right**: An illustration representing the a river under-pressure (left panel) and how riparian planting (right panel) might improve the health of the waterway over time. Sources: (left) conceptual model based on examples found within Langhammer *et al.* (2024) and illustration (right) from Land, Air, Water Aotearoa

Balancing uncertainty and confidence

Uncertainty is an integral part of forward projections and models—even in the freshwater example above the freshwater quality outcome is more uncertain as we move forward in time. In communicating environmental models, the uncertainty needs to be captured. There is a risk of losing trust if modelled outcomes are presented as a guarantee and do not eventuate. Michael Plank, a Professor of Mathematics from the University of Canterbury who has worked in a wide variety of fields including in ecology and epidemiology reflected that.

"My guiding principle is that models should always be transparent, people should always be able to see the assumptions and the data that is going into the models." — Michael Plank, University of Canterbury, 2024

Presentation of information at different levels and interweaving confidence intervals are both important strategies to communicate environmental challenges and progress. In cases where there is high uncertainty, it is also useful to reflect what the costs are to not using models at all. In such cases, the end result may be that the 'do nothing' scenario persists due to the lack of evidence. Conversely, in an ideal scenario, uncertainty in models could be the impetus to collect more (or different) data to enhance confidence.

59 Langhammer *et al.* (2024) The positive impact of conservation, *Science*

Naomi

"I understand that there is uncertainty when using models, but having animated projections for different policy options based on the best available information brings more clarity to my decision making. It also enables me to communicate our decisions more effectively".

The need for longitudinal data

"Longitudinal data is hugely important—you want to have consistent data collection practices over a period of time—ideally a quite long period of time, so you can see trends and changes" — Michael Plank, University of Canterbury, 2024

In contrast to long-term economic and social modelling (e.g. GDP, the NZ living standards framework or Census) which is commonplace, it is interesting to reflect on why robust longitudinal biotic data is comparatively so limited in Aotearoa. It likely falls into two core categories (i) biota are difficult to measure and (ii) investment into collection of long term datasets has been insufficient.

While there are certainly local examples where longitudinal monitoring has occurred (e.g. plankton tows in the southern ocean[60]), it is fair to say that we are paying the price for not laying down the necessary foundations—it is a common refrain when reading environmental studies to hear authors lament the lack of baseline data.

Visualisation of models

Mathematical models can be complex and unapproachable to many, but the insights they can give should be accessible to everybody. In particular, in order to tackle our many environmental challenges, we must understand change over time in the environment.

Because of this, we believe that it is no coincidence that in this report we happened to gravitate towards visualisations that show the past, or extrapolate into the future (e.g, examples from Lakes 380, Future Forests ranges, and MyOcean found within the chapter Exploring environmental data an visualisations across four domains, pages 17–31).

Animated visualisations (or 'sliders' linked to time) are a very intuitive way to see change over time. Animations can help us appreciate the magnitude of changes or effects that are occuring (e.g. the 'climate spirals' shown on page 18), and they can arguably make the situations they capture more real than static figures, tables or statistics.

60 Australian Antarctic Data on the Continuous Plankton Recorder since 1991

Data sources and systems

While visualising environmental data is important, the importance of the data itself and data structures for it to go into also cannot be overstated. Without good data and good data structures, the process of visualising it becomes significantly slower and more challenging, if not impossible.

Democratising data

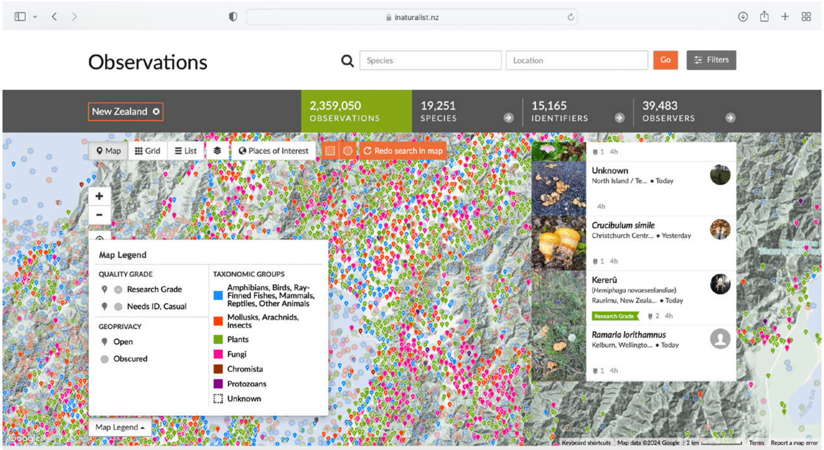
Publicly sourcing environmental data is an opportunity to greatly expand the scale and breadth of environmental data that can be collected. However, it also has benefits beyond the data itself. Engaging the public in collection of environmental data results in them having a better understanding of the state of the environment, and also promotes their involvement in environmental protection[61].

However, good systems of storing and visualising this publicly sourced data are needed to unlock these benefits. Volunteers are unlikely to continue enthusiastically collecting environmental data if it disappears into an inaccessible database or dusty archive and they cannot engage with it.

