Constructing a Publicly Available Biodiversity Map for the Avon-Ōtākaro River Corridor

Billy Greening, Kaylee Jamieson, Eva Kerton, Olga Kuzmin, Sarah Tervoort

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Contents

1. Executive Summary

- The Avon-Ōtākaro Redzone is an 11 kilometer stretch of land along the Avon-Ōtākaro River in Christchurch.
- This project focused on the creation of a publicly available biodiversity map of the Avon-Ōtākaro River Corridor, a project undertaken as part of the ecological restoration of the Christchurch redzone.
- This project originated from the Christchurch 2010-2011 earthquake sequence which saw liquefaction damage along 11km of the Avon River. Under guidance from The Nature Lab & Ōtākaro Living Laboratory, and various other experts, the primary research objective was to map historical biodiversity, identify hotspots, and assess areas for potential revegetation.
- The data collected came from historical black maps, current iNaturalist data, and soil classification information.
- The findings show that, pre-colonialism, the area was composed of herbaceous areas, wetlands, native shrubland, and tussock land, with key plants such as river, fern, tutu, and cabbage trees.
- The post-earthquake analysis shows a transition from a residential area to patchy grasslands and swampy areas.
- The findings also showed a strong relationship between historic sites and soil classifications, providing knowledge for past and future vegetation patterns and spread.
- This map will be a valuable resource for conservation efforts and public engagement as the area transitions into a blue-green corridor.

2. Introduction

This report is focused on the creation of a publicly available biodiversity map of the 602-hectare Avon-Ōtākaro River Corridor (AORC). The AORC stretches 11 kilometres along the Avon River, ending at the Heathcote Estuary. This project was requested by The Nature Lab & Ōtākaro Living Laboratory, whose principal goal is to establish a world leading example of a living laboratory within the corridor (Ōtākaro Living Laboratory, n.d.). The community partners requested this project as biodiversity throughout the corridor had not previously been formally mapped. The primary objectives of this project were to collate existing biodiversity spatial data, identify key areas of significance and present information to the public in a format that is accessible & navigable in the form of an interactive biodiversity map. The creation of this map aims to increase community engagement, help to inform the public on ongoing conservation efforts and to contribute to the restoration of biodiversity along the river corridor.

Christchurch resides on the outer edges of the Canterbury Plains, and prior to European arrival in the mid 1800's the environment consisted of mixed saline wetlands & grasslands that made up the Rokohuia Delta of the Waimakariri River (Canterbury Maps, n.d.). Upon European arrival, the area was extensively drained to make way for pastural land and urban development (Environment Canterbury, 2024). However, the past environment indicates a low water table and loose gravel soils, and with seismic activity this makes the area susceptible to liquefaction and inundation. The AORC was conceptualized post the 2010-2011 Christchurch Earthquakes, which saw the area undergo clearance of housing by CERA (Canterbury Earthquake Recovery Authority) between 2012 and 2015 (Pawson & Blakie, 2024). There was no approved framework to redevelop the area until the group Regenerate Christchurch proposed turning the area into a blue-green corridor with support from multiple community groups (Regenerate Christchurch, 2017). Christchurch City Council approved the plan and is currently responsible for the implementation of the regeneration plan (Department of the Prime Minister and Cabinet, 2019).

A review of relevant literature was vital to be undertaken before work began on the project. Five topics were identified as important to create a comprehensive understanding of biodiversity in the AORC. These topics consisted of the Christchurch's earthquake impact on biodiversity, the significance of biodiversity in urban ecosystems, global case studies of red zones, the ecological significance of wetlands, and the different techniques for mapping and spatial data. This report discusses the findings of the literature reviews. The report then expands on the methods, discussing how the data was collected and processed. The results of the map are identified in this report before being analysed in the discussion. The report ends with a conclusion of our findings, acknowledgements and references.

3. Literature Review

Before mapping the biodiversity of the AORC was conceivable, five areas were chosen to research to develop a working understanding of the study site: Earthquake impact on biodiversity, the significance of biodiversity in urban ecosystems, global case studies of red zones, the ecological significance of wetlands, and lastly different techniques for mapping and spatial data. These topics were chosen to develop a working understanding of the area, and to establish the best approach for the project.

2.1 Earthquake Impact on Biodiversity

When looking at how earthquakes influence biodiversity, it was decided to look at international case studies, the past in terms of dendrochronological studies, and the local Christchurch environment. The internal case study was the 2008 8.0 magnitude earthquake in the Chinese Province of Wenchuan. The 2008 event resulted in an overall decline in forest productivity, with flow on effects to species that depend on the forest (Zhang et al., 2011). However, the gaps the earthquake left in the forest could contribute to new species being able to grow and therefore result in higher biodiversity in the mid to long term (Zhang et al., 2011).

Dendrochronological studies on trees adjacent to earthquakes show that earthquakes can have both positive and negative effects on tree growth. Whether the impacts are positive or negative is reliant on the extent of damage, and the species that can best adapt to the changing environment (Wells & Yetton., 2004) (Vittoz et al., 2001). The fact that tree growth (which is a dimension of biodiversity) can be affected long after an earthquake is a useful foundation to build off when considering present day biodiversity roughly 12 years on since the earthquakes.

In the 2010-2011 Christchurch Earthquakes, damage to trees was mainly a result of trees exhibiting lean, soil liquefaction, and soil cracking (Morgenroth & Armstrong., 2012). Morgenroth & Armstrong (2012) recorded 384 trees removed from city parks as a direct result of earthquake damage, mainly from the Avon and Heathcote corridors. The 384 trees also didn't account for trees on private land, and the paper also highlighted those 30,000 trees exhibited some sort of damage over 4000 hectares across Christchurch (Morgenroth & Armstrong., 2012). This damage one year after the earthquakes gives an indication to impacts on the local biodiversity, and it can be assumed that many more trees have been removed in the years since.

2.2 Challenges of Biodiversity in Urban Ecosystems

Maintaining recovery efforts of biodiversity in urban ecosystems is challenging due to management issues, socioeconomic challenges, and cultural factors (Aronson et al., 2017). This leads to mixed priorities between stakeholders, impairing restoration and conservation of biodiversity in urban areas.

Preservation of biodiversity is hindered due to habitat fragmentation because of urbanisation (Lepczyk et al, 2017). By limiting the movement of species between habitats, this can give rise to novel ecosystems, impacting biodiversity further (Aronson et al, 2017).

Policymakers lack specific goals in conserving urban biodiversity, which make it difficult to hold cities accountable for their biodiversity loss (Nilon et al, 2017). This is also addressed by Lepczyk et al. (2017) who mention that urban restoration sites are of increasing importance however lack clear evaluation of success and effectiveness.

There is a lacking comprehensive approach to urban biodiversity restoration, as there is a dominance of plant-focused restoration efforts (McAlpine et al, 2016). This plant-centric focus limits the development of fully functional ecosystems as it lacks integration of animal species as well (McAlpine et al, 2016).

2.3 Global Case Studies of Red Zones:

This section reviews relevant literature on urban regeneration in post-disaster contexts, with a focus on the Christchurch red zone following the Canterbury earthquake. It emphasises community resilience's, ecological restoration and land use planning as critical elements for effective recovery while taking in cultural values and applying them.

Insights from global case studies revel valuable lessons that could be implemented for Christchurch

- Chernobyl, Ukraine illustrates how minimal human intervention can foster ecological recovery, possibly suggesting protentional for rewilding efforts in the red zone. (Freeman, 2022)
- Lower Ninth Ward, USA demonstrates the effectiveness of community engagement in integrating green infrastructure for sustainable recovery. (Morello-Frosch et al., 2011)
- Fukushima, Japan emphasises the need to balance environmental management with green space development post-disaster. (Nesheiwat & Cross, 2013)
- Bam, Iran showcases the importance of blending historical preservation with modern urban practices, applicable to Christchurch's unique heritage. (Ghafory-Ashtiany & Hosseini, 2007).
- L'Aquila, Italy highlights the necessity of integrating local cultural values into urban planning to reflect community identity. (Bravaglieri et al., 2021)

To summarise, this literature review underscores the importance of diverse methodologies and community perspectives in developing a biodiversity map that not only addresses the ecological needs but also fosters community engagement and resilience within the Christchurch redzone.

2.4 Ecological Significance of Wetlands

The role of wetlands and their ecological significance to Aotearoa was considered in the creation of the biodiversity map of the Avon-Ōtākaro 602-hectare redzone. Wetlands are permanently or intermittently wet areas that support flora and fauna adapted to wet conditions (Myers et al., 2013). The Avon-Ōtākaro redzone contains multiple wetlands within the area, including the Travis Wetland (Sieber, 2006). Therefore, the effect of wetlands on local environments and community-wetland interactions were vital to consider.

The most important ecological significance of wetlands identified by the literature were ecosystem services. Wetlands provide plenty of beneficial services including sequestering carbon, regulating atmospheric gases, and maintaining water quality (Dymond et al., 2021). Wetlands can also mitigate the effect of floods, protect shorelines, and filter pollutants alongside providing a habitat for a high proportion of threatened species (Myers et al., 2013). The literature explored the significance of wetlands to Māori. Wetlands hold cultural and spiritual significance to Māori and have continuously provided a steady source of mahinga kai for centuries (Dymond et al., 2021). Wetlands are ecologically significant to Aotearoa and vital to protect. Ausseil et al. (2008) argued limited spatial data on biodiversity in wetlands across Aotearoa has prevented successful management methods, hindering ecological significance.