"How do we create a space where people feel that they can actively participate in sharing information? The reality is that there is so much of it out there that is just not tapped into. We don't have the systems to share it back." — Aaron Napier, MfE 2024

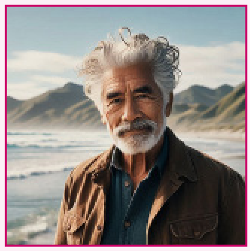
The iNaturalist[62] platform is a powerful way for the public to engage with biodiversity data. Through a global network, it provides a pathway for people, without expert knowledge, to contribute high quality species observations. There are a variety of options to submit observations but an easy way is for the user to simply provide an image using their phone camera to the iNaturailst app. The app will then suggest identification options and once at least two people agree on a species-level identification it can be promoted to research grade. All observations are displayed publicly by iNaturalist (see example on page 48), allowing users to see their contributions to the growing pool of data. So far, more than 190 million occurrences from around 478,000 species have been recorded by over 3 million people throughout the world. This illustrates a clear appetite from the general public to be involved with collecting environmental information, when they are given the opportunity.

61 Gouveia *et al.* (2004). Promoting the use of environmental data collected by concerned citizens through information and communication technologies. *Journal of Environmental Management*
62 iNaturalist



A map view of iNaturalist observations in a section of the lower North Island, Aotearoa New Zealand. Source: iNaturalist NZ

Hemi



"I've been fishing and collecting kai moana along this coast all my life, so I've seen a lot of changes in the species you can find here. Our local and intergenerational knowledge goes back further than online databases. I feel science organisations should care more about the evidence and insights from mana whenua. It's frustrating as kaitiaki because I know our knowledge is valuable when making good decisions"

Within the Aotearoa New Zealand context specifically, there is a huge amount of information available through local knowledge of the land. Setup of systems that allow tangata whenua, farmers, or other members of the general public to participate in collecting information about the environment would be very empowering and allow them to take ownership of tackling environmental issues.

"At the moment data feels really distanced from people. Organisations collect data but often store it in ways that the public struggle to understand or access, let alone have specialist tools to explore" — Aaron Napier, MfE, 2024.

The general public, research organisations and governments are not the only source of environmental data - businesses can also contribute. The Task Force on Nature-related Financial Disclosures (TNFD)[63] recently released their recommendations that businesses should assess, report and act on their nature-related data with more transparency - this might involve proactive release of

63 Recommendations of the Taskforce on Nature-related Financial Disclosures (TNFD) 2023, *report* environmental data. If this TNFD initiative is enacted it has the potential to change the environmental data landscape as such data has traditionally been held as proprietary.

Data systems, portals and access

New Zealand has some powerful data portals. For example, data.govt.nz[64] collates a large number of datasets into standardised formats, and presents the associated metadata alongside them. However, there is also a huge amount of environmental data which is not captured by these portals. Ensuring that our environmental data is available through data portals is needed to be compliant with the guiding principles of FAIR. If FAIR is fully realised for Aoteaora's environmental data it will benefit visualisation tools, transparency and also enable data to be 'AI ready'.

"It requires a commitment to reproducibility, and repeatability, and automation at an institutional level" — Finlay Thompson, Dragonfly Data Science, 2024

To make environmental data accessible and understandable to audiences across Aotearoa, it is becoming evident that we will need to do data visualisation on a larger scale than we are currently. This in turn will rely on having good data systems in place to support it.

If we want our visualisations to update dynamically as new information comes in, they need to be supported by a data system more robust than a spreadsheet. Likewise, it is clear that modern data systems are needed to keep pace with an ever-changing data landscape, where many new information sources are becoming available (e.g. satellite and eDNA data). Although behind-the-scenes systems require upfront effort to set up, they greatly lower the barriers to communicating the data clearly in future, and facilitate its reuse.

64 NZ Data Portal

Conclusions and Key Findings

"To halt the decline of an ecosystem, it is necessary to think like an ecosystem" — Douglas P. Wheeler, EPA Journal, 1990

This high-level report sought to cover a lot of ground over a 3-month tenure. What started out as a number of case studies that explored various environmental visualisations rapidly morphed into a wider discussion on science communication, engagement and trends in the field. In some respects we should have expected this as the topics are deeply interwoven.

The end result, we hope, has showcased why, and how, environmental data is critical to some of the 'wicked' problems that we face as a society. As the PCE noted in his June 2024 address to the Environmental Defence Society "The environment isn't the problem. We are". This begs the question—what are we going to do about it?

To address this loaded question let's first explore a "what not to do" scenario that would lead to bad environmental outcomes. First, we would ignore a raft of environmental problems and resist collection of data so we could justifiably continue to do what we had always done. Second, we would not collate data over time—lack of baselines would enable us to ignore change. Lastly, for whatever data should surface, we would aim to make it inaccessible to people who needed to see it.

Leaving 'what not to do' aside, the experts that we interviewed, and the websites we visited all had a clear underlying message; namely, that we are not going to unite to tackle environmental problems through poor data visualisations and lack of public engagement. Accordingly, there is a need to interweave enduring data solutions and narratives into our environmental mahi—they should not be an afterthought.