The literature supports the creation of a biodiversity map of the Avon-Ōtākaro redzone. The ecological health and wellbeing of wetlands is vital for the continuation of tikanga and Mātauranga Māori, however wetland degradation makes it increasingly difficult. Mapping biodiversity allows insight into the health and mauri of a wetland. Therefore, creating a map of spatial data on biodiversity in Canterbury wetlands will help mitigate management methods and address the concerns of Ausseil et al. (2008).

2.5 Review of Spatial data, Analysis and Mapping techniques for Biodiversity

Initial research into spatial data and methods essential for constructing an interactive biodiversity map of the Avon-Ōtākaro Red Zone, emphasised the significance of mapping the spatial distribution of biodiversity, for the purpose of understanding ecological fragmentation across space. This was highlighted as a major inhibitor to biodiversity, where human activities and urbanisation lead to the formation of isolated biodiverse areas. Studies commonly used Land cover, land use and remote sensing data to analyse and measure biodiversity in ArcGIS. Additionally, tools like inVEST were highlighted in some methods, using predictive modelling to estimate the value of biodiversity in an area based on existing ecology and that of its surroundings. While this may be less suitable due to the unique urban to city transition of the red zone. The data types used to analyse biodiversity, likely still would be for the red zone.

The literature suggests that presenting findings through platforms like an ArcGIS Dashboard, combining spatial and attribute data, could be a valuable tool for the creation of an interactive biodiversity map accessible to both researchers and the public.

4. Methods

The group's approach to creating a publicly available biodiversity map involved several key steps, including stakeholder consultation, data collection, data cleaning, and geospatial analysis.

The methodology used involved a mix of geospatial analysis and data collection from numerous sources. This method allowed the group to produce a biodiversity map of the AORC, which used historical and current biodiversity data and trends. This allowed the group to produce a visual aide for analysing spatial and temporal biodiversity trends.

3.1 Stakeholder Consultation

The process began with an initial meeting at the university with the group, Rob, Eric, Georgie, to understand the project's scope, and identify key data sources. A second meeting followed at the Climate Action Campus to familiarise the group with the area and allow them to identify sights of biodiversity value outside of iNaturalist observations. There were no specific criteria for identifying areas with high biodiversity value, however most of the areas had a high level of native and non-native tree plantings.

3.2 Data Collection and Sources

Software and Tools

- ArcGIS for geospatial analysis because of its compatibility with iNaturalist exports and the group's familiarity with it.
- iNaturalist due to it being the primary source for biodiversity observations in the area.
- Google Earth Pro to create shapefiles manually

Data was collected from multiple sources:

- iNaturalist exports for biodiversity observations, exported using the online export and download tools. Exports were limited to species with high observation amounts or species identified as important community partners such as tree plantings, insects, and lizards
- Blackmaps database for historical land and soil data, which was accessed directly through ArcGIS online
- Avon-Ōtākaro Forest Park website for sites of ecological significance, which were manually digitised using Google Earth Pro
- Redzone transitional lease data via email from Department of Conservation Ranger Zane Lazare
- Toilet and bike trails in the AORC area from City Council website

3.3 Data Cleaning and Processing

The iNaturalist data required cleaning once exported due to issues Māori names and their macrons pulling through with errors. For example, Māori words were pulling through with random symbology such as "M Ω nuka" and needed to be converted to "Mānuka". This process was done using Microsoft Excel 2021, which used the "Find and Replace" tool to correct issues with formatting (Microsoft, 2021).

Location errors, where data points were outside of the AORC border, were fixed using the ArcGIS "Extract Data" feature. This exported all sightings within' the AORC into its own layer, allowing the layer with errors to be deleted and keep only the valuable sightings. These errors likely occurred due to observations from the public being improperly labelled as in the AORC zone when they were not.

3.4 Geospatial Analysis

The layers included in the final ArcGIS map were:

- Foraging trees
- Bird species
- Planting species
- Arachnid species
- Invertebrate species
- Sites of significance as identified by AORC Network
- Soil classification
- Redzone transitional leases
- Blackmaps land cover (soils and vegetation)
- Toilets
- Bike trails
- iNaturalist observations

Pop-ups were configured and provided detailed information for each feature when selected. Additionally, filter options were provided to allow users to display specific features they wanted to see, such as species or land cover.

3.5 Visualisation

The final product used a topographic base map provided by ArcGIS, which gave a detailed visual aid of the geographical features in and around the area. This was intended to help with identifying terrain, elevation, and possible landforms affecting biodiversity spread.

The findings were presenting using an ArcGIS dashboard as this allowed for the integration of spatial and attribute data. This makes the biodiversity map accessible for researchers and the public.

5. Results

4.1 ArcGIS Map Datasets

Figure 1: Legend including five data types displayed in the ArcGIS Dashboard

Seen in figure 1 are the five datasets and their symbology; Black Maps Landcover Soil and Vegetation, Red Zone Transitional Leases, iNaturalist data and Significant Vegetation sites. All the data was sourced from stakeholders, open-source websites or created in Google Earth Pro.

4.2 ArcGIS Dashboard

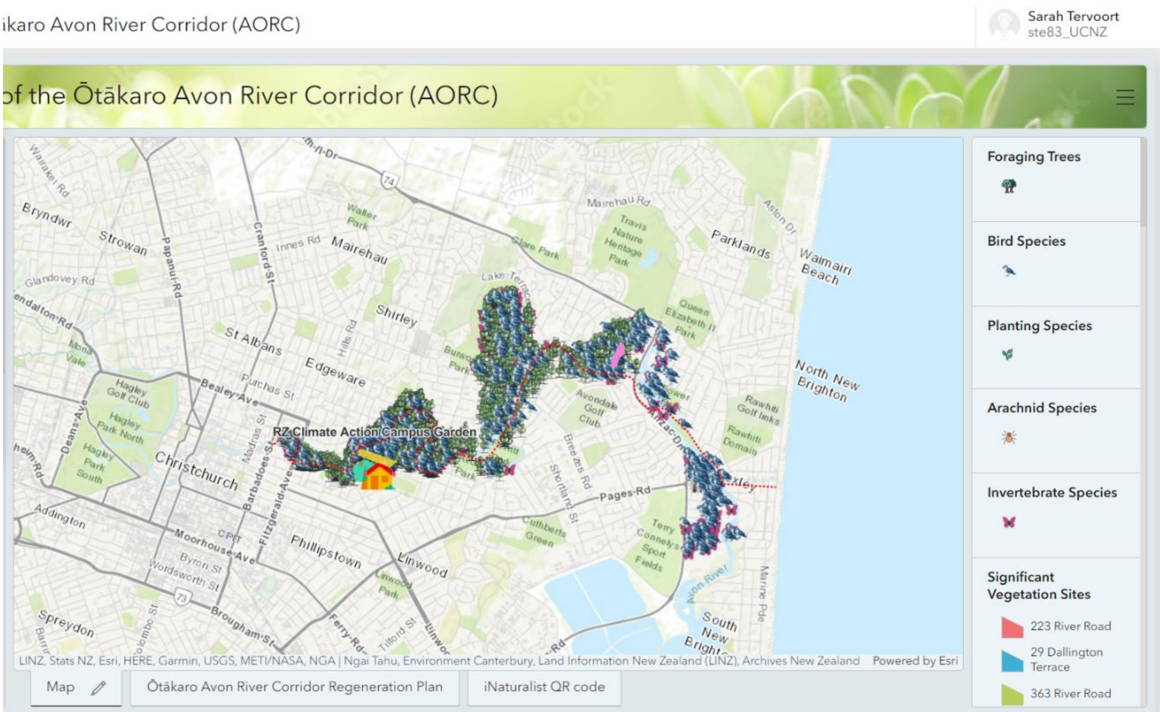

Figure 2: Avon-Ōtākaro red zone biodiversity map showing iNaturalist and significant sites layers

The platform selected to present the interactive biodiversity map, was an ArcGIS Dashboard this allowed for features including, Data filtration, Basic Spatial and Statical Data analysis queries, a QR code linking to iNaturalist and the original Regeneration plan to be displayed.