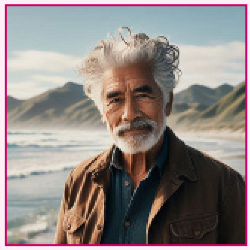
There are some powerful and breakthrough environmental measurement tools available to us from satellites that monitor plankton from space, to genetic tools that can characterise all the biota in a cup of seawater. But whatever the source and complexity of the data, there will always be a need to connect people to the forecasts and findings.

Although we did not surface examples in this report, we must remain aware that environmental data visualisations and data can also be used to mislead people. Transparency in the data we collate is vital to avoid obscuring poor data quality and even its absence.

A common thread throughout much of this report is the value of helping people understand that their actions matter. Visualisations, such as the plastic tracker, can show how our actions can have impacts on places and people across the globe. Art, good design and stories elicit emotional responses, make us more aware of environmental issues, and can make the flow-on effects of our actions clear.

A final comment from each of our personas (below) provides an insight of what each of them would like to see from environmental data in the (hopefully) not-so-distant future.

Hemi



"I imagine a future where biodiversity data is interwoven with local knowledge, and that this information is at our fingertips for myself and others to share. I would like to tell stories about our rohe in the past and present and how the decisions we make today are shaping tomorrow"

Naomi

"Ecosystem data from the rivers I manage is complex - but within a few years I can envisage models that more seamlessly integrate this complexity and provide greater assurance that we are making the right calls for future generations".

Daryl

"We are putting in some hard yards on the farm to work with nature, monitor outcomes, and improve practices. I'd like to be able to show environmental data from my farm to my neighbours, consumers and local government, so that they can see that we are making sound decisions".

Sam

"When I present to my class on the restoration at Orokonui ecosanctuary I'd love to be able to show the difference we have made from all that trapping, planting and weeding. An app where I can show my class how species are returning to this restored area, and why this matters, would be awesome".

Key findings

Our exploration of how environmental data is both communicated and visualised took us on a journey within Aotearoa and across the globe. Perhaps unsurprisingly, this exploration revealed that there is no single approach to what 'good' looks like. Within Aotearoa we found outstanding examples as well as some areas that needed work (or budget to do the work). It is also useful to reflect upon the most deficient form of environmental data, which is when data exists but it is not accessible at all, or sits behind paywalls—this is the antithesis of FAIR. To summarise this report, we wrap-up with five high level 'key findings'. It is our hope that these insights form the basis of more in-depth studies, recommendations or future actions.

1. **There is no single audience for environmental data.** Like our personas Daryl, Naomi, Sam, and Hemi, there are many people that benefit from well communicated environmental data, all with different needs. There is no universal 'one size fits all' approach. Instead, presenting environmental data at different levels, and in different styles, is critical to reach a wide diversity of audiences.
2. **Find engaging ways to present complex data.** Environmental datasets and issues are complicated. Added to this, we are limited in our time and attention spans and can be overloaded in our everyday lives. Presenting data in simple and engaging ways (e.g., personalising data, allowing exploration, through stories, virtual experiences, past and future trajectories) can help people to understand concepts, the messages in the data, and empower the action required to be nature positive.
3. **People should be involved in generating environmental data, not just informed.** Environmental data needs to be democratised by providing frameworks for people to collect and explore their own data, ideally over long time scales as opposed to one-off experiences. Enabling people to bring their own data to the table empowers them to take action and allows them (and their communities) to build a sense of environmental stewardship.
4. **Quality data and data systems and are essential.** Robust data and data systems underpin and enable effective visualisation and communication. Without high quality data, and without considering the data infrastructure, good data visualisation is made significantly harder or even impossible. FAIR environmental data will not be achieved without a focus across the data 'lifecycle', from collection to visualisation.

"We have to resist allowing the environment to become a lightning rod for our economic and social failures. The environment isn't the problem. We are." — Simon Upton, New Zealand Parliamentary Commissioner for the Environment, June 2024.

Acknowledgements

We would first like to acknowledge the support and funding of the OPMCSA (in particular Juliet Gerrard, Susie Meade and George Slim) and the wider Chief Science Advisors forum for providing the opportunity to dive into this fascinating topic. Like navigators they helped steer this project to different examples, and then shared their extensive networks to connect us to experts across the motu. For their time, and willingness to talk with us to share their expertise and insights, we are especially thankful to Javell Pereka, Rowan Howard-Williams, Aaron Napier, Susie Wood, McKayla Holloway, Siouxsie Wiles, Michael Plank, Simon Lambert, and Finlay Thompson. We are grateful to Matt Walters for using his excellent design skills on the formatting and presentation of this report, and Catherine Kirby for her assistance in our section covering Eco-index. We also thank Sam, Daryl, Naomi and Hemi for forcing us to look at problems and solutions through a variety of different perspectives - if you have related to any of their worries, aspirations and needs then they should be duly acknowledged too. Finally, we are grateful to all the people out there that generate environmental data and make it available for us to explore in innovative and engaging ways


JAN
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