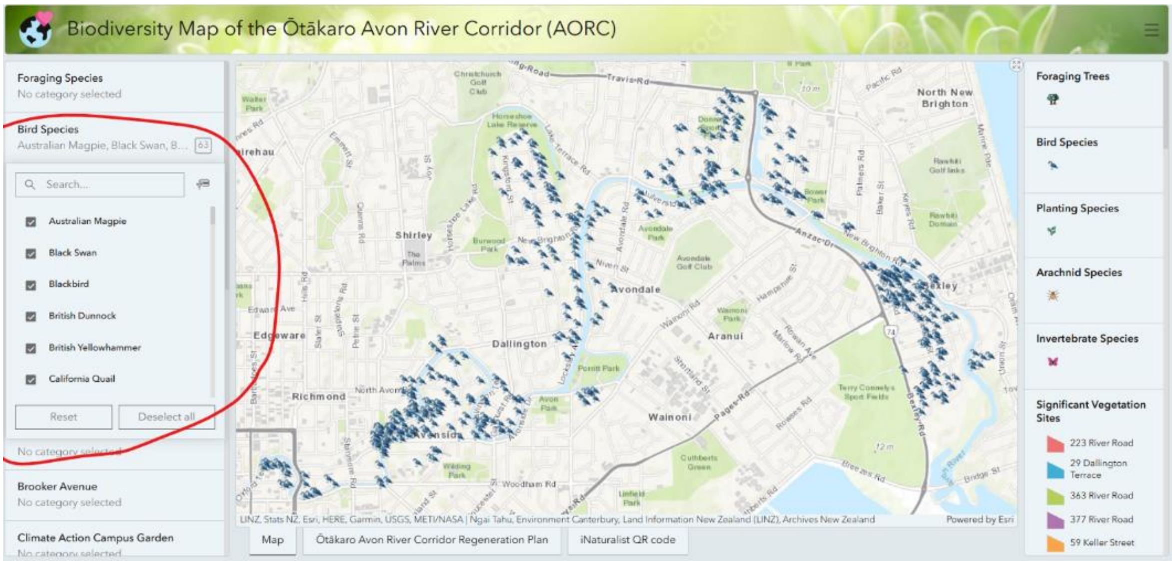

Figure 3: Avon-Ōtākaro red zone biodiversity map filtering to only bird species

Figure 3 shows an example of data filtration, where only specific data sets can be selected for display and specific species can be selected,

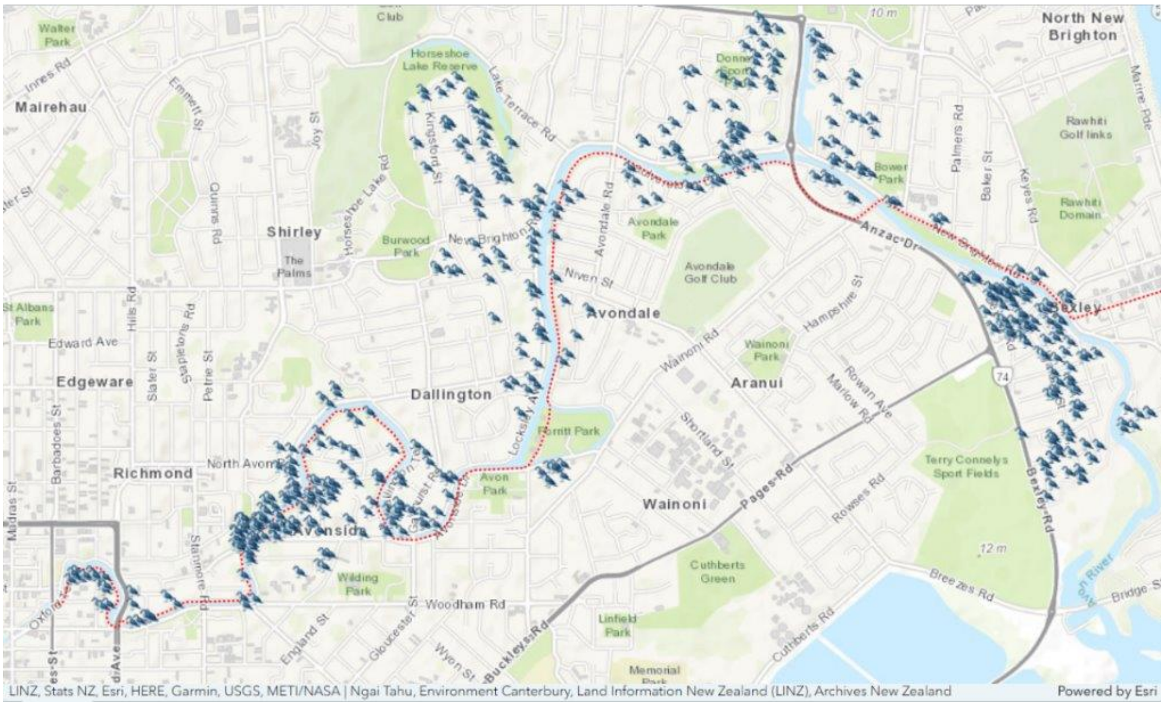

Figure 4: Avon-Ōtākaro red zone biodiversity map filtering to Birds and Bike trail layers for analysis

Figure 4 shows an example of how the ArcGIS dashboard can be used for Basic spatial analysis and Data exploration to investigate spatial relationships.

6. Discussion

6.1 Map Success

The objective of this project was to deliver a biodiversity map of the AORC in a publicly available form, showing both present and past biodiversity. On top of this, identifying areas of high biodiversity value and areas that had high potential for revegetation were also of concern during mapping. In regard to achieving this, the research group has given the community partners an ArcGIS Map and Dashboard that can store and visualize an array of data, as well as upload any new data that may come about. On top of this, a pamphlet outlining instructions on further use has also been passed on to the community partners to facilitate further utilisation of the map. Past biodiversity was achieved by exporting an already existing ArcGIS layer showing the boundaries of previous vegetation present before modern day Christchurch (pre-1850s). Lastly, the biodiversity map has been created in a timely manner in order to encourage public use of the AORC as the Christchurch City Council is beginning construction on the blue-green corridor.

6.2 Framework Considerations

In initial research several options to display spatial data were identified these included an ArcGIS Dashboard, ArcGIS Storymaps, or Powerbi. However, it was determined due to the size of datasets, spatial and statistical analysis needs, only the Dashboard would be a suitable platform for the project, considering accessibility, as both researchers and public would require access to the map.

Using an ArcGIS dashboard allows for the integration of diverse spatial datasets, to observe and analyse spatial relationships. The Dashboard would provide an accessible platform exploratory analysis while more complex relationship could be analysed in the ArcGIS map.

Additionally, it was important to the community partners that new data could be uploaded to the map for future research needs and to update existing data. for example, as more observations are uploaded to inaturalist. An ArcGIS Map and dashboard meet these needs as new features can be uploaded through the base map into the dashboard.

6.3 Key Takeaways

This report has gone into detail about the things that need to be considered when using digital maps and citizen science. Our research project has given our community partner a visualisation of biodiversity within the AORC, and the potential for future citizen science data to be added and updated as needed. Decisions were made along the way to make the map as accessible as possible, such as choices of layering and symbology, to make ease of use for the community partners and the public. The integration of community science data will hopefully engage the local community to contribute to the map as well as engage more with the AORC in general.

6.4 Limitations

The primary source of data used in the map is sourced from the citizen science site, iNaturalist. The arachnid, invertebrate, bird and planting layers were all provided by iNaturalist. iNaturalist is reliant on crowdsourced observations of biodiversity from the public. There are multiple considerations to consider when using iNaturalist data, our focus questions on using iNaturalist data were: What does and doesn't show? Does the data show biodiversity or social patterns? Does iNaturalist better represent outlier observations? Who uses iNaturalist to upload observations?

The spatial datasets utilised, evolved over the project as exploratory data analysis and research into the characteristics of iNaturalist data informed the need for data sets relevant to social relationships to be included in the map. The data, while displaying flora and fauna species, could display more social patterns than ecological. For example, the Te Ara Cycle Trail follows the Avon River in the redzone, and many observations follow along this trail relative to undeveloped areas. Another example is Horseshoe Lake, where iNaturalist observations align with roads and walkways which people frequently use. Therefore, the iNaturalist data is skewed to where people frequent, rather than showing biodiversity uniformly across the AORC.

Di Cecco et al (2021) warns that biodiversity scientists should consider whether user behavior results in systematic biases, and these potential biases should be considered before using it. There are both spatial and temporal biases that affect the data. For example, since iNaturalist is volunteer-based people have more time on the weekends and therefore a strong bias towards increased observations on the weekend. According to Cecco et al (2021), the total number of observations per day is 37% higher on weekends compared to weekdays, and for the total number of user days was 22% higher on weekends. The paper also found there were fewer observations in grasslands, shrublands, and agricultural areas, and an overrepresentation in developed areas. There are also seasonal variations in how often people upload their observations, for example in the summer people tend to upload more due to more people being outside. This doesn’t apply to trees, however for wildlife this will have significant impacts on data, for example in the case of birds they tend to be migratory, and timing of observation is critical.

In terms of historical data, the layer shows previous environments (i.e grasslands, shrublands, etc) and soils, however, doesn’t explicitly show past biodiversity. Although the layer lacks data on historical biodiversity, biodiversity can be inferred from the previous landscapes as native species tend to reside in specific areas.

6.5 Future Research

The foundations of the research project have been completed, therefore future research relies on implementation and diversifying the data set. It has been discussed what limitations citizen science contains, therefore incorporating multiple citizen science datasets such as e-bird would be helpful. Whether or not iNaturalist shows more social or ecological patterns, the next steps to resolve this may be to launch iNaturalist community days where individuals can go out together and examine under-represented areas of the AORC. This would be helpful to increasing community engagement as well as increase the detail of the map.

7. Conclusion

The creation of a publicly available biodiversity map for the Avon-Ōtākaro River Corridor represents a significant step towards understanding and enhancing the ecological health of this important area. This project not only provides a comprehensive overview of historical and current biodiversity within the corridor but also highlights the importance of engaging the community in conservation efforts. The dashboard will be an effective tool for community groups to investigate biodiversity in the AORC. The filters on the dashboard provide a quick and efficient method to analyse biodiversity data. Looking ahead, continued collaboration with community partners will be essential in monitoring the impacts of restoration initiates and ensuring that the biodiversity within the redzone will be preserved for future generations.

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9. References

ArcGIS Enterprise. (2020). Configure pop-ups—Portal for ArcGIS | Documentation for ArcGIS Enterprise. Arcgis.com. https://enterprise.arcgis.com/en/portal/10.5/use/configure-pop-ups.htm

ArcGIS. (2024). Apply filters (Map Viewer)—ArcGIS Online Help | Documentation. Arcgis.com. https://doc.arcgis.com/en/arcgis-online/create-maps/apply-filters-mv.htm

ArcGIS pro. (n.d.). Add a legend—ArcGIS Pro | Documentation. Pro.arcgis.com. Retrieved October 17, 2024, from https://pro.arcgis.com/en/pro-app/latest/help/layouts/add-a-legend.htm

Aronson, M. F., Lepczyk, C. A., Evans, K. L., Goddard, M. A., Lerman, S. B., MacIvor, J. S., Nilon, C. H., & Vargo, T. (2017). Biodiversity in the city: Key Challenges for Urban Green Space Management. Frontiers in Ecology and the Environment, 15(4), 189–196. Ecological Society of America Database. https://doi.org/10.1002/fee.1480

Ausseil, A. G., Gerbeaux, P., Chadderton, W. L., Stephens, T., Brown, D., & Leathwick, J. (2008). Wetland ecosystems of national importance for biodiversity: criteria, methods and candidate list of nationally important inland wetlands. *Landcare Research Contract Report LC0708/158.* https://www.researchgate.net/profile/Philippe-Gerbeaux/publication/240311149_Wetland_ecosystems_of_national_importance_for_biodiversityCriteria_methods_and_candidate_list_of_nationally_important_wetlands/links/5772fa3508ae2b93e1a7d0a1/Wetland-ecosystems-of-national-importance-for-biodiversityCriteria-methods-and-candidate-list-of-nationally-important-wetlands.pdf

Avon-Ōtākaro Forest Park. (2023). Avon-Ōtākaro Forest Park | Sites of ecological significance. Aoforestpark. https://www.aofp.co.nz/sites-of-ecological-importance

Blackmaps Geospatial. (2024). Black Maps Ltd. Blackmaps Geospatial. https://www.blackmaps.co.nz/

Bravaglieri, S., Zenoni, E., & Furioni, S. (2021). Beyond the Damage, the Reconstruction of L'Aquila. the Urban Book Series, 281–300. https://doi.org/10.1007/978-3-030-77356-4_16

Canterbury Maps. (n.d.). *Check out our newly digitised historic maps (Black Maps)*. https://canterburymaps.govt.nz/news/check-out-our-newly-digitised-historic-maps-black-maps/

Department of the Prime Minister and Cabinet. (2019). *Ōtākaro Avon River Corridor Regeneration Plan*. https://www.dpmc.govt.nz/our-programmes/greater-christchurch-recovery-and-regeneration/recovery-and-regeneration-plans/otakaro-avon-river-corridor-regeneration-plan

Di Cecco, G. J., Barve, V., Belitz, M. W., Stucky, B. J., Guralnick, R. P., & Hurlbert, A. H. (2021). Observing the observers: How participants contribute data to iNaturalist and implications for biodiversity science. *BioScience*, *71*(11), 1179-1188.

Dymond, J. R., Sabetizade, M., Newsome, P. F., Harmsworth, G. R., & Ausseil, A. (2021). Revised extent of wetlands in Aotearoa. *Aotearoa Journal of Ecology, 45(*2). https://research.ebsco.com/c/g6lqvo/viewer/pdf/kzwj7diecf

Environment Canterbury. (2014). Public/BlackMaps (MapServer). Gis.ecan.govt.nz/Arcgis/Rest/Services. https://gis.ecan.govt.nz/arcgis/rest/services/Public/BlackMaps/MapServer

Environment Canterbury. (2024, June). *Canterbury Wetland Threats*. https://www.ecan.govt.nz/your-region/your-environment/biodiversity-and-biosecurity/biodiversity/wetlands/canterbury-wetland-threats/

ezyZip. (2024). Convert KMZ To ZIP Online (No Registration Required!). Ezyzip.com. https://www.ezyzip.com/convert-kmz-to-zip.html

Freeman, L. A. (2022). A wonderland for wolves: A sociography of the Chernobyl Exclusion Zone. The Sociological Review, 70(4), 762–785. https://doi.org/10.1177/00380261221106525

Ghafory-Ashtiany, M., & Hosseini, M. (2007). Post-Bam earthquake: recovery and reconstruction. Natural Hazards, 44(2), 229–241. https://doi.org/10.1007/s11069-007-9108-3

iNaturalist. (2019). iNaturalist.org. INaturalist.org; INaturalist. https://www.inaturalist.org/

iNaturalist. (2023, December 6). How can I download data from iNaturalist? INaturalist Help. https://help.inaturalist.org/en/support/solutions/articles/151000170342-how-can-i-download-data-from-inaturalist-

Lepczyk, C. A., Aronson, M. F. J., Evans, K. L., Goddard, M. A., Lerman, S. B., & MacIvor, J. S. (2017). Biodiversity in the City: Fundamental Questions for Understanding the Ecology of Urban Green Spaces for Biodiversity Conservation. BioScience, 67(9), 799–807. https://doi.org/10.1093/biosci/bix079

McAlpine, C., Catterall, C. P., Nally, R. M., Lindenmayer, D., Reid, J. L., Holl, K. D., Bennett, A. F., Runting, R. K., Wilson, K., Hobbs, R. J., Seabrook, L., Cunningham, S., Moilanen, A., Maron, M., Shoo, L., Lunt, I., Vesk, P., Rumpff, L., Martin, T. G., & Thomson, J. (2016). Integrating plant- and animal-based perspectives for more effective restoration of biodiversity. Frontiers in Ecology and the Environment, 14(1), 37–45. https://doi.org/10.1002/16-0108.1

Microsoft. (2021). Find or replace text and numbers on a worksheet. Microsoft.com. https://support.microsoft.com/en-us/office/find-or-replace-text-and-numbers-on-a-worksheet-0e304ca5-ecef-4808-b90f-fdb42f892e90

Morello-Frosch, R., Brown, P., Lyson, M., Cohen, A., & Krupa, K. (2011). Community Voice, Vision, and Resilience in Post-Hurricane Katrina Recovery. Environmental Justice, 4(1), 71–80. https://doi.org/10.1089/env.2010.0029

Morgenroth, J., & Armstrong, T. (2012). The impact of significant earthquakes on Christchurch, New Zealand's urban forest. *Urban forestry & urban greening*, *11*(4), 383-389.

Morgenroth, J., Almond, P., Scharenbroch, B. C., Wilson, T. M., & Sharp-Heward, S. (2014). Soil profile inversion in earthquake-induced liquefaction-affected soils and the potential effects on urban trees. Geoderma, 213, 155-162.

Myers, S. C., Clarkson, B. R., Reeves, P. N., & Clarkson, B. D. (2013). Wetland management in Aotearoa: Are current approaches and policies sustaining wetland ecosystems in agricultural landscapes? *Ecological engineering, 56*, 107-120. https://doi.org/10.1016/j.ecoleng.2012.12.097

Nesheiwat, J., & Cross, J. S. (2013). Japan's post-Fukushima reconstruction: A case study for implementation of sustainable energy technologies. Energy Policy, 60, 509–519. https://doi.org/10.1016/j.enpol.2013.04.065

Nilon, C. H., Aronson, M. F. J., Cilliers, S. S., Dobbs, C., Frazee, L. J., Goddard, M. A., O'Neill, K. M., Roberts, D., Stander, E. K., Werner, P., Winter, M., & Yocom, K. P. (2017). Planning for the Future of Urban Biodiversity: A Global Review of City-Scale Initiatives. BioScience, 67(4), 332–342. https://doi.org/10.1093/biosci/bix012

NSW Environment Protection Authority. (2020). Google Earth Pro instructions. In https://www.epa.nsw.gov.au/ (pp. 1–4). https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/licensing/20p2118-google-earth-pro-instructions-premises-boundary.pdf

Ōtākaro Living Laboratory. (n.d.). *Welcome to the Ōtākaro Living Laboratory*. https://www.otakarolivinglab.org.nz/

Pawson, E., & Blakie, T. (2024). Managed retreat and experimentation: realising opportunity in the Ōtautahi Christchurch residential red zone, Aotearoa. *Kōtuitui: Aotearoa Journal of Social Sciences Online*, 1–21. https://doi.org/10.1080/1177083X.2024.2357546

Regenerate Christchurch. (April 2017). *Outline for the Ōtākaro-Avon River Corridor Regeneration Plan.* https://regeneratechristchurch.nz/assets/oarg-regeneration-plan-low-res.pdf

Sieber, T. L. (2006). Wetland conservation in Canterbury, Aotearoa: human-nature relationships and participation in local environmental groups. *Doctoral dissertation, Lincoln University.* https://researcharchive.lincoln.ac.nz/entities/publication/8749576c-7429-4345-ae99-11e9a7d48c00

Smith, H. (2024, July 29). Create a layer and add features | Learn ArcGIS. Learn.arcgis.com. https://learn.arcgis.com/en/projects/create-a-layer-and-add-features/

Vittoz, P., Stewart, G. H., & Duncan, R. P. (2001). Earthquake impacts in old-growth Nothofagus forests in New Zealand. *Journal of Vegetation Science*, *12*(3), 417-426.

Wells, A., & Yetton, M. (2004). Earthquake and tree-ring impacts in the middle and upper Buller River catchment. In New Zealand Earthquake Commission Research Report 03/492.

Zhang, J., Hull, V., Xu, W., Liu, J., Ouyang, Z., Huang, J., ... & Li, R. (2011). Impact of the 2008 Wenchuan earthquake on biodiversity and giant panda habitat in Wolong Nature Reserve, China. Ecological Research, 26, 523-531.